Optical Transceivers for Mobile Front-Haul and PON Applications

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Abstract *Low-cost tuneable lasers for PON transceivers are reviewed. Laser tuning is based on a remote signal from the OLT. The message channel is realized by envelope modulation with limited impact on the payload signal.*

Introduction

Data traffic in mobile networks is constantly increasing. With the transition from 3G over LTE, LTE-A to 5G, the mobile data rates have grown from 200 kbps to several Gbps, while at the same time the number of users as well as the number of antennas and base stations is growing exponentially. This places increased requirements on the optical network supporting the mobile network. The current trend goes towards separating the baseband unit (BBU), in which the signal processing for multiple antennas (or remote radio heads - RRHs) is performed, from the antenna itself, where the radio frequency processing takes place. This leads to two sections in the network, where optical data transmission is essential. In the mobile backhaul section, mostly Ethernet protocol data are transmitted between the data centres and the BBUs. The data rates currently required here are around one Gbps. Over the mobile front-haul section, the BBU is connected to the radio heads, currently mostly using the CPRI or OBSAI protocol with stricter timing requirements than Ethernet. While for 5G different splits of the processing in the BBU and the radio heads are discussed, still a very high-capacity connection between the BBU and the radio heads will be required. To maintain a sufficient low-cost of the mobile network, also the cost of these optical network segments need to be considered.

One approach to reduce the cost of the mobile backhaul and fronthaul systems is to share the network among multiple use cases. The capacity in access networks for enterprises follows similar capacity increases and, in urban areas, those networks have a similar footprint as fronthaul networks. To cover these different use cases with a uniform, low-cost solution, ITU-T SG15 is currently working on the standardization of a hubbed system with wavelength-agnostic spoke interfaces, in which those interfaces can be remotely controlled.

In this paper, we will first introduce the overall system structure, then discuss the tuneable transmitters, which have been proposed for this purpose, and will then explain the system running procedure, as currently included in the draft standard G.metro.

WDM-PON with remote wavelength control

Figure 1 shows the typical setup of a WDM-PON system. The OLT is connected to all ONUs via individual wavelengths. The interconnecting wavelength is determined by the port of the filter in the remote node, to which the ONU is connected. In the OLT, the wavelengths can either be terminated in individual, fixed wavelength transceivers or, to reduce space, multi-channel transceiver arrays can be used to terminate multiple wavelengths connecting to different ONUs. The ONU receivers detect any wavelength that is routed to the ONU in the remote node filter. To avoid a large variety of different ONUs, also the ONU transmitter should be tuneable and adaptable to any required wavelength to connect with the OLT through the remote node filter. This tuneable laser is a crucial device, and several implementation options will be discussed below. To reduce the cost of this

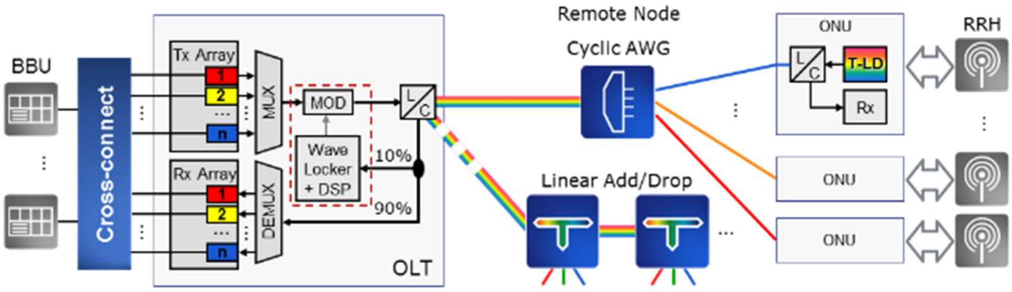

Fig. 1: WDM-PON system architecture

tuneable laser, the wavelength control is performed from the OLT. The tuning information is transmitted from the OLT to the ONU via a management channel.

Low-cost tuneable lasers

A key component for the low-cost network is a tuneable laser, required in the remote interfaces. While several solutions have been implemented and introduced in T-SFP+ modules, some of these components need to be re-designed to enable a low-cost solution. Furthermore, an important feature of the tuneable laser in the ONU is a simple tuning mechanism with few control parameters and avoiding mode hops when being tuned over the full spectrum[1].

Early full C-band tuneable lasers were reported, based on a modulated grating Y-branch laser[2]. Four control currents are required to provide gain pumping, perform the tuning of two gratings and to align the phase. A successor of this laser type is commercially available.

Another, also full C-band tuneable laser, based on multiple band reflection filters[3] also requires four injection currents for gain pumping, phase control, and tuning of two gratings. One of the currents is switched between different gratings, reflecting different parts of the spectrum[4]. A variant of this laser is also commercially available. Both of these lasers can be coupled to an external modulator in an integrated setup and a dispersion-limited transmission range of 80 km can be achieved without chromatic dispersion compensation.

More recently, tuneable vertical cavity surface emitting lasers (VCSELs) have been demonstrated for a tuneability of over 100 nm[5,6]. The short cavity length of these lasers enables a large mode-hop free tuning range. For these lasers, only two tuning currents are required, for gain pumping and to control the cavity length via a micro-movement of one facet. However, due to the typical chirp of VCSELs, the dispersion tolerance of the transmission is limited to about 10 km for a 10-Gbps signal. It has been shown, however, that by over-compensating the chromatic dispersion a transmission range of 0 to 40 km over standard SMF can be achieved[7].

To enable a full integration of the ONU optical engine, a tuneable laser based on a polymer platform has been demonstrated, where the temperature tuneable grating was realized in the polymer and an InP based gain chip was hybrid integrated[8]. This photonic integrated circuit (PIC) also contained the band splitter required to separate the signal directions and a receiver photodiode. While three tuning currents are required for gain pumping, phase control and heating of the tuneable grating, the tuning range of a single grating covered half of the C-band, sufficient for some applications currently proposed in the draft of G.metro.

OLT based ONU tuning

Cost reduction of the ONU module can be achieved in part by a low-cost design and packaging concept of the tuneable transmitter. The tuneable laser approaches discussed above are able to support this goal. Another crucial cost component of the tuneable ONU, however, is the calibration of the injection current for each operating wavelength – and for uncooled devices over the full operating temperature range[4]. Especially for a higher number of tuning currents, this can be time consuming and correspondingly quite expensive in production. To avoid a precise wavelength calibration, the G.metro WDM-PON system provides an OLT-based wavelength control. ONU lasers do not need to be sufficiently calibrated, but need to continuously sweep over the operating wavelength range upon turn-on.

When the tuning reaches the matching wavelength of the filter port (AWG or add/drop) to which the ONU is connected, the OLT will detect the ONU signal and confirm this to the ONU via the management channel. To avoid interference with existing channels during tuning, the ONU transmit power is reduced and the filter needs to provide sufficient isolation[9].

Additional cost advantages can be achieved by removing the wavelength locker from the ONU and providing a wavelength control at the OLT for all channels.

This centralized wavelength control requires the implementation of a management channel from the OLT to the ONU as well as an identifier or label that is added to the upstream (ONU to OLT) wavelength. In the current draft of G.metro, the management channel is realized by an envelope modulation of the optical signal with a 50 kbps Manchester coded signal. The upstream channels are labelled by envelope modulation with distinct pilot tones around 50 kHz.

The modulation depth of the message channel is a critical value, as it affects the payload channel. Figure 2 depicts the impact of the message channel modulation on 2.5 and 10 Gbps NRZ-modulated payload signals. At a bit error rate (BER) of 10^{-12}, a message channel modulation depth of 15% leads to a penalty of approximately 1 dB for a 2.5 Gbps signal, while for the 10 Gbps signal the penalty is only 0.4 dB. On the other hand, the BER of the message channel is reduced with increasing modulation depth. Figure 3 shows the BER as function of the received power for different values of the modulation

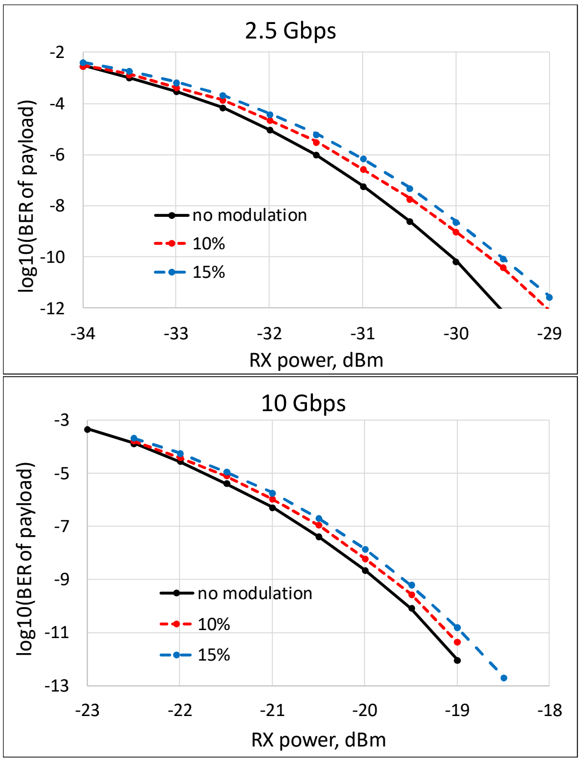

Fig. 2: BER of 2.5 and 10.3 Gbps payload signal over received power. A Manchester encoded message channel at 50 kbps is envelope modulated with different modulation dept onto the payload. Solid line: no message modulation, dotted line: 10% modulation depth, dashed line: 15% modulation depth

depth. As the payload modulation acts as noise-like impairment for the message channel, a BER floor is observed, which is lower with increased modulation depth. It can be seen that for a modulation depth of more than 11% the error rate is below 10^{-6}. A simple error correcting code, like a Hamming code, can be applied to yield a quasi error-free message channel.

Conclusions

Metro WDM-PON systems combine applications of mobile fronthaul and backhaul with business access. A crucial component to achieve a cost efficient transmission is a low-cost tuneable transceiver. Several tuneable laser technologies have been introduced, which could be able to meet these requirements. Furthermore, a wavelength agnostic operation together with a centralized wavelength control help to overcome the high cost of laser calibration and individual wavelength control. Necessary functionality of the system is a message channel between OLT and ONU and a labelling of the wavelength channels. It has been shown that the message channel can be implemented without major impact on the channel payload. Metro WDM-PON systems according to the draft G.metro standard are therefore promising candidates for integrated mobile fronthaul, backhaul, and business access systems.

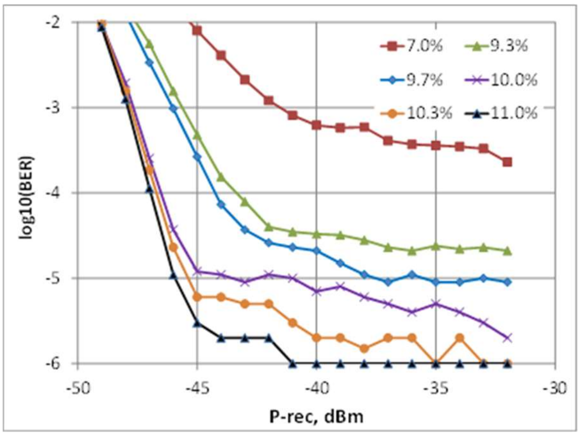

Fig. 3: BER of 50 kpbs message channel in the presence of 2.5 Gbps payload signal for different modulation depths

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References

[1] K. Grobe et al., "Access Networks Based on Tunable Lasers," J. Lightwave Technol., Vol. **32**, no. 16, pp. 2815-2823 (2014).

[2] J. O. Wesström et al., "State-of-the-art performance of widely tunable modulated grating Y-branch lasers," Proc. OFC, TuE2, Los Angeles (2004).

[3] D. C. J. Reid et al., "A novel broadband DBR laser for DWDM networks with simplified quasidigital wavelength selection," Proc. OFC, ThV5, Anaheim (2002);

[4] S. H. Lee et al., "Athermal Colourless C-band Optical Transmitter for Passive Optical Networks," Proc. ECOC, Mo.1.B.2, Torino (2010).

[5] T. Gruendl et al., "First 102 nm Ultra-Widely Tunable MEMS VCSEL Based on InP," Proc. IEEE Phot. Soc. 24th Ann. Mtg., ThDD1, (2011).

[6] Y. Rao et al., "Long-Wavelength VCSEL Using High-Contrast Grating," J. Sel. Top. Quant. Electron., Vol. **19**, no. 4, p. 1701311 (2013).

[7] C. Wagner et al., "Full C-band Tunable MEMS-VCSEL for Next Generation G.metro Mobile Front- and Backhauling," Proc. OFC, W2A27, Los Angeles (2017).

[8] Z. Zhang et al., "C/L-Band Colorless ONU Based on Polymer Bidirectional Optical Subassembly," J. Lightwave Technol., Vol. **33**, no. 6, pp. 1230-1234 (2015).

[9] C. Wagner et al, "Impairment Analysis of WDM-PON Based on Low-Cost Tunable Lasers," J. Lightwave Technol., Vol. 34, no. 22, pp. 5300-5307 (2016).