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Experimental Demonstration of a 10 Gbit/s/wavelength 27 km-reach WDM/TDM-PON based on Reconfigurable OADM and Colourless ONU

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Abstract We present experiments on a wavelength-flexible WDM/TDM-PON with an integrated reconfigurable OADM and a reflective electro-absorption modulator. We successfully transmit multiple wavelength channels of 10 Gbit/s each over 27 km SSMF in different bandwidth allocation schemes.

Introduction

In order to meet the future bandwidth demands driven by the emerging applications (e.g. HDTV) and growing number of users, advanced solutions for last-mile networks are being developed. The network presented here provides high bandwidth on-demand in a cost-efficient manner thanks to integratable elements such as an optical add/drop multiplexer (OADM)¹ and a colorless optical network unit (ONU)². The OADM enables remote network reconfiguration as a result of wavelength channel switching. The centralized light generation and remote continuous wavelength (CW) modulation omits the need for a light source in the ONU. On/off keying (OOK) is used which requires simple direct receivers (RX).

Network Architecture

The dynamically reconfigurable Broadband Photonics (BBPhotonics) network^{3,4} connects 16 ONUs to every remote node (RN). All 4 RNs are connected by an

carrier to be modulated there with upstream (US) data. Such FSR-coupled channel pair is dropped at a single drop port of the OADM, Fig 2(c). For network management the 100Base-X protocol is used⁵ and the channel (1310/1490 nm) is coupled into the ring via CWDM at the CO and RNs. OADM, the main part of the RN, is an integrated structure of individually controlled thermally tuneable micro-ring resonators, an example of an 8-port OADM is given in Fig. 2(a). The temperature dependency of the refractive index of a ring is used to tune resonant frequency. The time required to switch from one wavelength channel to another (50 GHz) is 6 ms (measured at max. correctly received UDP packets), and it is not critical even for real-time applications such as VoIP, where packets contain 10-20 ms of voice data. Using the OADM a single wavelength pair can be dropped to one (PtP) or multiple users (PtMP). The latter is achieved by detuning a ring with 5-10 GHz from the broadcast wavelength which results in drop-and-continue operation of the ring. The integrated ONU, Fig. 2(b), contains a tuneable Mach-Zehnder interferometer (MZI) with FSR equal to the double FSR of the OADM, Fig. 2(d), so any FSR-coupled channels are decoupled at the two outputs of the MZI. The ONU contains a photodetector for DS data and a semiconductor optical amplifier-reflective electro-absorption modulator (SOA-REAM) to transmit the US data (NRZ). Besides providing gain and modulation, the SOA-REAM can operate in complete C-band thanks to the broad optical bandwidth.

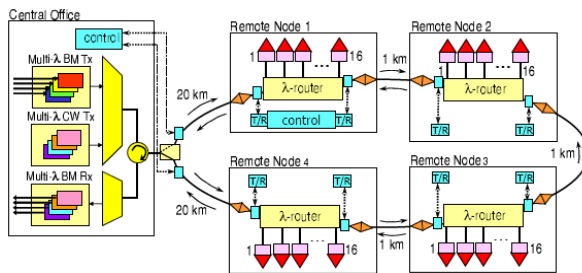


Fig. 1: BBPhotonics access network architecture

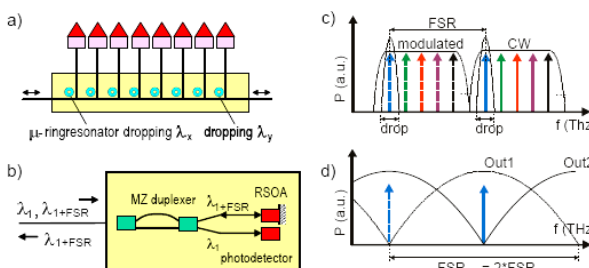


Fig. 2: a) OADM, b) ONU arch., c) OADM, d) ONU wav.

SSMF ring network with a central office (CO), Fig. 1. The CO transmits 8 FSR-coupled data and CW wavelength pairs, where FSR is the free spectral range of the OADM (integer multiple of 50 GHz). The downstream (DS) data channel (NRZ) contains the data to be received by the ONU, and the DS CW is a

Testbed structure

The CO consists of 4 lasers generating λ_1, λ_2 (for 10 Gbit/s DS data) and $\lambda_{1+FSR}, \lambda_{2+FSR}$ (for DS CW). All channels are coupled into the feeder fiber by a 4:1 coupler. The RX part of the CO consists of a tunable filter (required due to the FSR_{OADM} unintentionally not an integer multiple of the ITU grid interval), step attenuator for bit error rate (BER) measurement, 90/10 splitter for received optical power (ROP) measurement and an SOA-preamplified commercial 10 Gbit/s RX. The RN consists of an OADM, which is a simplified version of the OADM from Fig. 1b supporting up to 4 add/drop channels. Due to low return loss of the OADM (low signal-to-crosstalk ratio, SCR) two OADMs were applied with circulators to

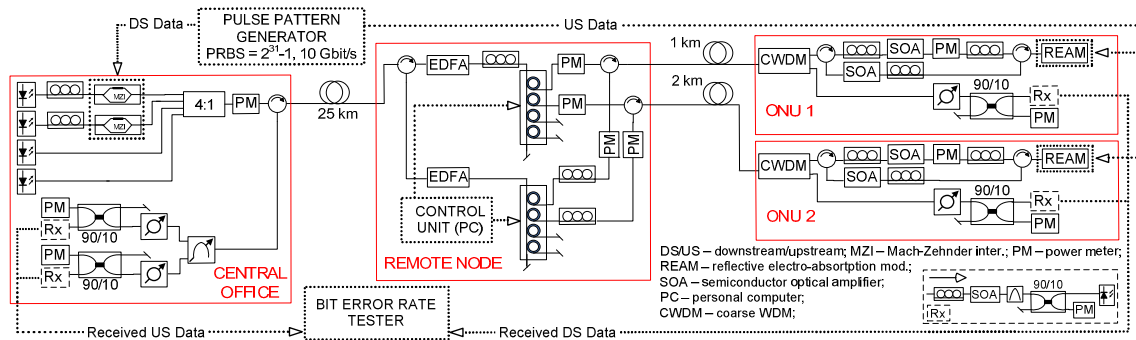


Fig. 3: Testbed of 10 Gbit/s wavelength-flexible hybrid WDM/TDM-PON

separate adding and dropping operations and block the reflections. To compensate for the high insertion loss of the OADMs an EDFA in each direction is used. To maintain the maximum transmission polarization controllers are inserted next to OADMs. The ONU contains a CWDM followed by a DS part (similar to the CO RX part) and US part consisting of two SOAs and circulators, an REAM, and polarization controllers. The bit sequences provided to the DS and US modulators were decorrelated.

Experimental results

Fig. 4 shows the experimental results for DS and US transmission. Two wavelength allocation schemes were applied showing the capability of PtP (ONU#1 gets λ_1 and λ_{1+FSR} and ONU#2 gets λ_2 and λ_{2+FSR}) and PtMP (ONU#1 and ONU#2 share λ_1 and λ_{1+FSR}) communication. Two reference measurements were taken for the DS RX for λ_1 and λ_2 .

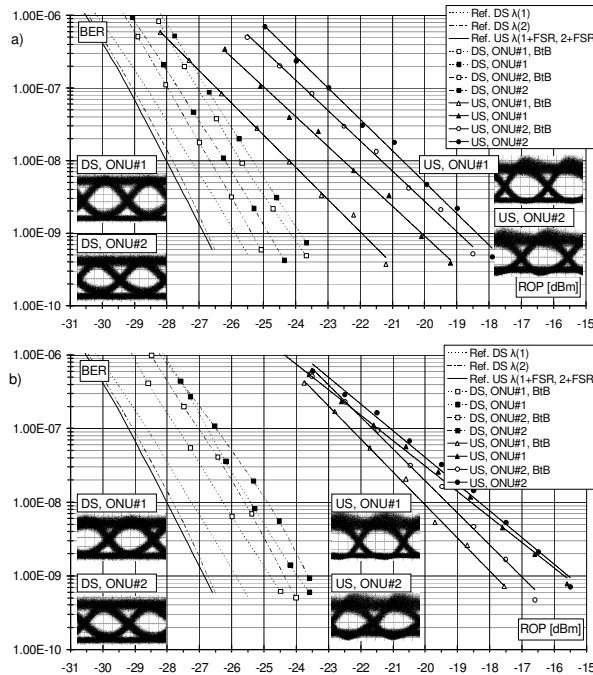


Fig. 4: Results for a) PtP and b) PtMP configuration

For the PtP case there is 1 dB power penalty (PP) in a DS BtB (attenuators in place of fiber-spans) which can be assigned to the polarization instability and the

misalignment of the optical filters. After inserting the fiber spans an additional negligible PP of around 0.4 dB can be noticed. For PtP BtB US the main source of PP is the coherent intrachannel crosstalk caused by the imperfect suppression (20 dB) of the drop channels of the OADM resulting in the SCR_{coh} of 20 dB and PP=2 dB for each ONU. A significant contribution to the total PP brings lower extinction ratio (ER) of the REAM (ONU#1 ER=10 dB and ONU#2 ER=7.5 dB) wrt the reference modulator (12 dB) which gives 0.7 dB and 1.5 dB PP for ONU#1 and ONU#2, respectively. The other distortions are the ASE noise accumulation in the complete DS CW transmission (EDFA, SOA) and US data transmission (SOA, EDFA, SOA), polarization instability and optical filters misalignment (total 2.0 dB). The inclusion of fiber-spans adds 1-1.5 dB PP which is due to the Rayleigh backscattering (RBS) resulting in intrachannel incoherent crosstalk (SCR_{incoh} =20 dB).

During the PtMP measurement to simulate TDM one ONU was working at a time while the other one had the SOA and REAM biases set to 0V. For DS transmission the ~3dB multicast loss in the OADM was covered with the available power budget and no significant difference in BER was observed. For US lower CW power injected into the ONU caused lower extinction ratio (0.8 dB) and output power. The lower power results in a stronger impact of backscattering of the CW carrier (SCR_{incoh} =18 dB) and, therefore, brings additional 2-2.5 dB PP.

Conclusions

We have demonstrated simultaneous up- and downstream traffic at 10 Gbit/s per channel over 27 km SSMF in various wavelength configurations, which is a proof of principle of the BBPhotonics architecture. The work has been done in the Freeband Broadband Photonics project, sponsored by the Dutch Government (BSIK 03025).

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