Performance Analysis of a Variable-Weight OCDMA System under the Impact of Fiber Impairments

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***Abstract*— The impact of Chromatic Dispersion (CD) and Non-Linear Effects (NLE) including Self-Phase Modulation (SPM) and Four-Wave Mixing (FWM), on the performance of a Variable-Weight Optical Code Division Multiple Access (VW-OCDMA) system at 1.25 Gbps is analyzed by simulation. The results show that CD is the most dominant effect, which increases the users bit error rate (BER) especially for the users with higher weights. In order to investigate the performance of system in service differentiation for users with different weights, Dispersion Compensating Fiber (DCF) is used to mitigate the effect of CD caused by Single Mode Fiber (SMF). The results show that users with higher weights have better performance as expected and impact of NLE is negligible for distance up to 150 km, considering low launched power.**

I. Introduction

Recently, OCDMA systems are among the popular choice of research areas deployed in metro networks as they could provide service differentiation for different quality of signals in such networks. Among several coding techniques developed in OCDMA, Spectral Amplitude Coding (SAC) system has been considered as a candidate to provide Quality of Service (QoS) by varying the code weights for different users [1].

SAC-OCDMA, which was first introduced by Zaccarin and Kavehrad [2], is an encoding technique achieved by varying the wavelength components. Wavelength components of optical pulse are encoded at the spectral encoder by obstructing or transmitting specific wavelength components in accordance to a signature code. At the receiver side, as in most SAC systems, a balanced receiver is deployed, where two decoders are used to detect the desired signals. One has similar structure as the encoder and the other is used to filter the interfering signal, mostly using complementary subtraction [3]. Two detection techniques were developed to cancel the multiple access interference (MAI) using balanced detector, which are complementary [2] and AND detection [4] techniques.

In the actual implementation, which optical fiber is employed, the fiber impairments such as Chromatic Dispersion (CD), which occurs due to different speed of different wavelengths in the optical medium, and Non-Linear Effects (NLE) such as SPM, can greatly reduce the performance of the system, especially when the bit rate is high [5]. SPM is caused by the intensity dependency of refractive index that induces a chirp to a pulse. As a multi-wavelength system, SAC OCDMA suffers from the effect of Four-Wave Mixing (FWM), which generates new frequencies near and/or on top of the original signals and further lead to distortion in detection process.

Variable Weight SAC (VW-SAC) system supports users with different code weights, which users with higher weights have lower Bit Error Rate (BER) due to the higher power received at the photo detector.

In this paper, effect of fiber impairments on the performance of a VW-SAC OCDMA system is analyzed. In order to achieve service differentiation, four users with different weights of 6, 4 and 2 are used to present different QoS.

II. System Description

The proposed architecture of a VW-SAC OCDMA system for k number of users and w code weights is shown in Fig. 1. For the sake of simplifying the diagram, transmitter and receiver of one user depicted.

At the transmitter side, w CW lasers with different wavelengths $\lambda 1, \ldots, \lambda w$ are used to form the kth user's signature code with weight of w. The optical signals output from CW lasers are then combined together using a multiplexer (MUX).

A Mach-Zehnder modulator (MZM) is used to modulate the users' binary data, which formed as Non-Return-to-Zero (NRZ) signal to the optical carrier. Modulated signals from all users are then combined using a power combiner, and transmitted over optical fiber.

At the receiver side, a splitter is used to broadcast the received signal followed by another two-branch splitter per user to provide equal power for both arms of balance detector. A balanced receiver is used to extract users data, where a series of fiber Bragg gratings (FBGs) are used to filter the actual and the interfering code in each arm of the balanced receiver. In this study, AND detection technique is used due to better performance than complementary detection [4].

Several codes have been developed to support QoS in SAC-OCDMA systems by varying the code weights of different users. Examples of such codes are multi-weight unipolar code based on Optical Orthogonal Code (OOC) [6], Multiple Weight Random Diagonal (MW-RD) [7] and variable weight code using Khazani-Syed (KS) code [5]. In this paper, VW-KS code is used since it maintain a tolerable code length compared to other codes.

III. Simulation Parameters

Four users with weight of 2, 4 and 6 are modeled in this study. As this study focuses on metro networks, transmission link up to 150 km distance is considered utilizing SMF with characteristics shown in Table I. The test carried out at pseudo

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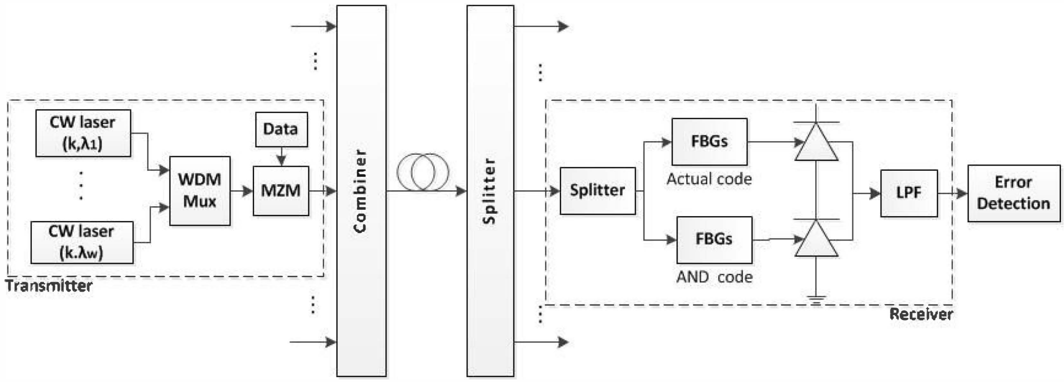


Fig. 1. The proposed architecture of VW-SAC system.

random binary signal (PRBS) 2^{10-1} curved with a NRZ pulse generator operating at 1.25 Gbps. All lasers powers are set to 0 dBm while launch power into SMF is fixed at 3 dBm. This system is also simulated with dispersion compensation mechanism, whereby in this case dispersion compensating fiber (DCF) is used. The parameters of DCF are also included in Table I.

TABLE I
PARAMETERS OF SMF AND DCF

Parameter	SMF	DCF
Attenuation (dB/km)	0.2	0.62
Dispersion $(ps/nm.km)$	16	-100
Dispersion slope $(ps/nm^2 km)$	0.08	-0.35
Nonlinear refractive index (m^2/W)	2.6×10^{-20}	2.6×10^{-20}
Effective core area (m^2)	80	12

To investigate the FWM and dispersion effects, three different chip spacing of 25, 50 and 100 GHz are tested. Performance of the system is evaluated using BER estimation and eye diagrams.

IV. RESULTS AND DISCUSSION

Figs. 2 (a), (b) and (c) show BER as a function of transmission distance for different user with chip spacing of 25, 50 and 100 GHz, respectively. As the results implies, in all channel spacing, users with the higher weight show more sensitivity to fiber impairments. Reference to BER of 10^{-9}, users with weight 6, 4 and 2 can transmit up to around 20, 25 and 70 km, respectively, at 25 GHz spacing. In this case, fiber CD is the main impairment that limited the transmission length. As chip spacing increased, system performance is reduced due to the effect of CD. At 50 GHz, the transmission length of users with weight 6, 4 and 2 is reduced to around 10, 12 and 45 km, respectively. Performance of the system even become worst at 100 GHz spacing, where only user with weight of 2 can reach to the reference BER at around 25 km. This results show that FWM is not a prominent effect compared to other impairments, since increasing chip spacing did not improve performance of the system. Instead, the performance degradation is mainly due to the increase of system dispersion at the larger spacing. This is due to the utilization of multiple wavelengths per user in VW-OCDMA system, which each of the wavelengths contributes their own dispersion, since they travel at different speeds. Thereby, the user with higher number of weights experience more dispersion compared to the user with less weight.

In some points e.g. 115 km in Fig. 2 (a) and 58 km in Fig. 2 (b) for user with weight 2, BER is decreased with the increase of distance. This indicates time skewing can slightly improve the eye pattern of user. As shown in Fig. 2 (c), performance of user with weight four improves due to the changes in the wavelengths chosen for 100 GHz.

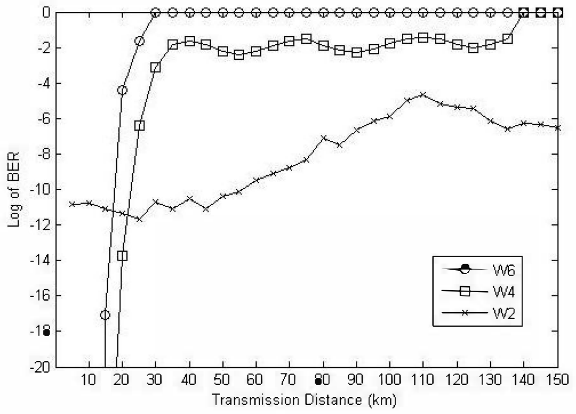
The performance degradation shown in Fig. 2 is a known effects resulting from fiber impairments. However, this finding had proven yet an important contradicting result for OCDMA; higher weights do not always outperform the lower ones, especially in the presence of transmission fiber. It can only outperform the lower counterparts, if the chromatic dispersion had been compensated accordingly.

In another study, the prominent effect degrading the system performance is investigated at 50 GHz chip spacing considering three conditions::

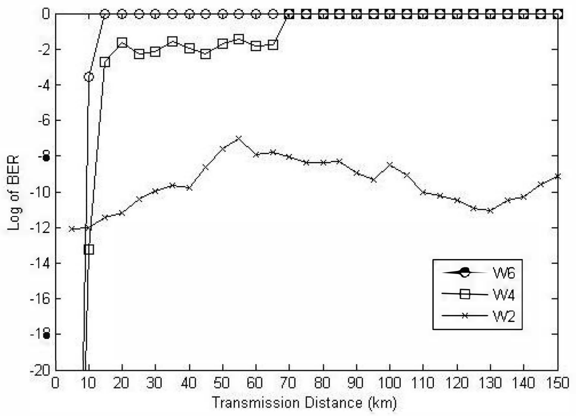
1) In the absence of CD and SPM, an attenuator is used to control the received power.
2) In the presence of both CD and SPM.
3) Only in the presence of SPM.

Figs. 3 (a) to (i) show the eye diagrams of different users after 50 km transmission distance. Considering the first condition, Figs. 3 (a), (b) and (c) show the eye diagram of the users with weight 6, 4, and 2, respectively. As the eye diagrams imply, in the absent of CD and SPM, the user with the higher weight performs better than the user with the lowe weight.

As shown in the Fig. 3 (f), user with weight 2 has better performance in the presence of CD and SPM in comparison with just in the presence of SPM (Fig. 3 (i)). This indicates that SPM can slightly mitigate the dispersion effect.



(a)



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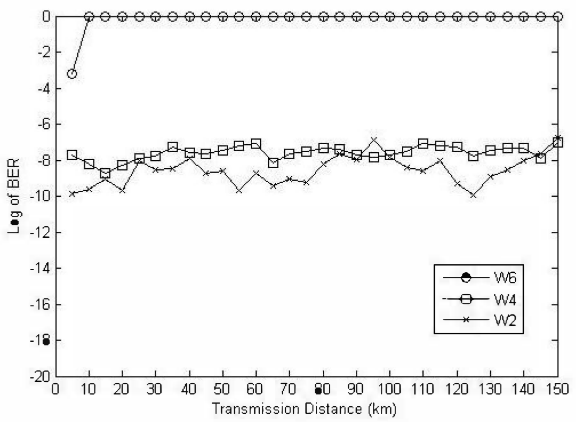
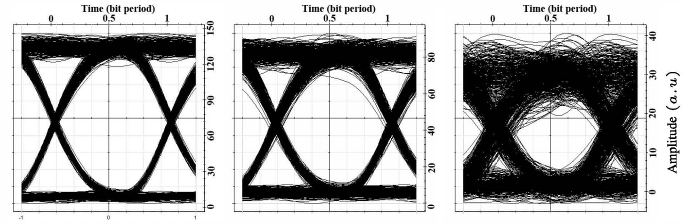


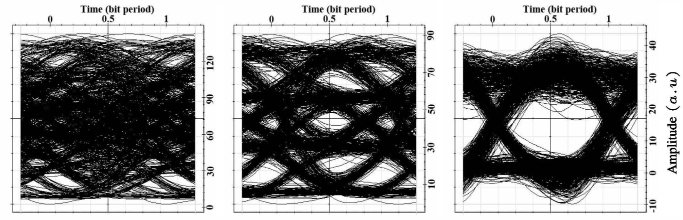
(c)

Fig. 2. BER versus transmission distance for different chip spacing of (a) 25, (b) 50, and (c) 100 GHz.

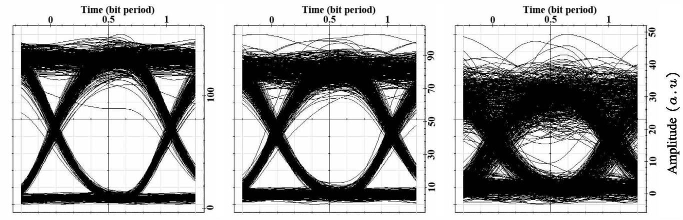
Comparing the results shown in Fig. 3 (a), (d), (g) and Fig. 3 (b), (e), (h), it can be seen that the most dominant effect, which causes signal distortion in users with higher weights, is CD where the effect of SPM is negligible. Hence, without dispersion compensation, VW-OCDMA system cannot support



(a) (b) (c)



(d) (e) (f)



(g) (h) (i)

Fig. 3. Eye diagrams after 50 km transmission distance for three conditions: (a), (b) and (c) in absence of CD and SPM for user with weight 6, 4, and 2, respectively; (d), (e), and (f) in presence of both CD and SPM for user with weight 6, 4, and 2, respectively; (g), (h), and (i) in presence of SPM and absence of CD for user with weight 6, 4, and 2, respectively.

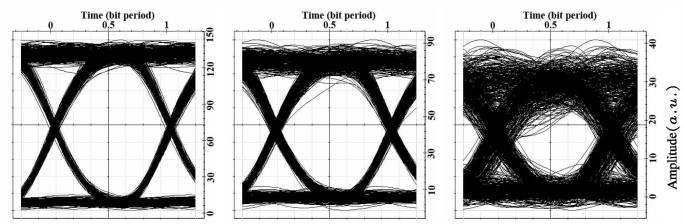


Fig. 4. Eye diagrams of system after 50 km transmission distance when DCF is employed to mitigate CD effect for use with weight (a) 6, (b) 4, and (c) 2.

QoS in implementation with the presence of transmission fiber. This hypothesis was consequently proven by our system with DCF, as depicted in Fig. 4. Fig. 4 gave the anticipated results where higher weights perform better than the lower ones.

V. Conclusion

We have developed a VW-SAC system using VW-KS code to investigate the impact of fiber impairments in OCDMA system providing QoS by varying the users code weights. It is found that users with higher code weights are mostly affected by fiber impairment especially CD where increasing the input power is not the solution for this kind of systems. Therefore dispersion compensation techniques are required to maintain the tolerable BER for users with different weights. Also, analysis of VW-OCDMA system performance using different types of fiber such as Dispersion Shifted Fiber (DSF) and Non-Zero Dispersion Shifted Fiber (NZDSF) can help to better understand of dispersion and NLE effects. Our results with dispersion compensation mechanism have shown that higher weights perform better, as claimed by other researchers; hence, bringing the implementation of QoS in the physical layer closer to reality.

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