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Application of optical frequency comb generation with controlled delay circuit for managing the high capacity network system

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A B S T R A C T

The generation of optical frequency comb (OFC) with novel controlled delay circuit is presented in this study. The proposed OFC is based on a single laser source which is cascadingly connected with three modulators; all the modulators are tailored by RF signal while incorporating no phase shifter or electrical/optical amplifier. The proposed OFC is used as a source at optical line terminal (OLT) of WDM-PON setup, which serves multiple users with a single laser source making OLT side very cost effective. 41 comb lines with over 40 dB tone to noise ratio and high side mode suppression ratio, least amplitude difference of under 0.3 dB, with cost effective setup is an attractive source for WDM-PON system. The frequency spacing is 32 GHz between OFCG lines which provides enough bandwidth for data transmission, the overall bandwidth provided by this scheme is 1.2 THz. Using DPSK modulation technique across each frequency of OFCG, the controlled delay circuit increases the capacity by factor two, whereas by deploying DQPSK modulation technique, it quadrupled the overall capacity in downlink transmission. Thus, the system offers four times increased capacity ∼1.6 Tbps by deploying state of the art technique for modulation and generating OFC with controlled delay. The average power penalty in the downlink and uplink transmission is 2.5 dBm and 3.13 dBm.

1. Introduction

Nowadays, to support multimedia applications, the convergence of optical and wireless networks become a challenging research area for the betterment of QoS and to increase the data rate capacity [1,2]. Due to the exponential growth of bandwidth dependent applications, triple play services really demand the adoptability of optical multicarrier (OMC) at the optical line terminal (OLT) in the next generation optical access network. The best candidate of known time for supporting high data rate in optical access network and long haul transmission is OMC, also known as optical frequency comb (OFC) [3–5]. The OFC offers a series of frequencies with equal frequency difference among them. The frequency spacing can be controlled by the RF source tailored with the modulators in the OFC generator. Many techniques have been reported for frequency locked OFC generation by cascading various modulators [6–12], while the others by employing mode locked lasers and using recirculating frequency shifting (RFS) loops [13–20] in the feedback. The mode locked laser technique normally suffers from complexity of cavity and therefore, does not offer tunability of free spectral range [21].

The techniques incorporating modulators in cascade and by using the RFS loops are tailored by high power RF signal, and have used electrical/optical amplifiers and filters. Similarly, techniques referred for RFS loops mostly use single side bands for generation of more carriers [13–16,22], yet, it is effected by amplitude spontaneous emission noise, same is the case for cascading configuration, which can be controlled by using extra filters [23–25]. In the same fashion, the techniques referred for cascaded configurations incorporate high powered electrical/optical amplifiers [3,7] and filters [26], have used more than one clocks [11], and produced least number of comb lines [6–12,25,27]. Recently dual parallel Mach-zehnder modulator (DP-MZM) based OFC is proposed but with limited number of OFC lines [27], although the DP-MZM utilizes two sub MZMs in the parent MZM but the number of comb lines are limited as compared to the proposed one.

The last mile network in the optical access networking is

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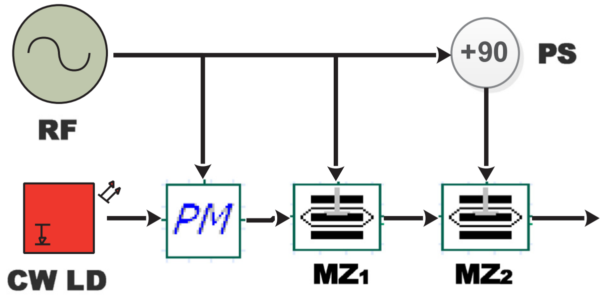

Fig. 1. Schematic presentation of OFC with a delay circuit and combiner.

wavelength division multiplexed passive optical network (WDM-PON) that can provide enough bandwidth for triple play services to the end users. But for high number of users, the size of the transmitter increases as many lasers are required in that case. Similarly, the other major issues include high power operations, maintenance and increased cost. Therefore, the deployment of OFC source at OLT side seems to be a wise idea, which can provide space for many users with low power and minimized costs to send multimedia files. Recently, we presented multicarrier based OLTs for access network [28,29]. The proposed system in [28] provided low capacity ~40 Gbps with costly setup as compared to [29]. However, in the current proposed model, the system offers increased capacity of four folds with almost same system's budget [29] but with better results and remark that the system is fairly practical. The current version incorporates three contributions. Firstly we introduced a controlled delay logic with changed parameters in the OFCG based 410 Gbps WDM-PON where DPSK modulation technique is applied across each carrier and observed the doubling in data rate support. Secondly, we employ differential quadrature phase shift keying (DQPSK) based transmitters across each frequency along the controlled delay circuit, and at last we deploy the proposed model at OLT side of the WDM-PON that support many users who could send high data rate equal to 1.64 Tbps in downlink and 410 Gbps in the uplink transmission. Since DQPSK supports two bits per symbol, therefore, it increases the capacity of the system two times further, consequently, the overall capacity of the system is increased four folds with the help of controlled delay and DQPSK modulation scheme, which is the best scenario to date for next generation optical access network. This way the bandwidth hungry applications can be easily satisfied in the next generation access network by deploying the proposed system, each user would be able to transmit 40 Gbps data rate.

2. Detailed structural design of OFCG with simulation results

The schematic presentation of the proposed OFC is presented in Fig. 1, where RF: shows the microwave signal, CW LD: continuous wave laser diode, PM: phase modulator, MZM: Mach Zehnder modulators, and PS: phase shifter. The OFC generator consists of three modulators employed in cascaded way and tailored by RF signal, in this article the frequency spacing is 32 GHz instead of 10 GHz which is different from [29], it produces broader spectral bandwidth too. This way more data can be transferred, OFCG is controlled with symmetry factor of the MZMs. In this model, the laser frequency is 192.15 THz, sample rate is ~0.64 THz, power is ~10 dBm which produces the OFC with amplitude difference of maximum 2 dB in few comb lines but less than 0.5 dB in most of the frequencies. The modulation depth of the phase modulator, extinction ratios and symmetry factor of the MZMs is carefully selected for providing the high number of OFCs.

The output of phase modulator can be given by Eq. (1) [29]:

$$E_{PM_{out}} = E_o \sum_{n=-\infty}^{n=+\infty} J_n(\pi I)[\exp(j2\pi(f_c + nf_s)t)] \quad (1)$$

The output of laser and RF source with a frequency f_s can be given as:

$$E_{las} = E_o exp\ (j2\pi f_c t) \quad \text{and} \quad f_s(t) = IP_\pi sin(2\pi fst) \quad (2)$$

where I is the modulation index and $P\pi$ is the half wave voltage of phase modulator.

The output of first MZM can be given as [26,29]:

$$E_{MZM_1-out}(t) = \frac{1}{\sqrt{2}} E_o \sum_{n=-\infty}^{\infty} \left[J_n\left(-\frac{\pi I_1}{M_{\pi 1}}\right). \exp\left(j\frac{\pi V_{b-1}}{M_{\pi 1}}\right) + J_n\left(\frac{\pi I_1}{M_{\pi 1}}\right)\right]. \exp[j2\pi(f_c + nf_s)t] \quad (3)$$

where V_{b-1} is the biasing voltage at MZM_1. $M_{\pi 1}$ is the half-wave voltage for MZM. The output of second MZM can be given as:

$$E_{MZM_2-out}(t) = \sum_{n=-\infty}^{\infty} A_n(I_1, I_2, V_{b-1}, V_{b-2}, \Delta\varphi).\ \exp\ [j2\pi(f_c + nf_s)t] \quad (4)$$

In Eq. (4), $A_n(I_1, I_2, V_{b-1}, V_{b-2}, \Delta\varphi)$ indicates the variable of nth order about $I_1, I_2, V_{b-1}, V_{b-2},$ and $\Delta\varphi$.

The laser's output is modulated with RF signal at PM, which produces certain OFCs with most of the weaker sidebands presented by first equation which are maximized to 33% (w.r.t final output) at the output of MZM_1 which is more than [29], where as 70% of the carriers are energized and get flattened at the output of MZM_2 as shown in Fig. 2 [29], but with increased frequency spacing. All the weak sidebands are get flattened by providing more bandwidth for high data rate transmission. The output of PM is shown in Fig. 2(A) and that of the MZM_1 is shown in Fig. 2(B) and (C) shows the final spectrum of OFC at MZM_2 [26] while Fig. 2(D) shows the output of MZM_2 of the current scheme which don't have any sidebands by equalizing all the possible sidebands with larger frequency spacing and different symmetry factor of the MZMs. The Extinction ratio of the MZMs is 30 dB, so the bandwidth become broader and is increased to 1.2 THz. The amplitude difference in few comb lines is between 2 dB at both the sides of OFC and is less than 0.5 dB in most of the comb lines. The generated OFC signals have high tone to noise ratio (over 40 dB). Fig. 2 presents the final output of MZM_2. All these results are achieved by using internationally available software called OptiSystem. For achieving these simulation results the resolution of optical spectrum analyzer is kept at 0.01 nm for MZM_2 giving high TNR value around 40 dB.

The generated OFC is compared with the referenced state of the art techniques which have utilized cascaded configuration and showed that the proposed model is cost effective with better results in comparison to the mentioned cascaded configurations. Furthermore, it generated greater number of OFC lines with greater TNR and least amplitude difference by providing broader spectrum with high frequency spacing. We have compared the proposed scheme with all the referenced schemes using cascaded configurations, demonstrated in Table 1.

3. Detailed investigation of OFC based high capacity WDM-PON with controlled delay logic

In this arrangement, new architecture is adopted for the OLT side of WDM-PON structure. In conventional optical access network, 50% of the whole budget is required at OLT side of the access network due to its complexity, size and maintenance costs. A lot of research has already been done for making the colorless transmission at ONU side of the access network. Yet, there is a lot of space to be discovered for making OLT cost effective, reduced in size, operatable by low power etc. High data rate demand by huge number of users the increased number of laser array makes it costly with high power setup and maintenance. In such case the deployment of OFC at OLT is a wise and cost effective thought with low power requirements and praise worthy solution. In the proposed setup, new model is adopted with an increased capacity up to four times comparing with our previous scheme [29].