Long wavelength VCSELs exploitation for low-cost and low-power consumption metro and access networks

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ABSTRACT

Long wavelength VCSELs are demonstrated to be able to support metro and access networks in order to achieve low-cost and low-power consumption transceivers. In particular, the exploitation of discrete multitone (DMT) direct modulation allows to achieve high transmission capacities and the availability of widely tuneable MEMS-VCSELs to sustain agility, reconfigurability and colourless features of networks.

Keywords: VCSELs, metro networks, access networks, discrete multitone transmission.

1. INTRODUCTION

In recent years, we are assisting to a continuous growth of bandwidth demand in the access and metro optical networks. The optoelectronic front-ends should support this traffic growth, not only by increasing the transmission rate, but also facing new challenges in terms of costs and power consumption. Moreover, also in view of the aggregation of the metro access networks and for the support of heterogeneous networks, it is expected a migration towards more flexible, efficient and agile paradigms.

Photonic technologies can provide new energy- and cost-efficient solutions, starting from the adoption of direct modulation (DM) of the laser sources; among them vertical cavity surface emitting lasers (VCSELs) allow a reduction of transmitter cost, power consumption and footprint. VCSELs have been usually considered for datacom applications at 850 nm. Recently, their potential has been shown in the third fibre communication window [1] for 100G applications as well as for passive optical networks (PONs) and programmable and modular sliceable bandwidth/bitrate variable transceivers-based metro networks [2-4].

To achieve high transmission bit rates advanced modulation formats have been proposed in order to exploit limited bandwidth devices. In particular multicarrier modulation, as discrete multitone (DMT) or orthogonal frequency division multiplexing (OFDM), can exploit bit and power loading at digital signal processing (DSP), enabling an efficient usage of the bandwidth resource as a function of the requested capacity and transmission distance. On one hand this allows dynamic and flexible adaptation to traffic/channel conditions and spectrum fragmentation mitigation in metro networks [5] and on the other to upgrade actual access networks in a cost-effective way by avoiding expensive premium opto-electronic parts [6].

In particular, in this second case also direct-detection is mandatory and receivers using limited bandwidth should be used to enable 25G and 40G PONs. Moreover, the next proposals targeting a line rate increase should also be compliant with time and wavelength multiplexed-PONs (TWDM-PON) of NG-PON2 [7,8] standard. Specifically, the optical network unit (ONU) transmitters have to be colourless, preferably tuneable over 4-8 times the grid-spacing, with very high side-mode suppression (SMSR) to avoid crosstalk into neighbouring channels.

In this paper, we prove the exploitation of a long-wavelength widely tunable VCSEL [9] to achieve transmission rates higher than 25 Gb/s for fiber lengths compliant with metro-access distances; in particular we demonstrate the capabilities of a tunable transmitter, presenting low-cost and reduced footprint. DMT modulation combined with direct detection (DD) is employed to use limited-bandwidth VCSELs and standard receivers suitable for 10 Gb/s operation, targeting a transported capacity greater than 25 Gb/s. Transmission up to 40-km standard single-mode fiber (SSMF) without any chromatic dispersion (CD) compensation is reached in the whole C-band thanks to the exploitation of asymmetrical filtering of the received signals.

2. MEMS TUNABLE VCSEL

The employed single-mode widely tunable long-wavelength VCSEL is based on a long wavelength Indium Phosphide (InP) Buried Tunnel Junction (BTJ) VCSEL and features a MEMS top mirror [10]. The small air gap between the surface of the base VCSEL and the MEMS can be thermo-electrically controlled. The change in air gap leads to mode-hop free tuning of the laser wavelength of about 90 nm (from 1517 nm to 1608 nm), showing a SMSR above 45 dB on the entire tuning range.

The employed VCSEL was packaged in a transmitter optical subassembly (TOSA) with a standard LC connector. Inside the TOSA package a thermoelectric cooler, a thermistor and a monitoring diode have been included. Only one control signal is required to tune the laser without mode hops across the full tuning range. In total, 8 pins are required to allow the transmitter control. The peak optical fiber-coupled power is 1.2 mW at 22°C with a bias current of 32 mA. The VCSEL has a maximum S-21 3-dB bandwidth of about 7 GHz at 1550 nm, while on a 47-nm wavelength range a minimum bandwidth of 4.5 GHz is guaranteed [11].

3. EXPERIMENTAL SET UP

Fig. 1 shows the experimental setup employed for the evaluation of the transmission performance in the scope of metro/aggregation and access network. The previously described tunable VCSEL is hosted at the user side; the laser is directly modulated by a DMT signal. The DMT signal is calculated by Matlab® and is composed by 255 sub-carriers in 8-GHz range, i.e. the sub-carrier spacing is 31.25 MHz. Chow's algorithm [12] is used with the measured signal to noise ratios (SNRs) to perform bit- and power-loading (BL/PL) setting the target bit error rate (BER) to $3.8\cdot10^{-3}$, as for 7% overhead advanced hard-decision forward error correction (FEC). Following serial to parallel conversion, inverse fast Fourier transform (IFFT) and parallel to serial operations we added a cyclic prefix (CP) of about 2.1% of the symbol length. Then, after peak-to-average power ratio (PAPR) limitation, the obtained DMT signal is sent for digital to analog conversion to a 50-GS/s arbitrary-waveform-generator (AWG) with 14-GHz electrical bandwidth. The employed modulation amplitude is 950 mV while the VCSEL is biased at 16 mA; both current and modulation amplitude are maintained constant for the entire C-band wavelength tuning range.

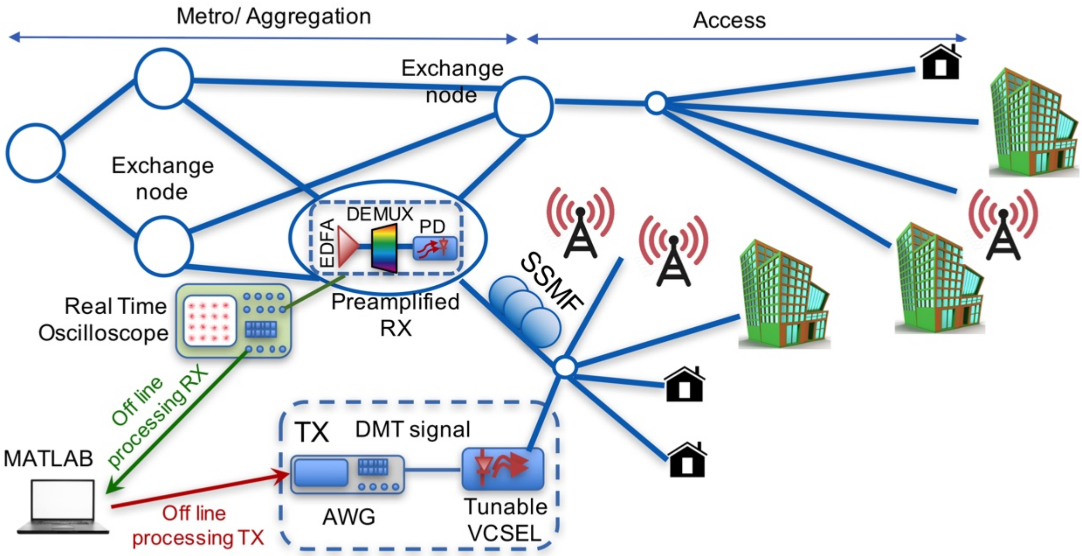


Fig. 1. Metro/ aggregation and access network: experimental setup.

The optical DMT signal is transmitted over up to 40-km of uncompensated SSMF. At the receiver end, a low-noise Erbium-doped fiber (EDF) preamplifier and a variable optical attenuator (VOA) anticipate a demultiplexer (DEMUX) followed by a standard PIN receiver suitable for 10 Gb/s operation. The DEMUX can be the central office (CO) wavelength multiplexer (WM) in NG-PON2 compliant PONs or a wavelength selective switch (WSS) in the metro/aggregation network exchange nodes. After the PD the received signal is acquired by a Tektronix real-time oscilloscope (DPO 73304DX) with 8 bits vertical resolution, 50 GS/s and 33-GHz electrical bandwidth. After analog to digital conversion off-line processing performs CP removal, FFT operation, digital symbol synchronization, sub-carriers phase recovery, equalization and demodulation; finally the BER count is operated.

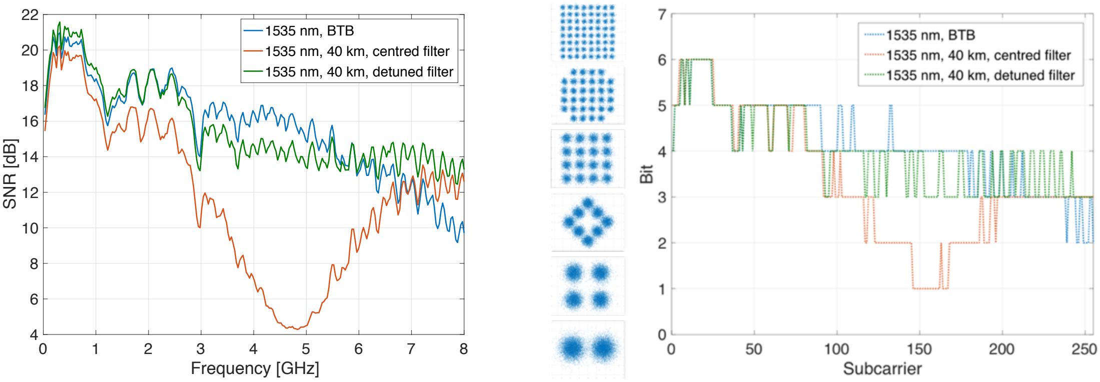
To cope with the CD accumulated over SSMF propagation distances up to 40 km, we also evaluated the impact of asymmetrical filtering [13], provided by the DEMUX on the DMT transmission performance. Specifically, in our setup, a 0.3-nm tunable optical filter mimics the DEMUX and is fine-tuned with respect to VCSEL emission wavelength thanks to the exploitation of an electrical spectrum analyzer. Performance evaluation is provided comparing results achieved with the filter centered at the VCSEL emission wavelength and with 5-GHz detuning.

4. EXPERIMENTAL RESULTS

4.1 Signal to noise ratios measurements

Exploiting DD, we transmitted a probe DMT signal mapped with uniform QPSK loading, obtaining the SNR of each sub-carrier which provides the estimation of the channel characteristics. An example of measured SNRs in case of back-to-back (BTB) condition, 40-km SSMF propagation with centered filter and 40-km SSMF propagation with detuned filter is shown in Fig. 2(a) at 1535 nm. After 40 km of SSMF propagation (red curve), the cumulated chromatic dispersion leads to an evident frequency dip around 5 GHz, where the corresponding SNR shows a minimum of about 4 dB. Thanks to the filter detuning (green curve), the impact of chromatic dispersion is mitigated leading to an almost unchanged SNR response with respect to the BTB condition.

As previously described, the measured SNRs are exploited for performing Chow's algorithm. This BL/ PL procedure gives the bits per symbol distribution among the different sub-carriers reported in Fig. 2(b); in the left side inset, examples of the corresponding received constellations are also displayed.



a) ¶ ¶ b)

Fig. 2. a) Measured SNRs at 1535 nm and b) corresponding bit mapping of the 255 sub-carriers for back-to-back condition (blue curve), after 40-km SSMF propagation with centered filter (red curve) and detuned filter (green curve). Examples of the received constellations are shown on the left inset of b).

By comparing the blue curve and the red curve it is evident that in the case of 40-km SSMF transmission with the centered filter, in correspondence the SNR frequency dip at 5 GHz, it is necessary to exploit lower-order modulations, leading to a reduction in the total transported capacity with respect to BTB. On the other hand, as expected, a clear improvement of the total capacity transmitted after 40 km of SSMF is obtained by detuning the optical filter; in this case, in fact, we actually achieve a high-frequency equalization and a bit mapping among the sub-carriers similar to the BTB condition can be employed.

4.2 Capacity measurements and discussion

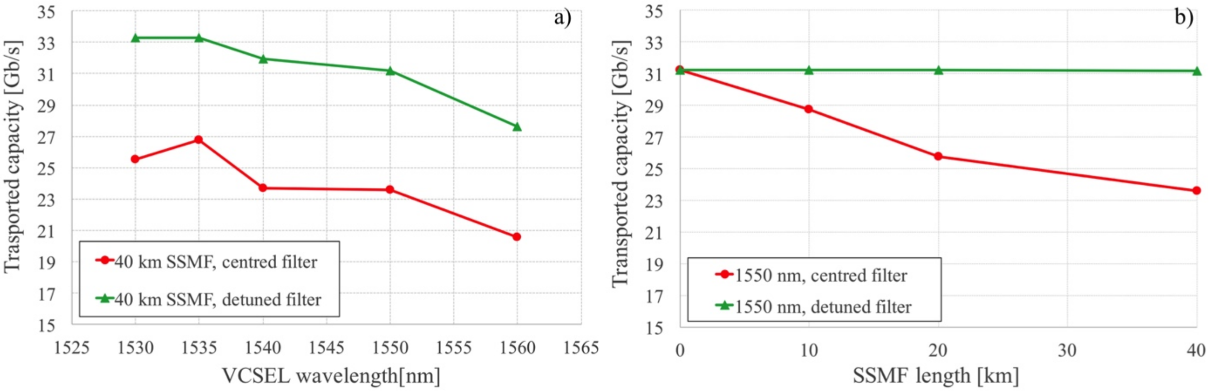


Fig. 3. a) Total capacity transported by the system with centered (red line, circles) and detuned (green line, triangles) filter. b) Total capacity transported at 1550 nm vs propagation length in case of centered filter (red line, circles) and detuned filter (green line, triangles).

Fig. 3a) presents the total capacity achieved at the target BER of $3.8{\cdot}10^{-3}$ after 40-km SSMF transmission for -6 dBm received optical power: the red-circle curve displays the case of centered filter, while the green-triangle curve the case of detuned filter. When the filter is centered to the VCSEL emission, the transported capacity varies between 27 Gb/s at 1535 nm and 20 Gb/s at 1560 nm. This capacity decrease is due to the choice to maintain the same bias current and RF modulation amplitude during the measurements over the whole C-band; moreover, at higher wavelengths, also the VCSEL shows a slightly lower bandwidth. On the other hand, in case of filter detuning, transmission capacities higher than 27 Gb/s are achieved in the entire C-band.

Then, the total capacity achievable as function of the SSMF propagation length has been experimentally evaluated. Fig. 3b) shows the results for 1550 nm in case of centered (red-circle curve) and detuned (green-triangle curve) optical filter. As expected, when the filter is detuned no reduction of the capacity depending on the SSMF length is noticeable, confirming bit-rates higher than 30 Gb/s up to 40 km. On the other hand, when the filter is centered, 25-Gb/s capacity is achieved up to 20-km SSMF propagation. In particular, similar results are demonstrated for all the wavelengths in the C-band under 1550 nm.

5. CONCLUSIONS

We demonstrated that widely-tunable directly-modulated MEMS-VCSELs can be employed as transmitters to bridge more than 20-km uncompensated SSMF with higher than 25 Gb/s capacities over the entire C-band. This performance can be obtained with direct detection thanks to DMT modulation employment which allows to adapt the capacity to the requested transmission distance. Moreover, the employment of a detuned filtering can extend the transmission distance beyond 40-km SSMF with more than 30-Gb/s capacity.

This can be a very promising solution to realize high-bandwidth TWDM PONs with low-cost, reduced footprint, colorless optical network unit sources, targeting at least 25 Gb/s capacity while exploiting devices suitable for 10 Gb/s operation.

Furthermore, these results confirm that thanks to DMT, enabling spectral manipulation, DM widely tunable VCSELs can represent cost-effective and energy-efficient building blocks, for the implementation of programmable and modular sliceable bandwidth/bitrate variable transceivers suitable for optical metro network applications.

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