Overlapped-Subcarrier Multiplexing For Hybrid Tdm/Wdm Passive Optical Networks

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Abstract

An innovative overlapped-subcarrier multiplexing (O-SCM) technique is proposed for wavelength-division multiplexed (WDM) passive optical networks (PONs).Allowing a certain amount of spectral overlap between the uplink and the downlink maximizes the spectrum usage of bandwidth-limited reflective semiconductor optical amplifier (RSOA)-based optical network units (ONUs), while reducing the effect of Rayleigh backscattering. In this paper, we report successful experimental demonstrations up to 2.5 Gb/s symmetrical bit rates over a 20 km bidirectional PON, using a 2 GHz bandwidth RSOA. In future we are going to develop hybrid TDM-WDM passive optical networks with dynamic wavelength allocation. These new scheme enable different ONUs to efficiently share (both in time and wavelength) the access network bandwidth to achieve better utilization.

Keywords— Fiber-to-the-home (FTTH), passive optical networks (PONs), reflective semiconductor optical amplifiers (RSOAs), subcarrier multiplexing (SCM), wavelength-division multiplexing (WDM).

1. Introduction

BANDWIDTH demand in access networks is exponentially increasing and is expected to continuously grow over the next decades [1]–[3]. According to the Cisco Visual Networking Index [4], the total global Internet Protocol (IP) traffic will quadruple from 2009 to 2014. This will drive the peak data rates per user to 1 Gb/s or even more in the near future, and will force much more symmetry in traffic in fiber-to-the-home (FTTH) access networks. Today's passive optical network (PON)-based access networks operate on a time-division multiple-access (TDMA) basis, and therefore cannot cope with such bandwidth demand explosion. In gigabit-capable PON (GPON) standards, a 2.5 Gb/s line rate is shared between 32 subscribers, compared to only 1.25 Gb/s for symmetric GPON operation and Ethernet PON (EPON) standards. This limits the peak user bit rate to less than 100 Mb/s, forcing network operators and service providers to re-think upgrading their networks. 10G-PON recent standards can help increase the lifetime of legacy systems in a cost-effective way by re-using the existing optical distribution network (ODN) infrastructure. However, because of their TDMA nature, the bit rates will still be limited to only sub-gigabit per second per user. Further scaling (higher than 10 Gb/s) using TDMA will be difficult to achieve because of both technological and economical issues.

In this dilemma, wavelength-division multiplexing (WDM) is considered a natural choice for next generation access as proposed in the literature by several research groups, and as discussed by the Full Service Access

Network (FSAN) standardization group. Full connectivity can be achieved in WDM by assigning a dedicated wavelength to each optical network unit (ONU), i.e., user. Incorporating WDM in access networks provides higher bandwidth and better security than time division multiplexed (TDM) PONs which operates in a single wavelength broadcast-and-select mode. Despite the advantages of WDM technology, cost still remains the main issue for access networks. In order to avoid the costs and inventory complexities associated with having distinct WDM transceivers, wavelength-independent colorless ONUs will be required for next generation WDM PON deployments [9]–[11]. Due to their low fabrication cost, small form factor, ease of integration, and ability to achieve both amplification and modulation, reflective semiconductor optical amplifiers (RSOAs) have been widely used as colorless ONU.

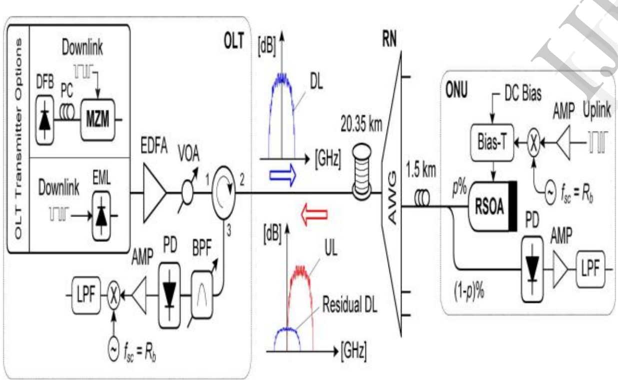

Fig 1: Architecture of the proposed WDMPON with overlapped-SCM (AMP: amplifier, BPF: 50GHz band pass filter, DC: direct current, DFB: distributed feedback, DL: downlink, EDFA: erbium-doped fiber amplifier, EML: electro-absorption modulated laser, LPF: low pass filter, MZM: Mach- Zehnder modulator, PD: photodiode, PC: polarization controller, RF: radio frequency, UL: uplink, VOA: variable optical attenuator).

2. Proposed WDM PON with Overlapped-SCM

The architecture of the O-SCM WDM PON is based on an existing single-feeder topology connecting the OLT to the ONUs through an arrayed waveguide grating (AWG)-based remote node (RN) as shown in Fig. 1. The O-SCM technique enables full-duplex communications while partially reducing the effect of Rayleigh backscattering as in conventional SCM systems. The insets in Fig. 1 show the electrical RF spectra of a typical 100% O-SCM system illustrating the frequency overlap between the uplink and downlink spectra. Because of that overlap, it is expected that the ability of the O-SCM to reduce the effect of Rayleigh backscattering will not be as good as for conventional SCM systems, but better than simple baseband transmission. In the proposed O-SCM system, the downlink is kept at baseband, whereas the uplink is sent over an RF subcarrier using fully O-SCM (i.e., 100% O-SCM), where the subcarrier frequency fsc is equal to the bit rate Rb.

Note that if needed, partially O-SCM with Rb < fsc < 2Rb can also be used to reduce the amount of crosstalk due to the overlap. At the ONU, a fraction of the downlink power is detected by a p-i-n photodiode (PD) and the remaining portion is used to seed a gain saturated RSOA for efficient re-modulation. The extinction ratio (ER) of the uplink is set higher than that of the downlink to facilitate data erasure and re-modulation [12]. Part of the up-converted uplink spectrum overlaps with the residual downlink that is highly suppressed due to the gain squeezing and high pass filtering effect of the saturated RSOA. At the OLT side, the uplink is recovered after down-conversion as the residual downlink acts as additive high frequency noise that is suppressed by a low pass filter (LPF).

3. Principle Of Operation Of The O-SCM System

The key aspect to understand how the proposed O-SCM system works is to recognize that the overlap is actually between the up-converted uplink and the residual downlink (and not the downlink). This implies that the RSOA must be operated in saturation mode which is also necessary for the data re modulation to take place. As the RSOA is further driven into saturation, the downlink signal is efficiently erased and highly suppressed allowing for a 100% overlap. From a design perspective, it is important to carefully select the p% coupling ratio of the 1mul2 ONU coupler to guarantee that enough power goes to the downlink receiver while having sufficient power to saturate the RSOA. There is no advantage to having the downlink power exceed the required sensitivity. On the other hand, it is desirable that the RSOA input power be higher than its input saturation power for more efficient data erasure and re modulation. However, driving the RSOA more into saturation would cause the RSOA gain to drop to zero and the output power to saturate, thus affecting the performance of the uplink. Taking the above factors into consideration, there exists an optimum p% that maximizes the power budget by minimizing the required OLT launch power for error-free operation. The other important design parameter would be the selection of the ER for both downlink and uplink, as previously discussed.

4. Performance Limitations Of The O-SCM System

For a certain bit rate, the performance of the O-SCM technique is bounded by the percentage of overlap from one side and the modulation bandwidth of the RSOA from the other side. Decreasing the subcarrier frequency from twice the bit rate (zero overlap) to exactly the bit rate (full overlap), induces more crosstalk between the up-converted uplink and the residual downlink. The RF mixers further degrade the performance as they have a tendency to cut lower frequencies in their pass bands. Whereas, moving to higher subcarrier frequencies, the performance is primarily limited by the modulation bandwidth of the RSOA. It is clear that there exists an optimum operating point that trades off the amount of overlap versus the modulation bandwidth of the RSOA. At high bit rates compared to the RSOA bandwidth, it is much easier to allow a 100% overlap than going to higher subcarrier frequencies. This can be achieved by deeply saturating the RSOA (if the power budget permits) so that the downlink is highly erased, or by decreasing/increasing the ER of the downlink/ uplink. In addition, FEC or DSP techniques can be used to increase the link margin.

Our solution appears to be attractive for network operators, as it exploits the existing PON infrastructure while employing low-cost optics and mature WDM technology, combined with inexpensive electronics to achieve SCM and possibly DSP for higher bit rates. For field deployments, a thermal AWGs, polarization independent EMLs and RSOAs are commercially available at very competitive pricing, making our solution a potentially cost-effective upgrade for existing PONs.

5. Experimenal Results

The transmitter and receiver circuits are simulated in OPTIWAVE software.

5.1 Eye Diagram: Quality Factor

The eye diagram shows the superposition of all mutually overlapping bits in the signal. The eye opening indicates the differentiability of the logic 1 from the logic 0. The more the eye is wide open, the greater the differentiability is, because it's better signal noise to ratio.

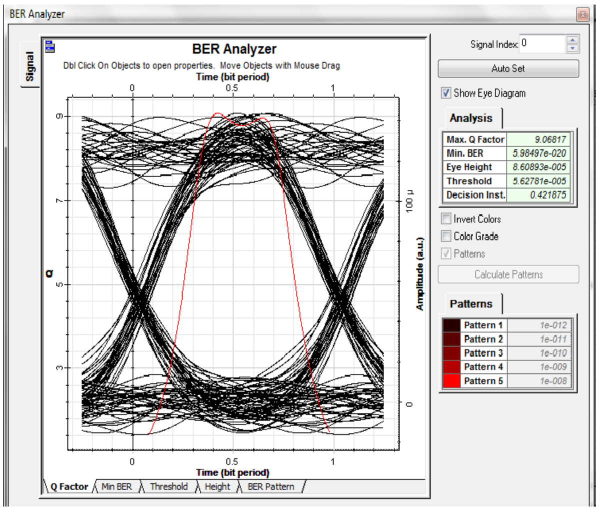

Fig 2: Quality factor of the signal

Fig 2 shows the quality of the signal which is being received in the receiver side.

5.2 Min BER

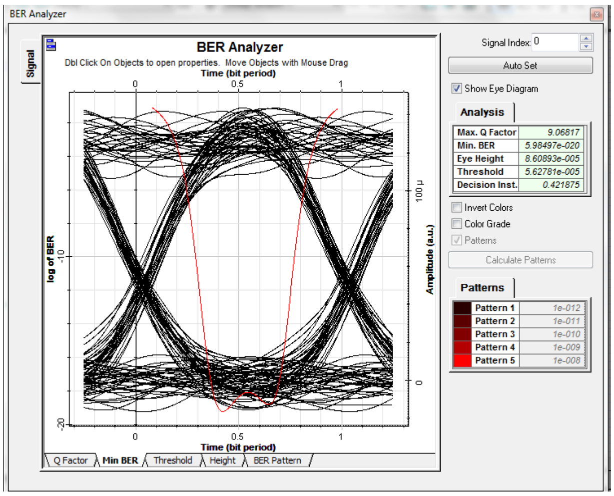

Fig 3: Min BER

Fig 2 shows the minimum bit error rate of the bits being transmitted through the circuit. The signal for minimum bit error rate should be exactly inverse of the quality signal

5.3 Threshold

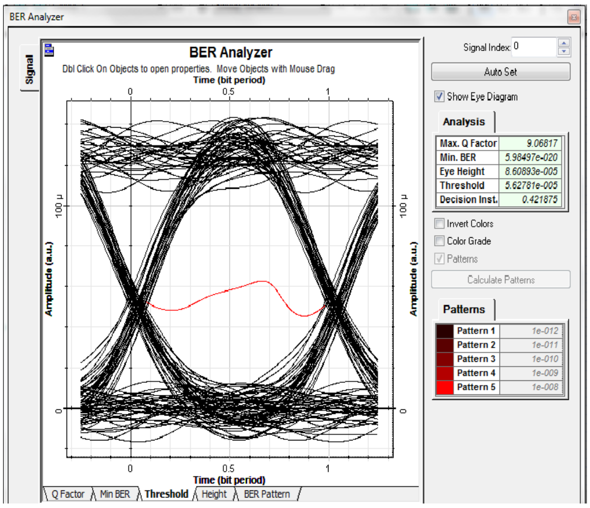

Fig 4: Threshold

Fig 4 shows the threshold level by which the receiver decides the transmitted bit to be 1 or 0.

5.4 Height

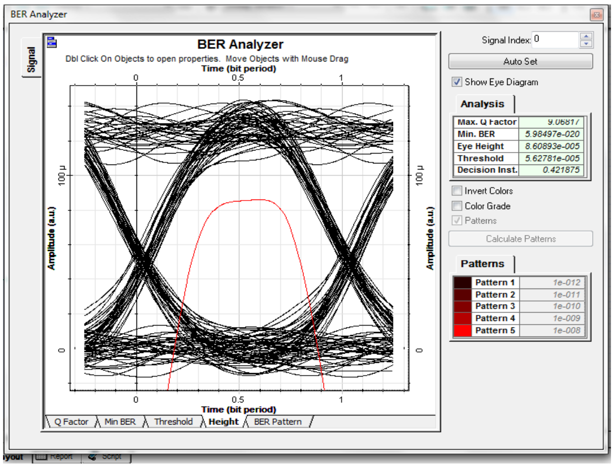

Fig 4: Height of the eye opening

Fig 4 shows eye height versus Decision Instant

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5.5 BER Pattern

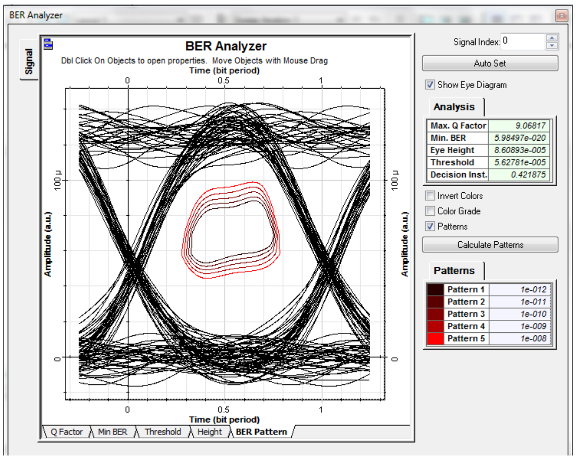

Fig 5: BER Pattern

When Calculate Patterns is selected, displays the regions where the BER value is less than the user-defined values.

6. Conclusion

We presented an innovative solution for next generation.WDM PONs based on an overlapped-SCM technique that exploits the modulation bandwidth of commercial RSOAs to its maximum compared to conventional SCM techniques. The experimental verification and the mathematical model of the proposed O-SCM system were reported. We have shown good agreement between the developed model and the experimental demonstration. Moreover, we addressed the major design guidelines for a successful O-SCM WDM PON system. From an experimental perspective, we demonstrated a symmetric 2.5 Gb/s system using OOK direct modulation of inexpensive in expensive EMLs and RSOAs at the OLT and ONUs, respectively (a reference 1.5 Gb/s demonstration was also considered for proof-of-concept and sake of comparison with previous work). Error-free operation was achieved over a 20km PON with 100% O-SCM, without dispersion compensation, and without the need for FEC codes or DSP. The OLT launched power was optimized through the design of the ONU to maximize the PON link margin.

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