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Citation for published version (APA):
Urban, P. J., Laat, de, M. M., Klein, E. J., Koonen, A. M. J., Khoe, G. D., & Waardt, de, H. (2008). 1.25 Gbit/s bidirectional link in an access network employing a reconfigurable optical add/drop multiplexer and a reflective semiconductor optical amplifier. In *10th Anniversary International Conference on Transparent Optical Networks, 2008. ICTON 2008. 22-26 June 2008, Athens, Greece* (pp. 166-169) https://doi.org/10.1109/ICTON.2008.4598760

DOI:
10.1109/ICTON.2008.4598760

Document status and date:
Published: 01/01/2008

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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1.25 Gbit/s Bidirectional Link in an Access Network Employing a Reconfigurable Optical Add/Drop Multiplexer and a Reflective Semiconductor Optical Amplifier

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ABSTRACT

In this paper, we demonstrate symmetrical bidirectional transmission of 1.25 Gbit/s wavelength channels in an access network link employing centralized light generation, colourless Optical Network Unit (ONU) and a Reconfigurable Optical Add/Drop Multiplexer (ROADM). The architecture of ONU is based on a Reflective Semiconductor Optical Amplifier (RSOA). The ROADM is constructed with thermally tuned micro-ring resonators. We present the results of transmission experiments and switching time measurement, which prove the concept of a transparent link with flexible bandwidth on-demand provision using cost-efficient elements.

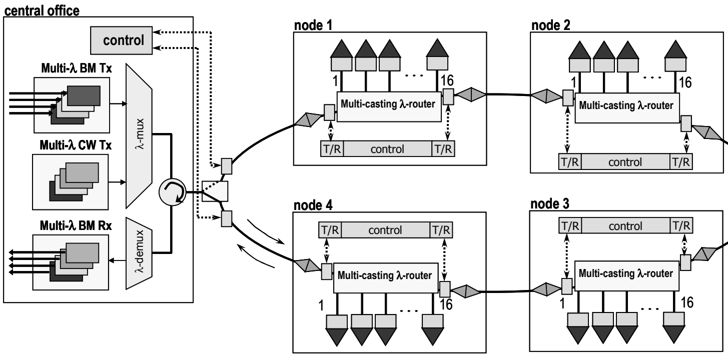
Keywords: reconfigurable access network, FTTx, reflective semiconductor optical amplifier, optical add/drop multiplexer, microring resonators.

1. INTRODUCTION

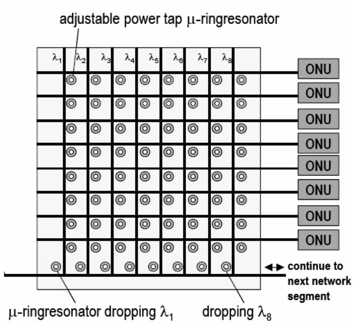
Nowadays, the demand for high bit rate transmission in access network domain is becoming more important. It is driven by emerging bandwidth-hungry applications (e. g. IPTV), which will be more popular in coming years. Copper cable will be no longer sufficient for access network infrastructure and the optical fiber will have to be pushed closer to the user premise. Advanced network features, like dynamic bandwidth allocation, network transparency and long reach, have to be developed to satisfy the needs of Fiber-to-the-X (FTTX) technologies.

2. NETWORK ARCHITECTURE

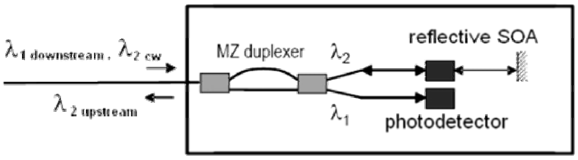
The Broadband Photonics (BBPhotonics) network consists of the distribution part in the ring topology and point-to-point connections between RNs and ONUs (Fig. 1a). Bidirectional transmission over a single fiber is applied. Detailed description of the network architecture is shown in [1, 2]. The key elements of the network are the Wavelength Router (WR) situated in the Remote Node (RN) and the RSOA placed in the ONU.



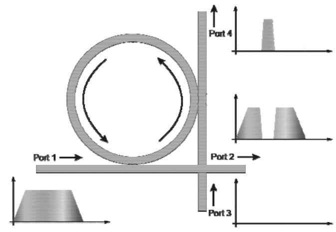
a) Distribution network.



b) Wavelength router.



d) 1.25-2.5 Gbit/s Optical network unit.



c)Ring resonator.

Figure 1. Network Architecture.

The WR is a matrix of microring resonators which are thermally tuned [3]. The example of an 8-port WR is given in Fig. 1b and the scheme of operation is given in Fig. 1c). The ring is coupled into two waveguides with a four port configuration (two inputs and two outputs). When a broadband signal is input via port 1 and the ring is

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in resonance for λ_{drop} this wavelength is dropped on port 4 and the remaining non-resonant wavelengths are transferred to port 2. This way single wavelength channel can be dropped to one or more ports providing unicasting and multicasting together with dynamic network reconfiguration. The designed Free Spectral Range supports the ITU-T WDM grid.

The ONU consists of a Mach-Zehnder interferometer and is shown in Fig. 1d. It separates or combines downstream and upstream signals. The downstream data is sent to the photodetector. The downstream CW beam generated in the Central Office (CO) goes to the RSOA where by the means of intensity modulation the upstream data is imposed on the optical carrier and returned to the CO. The capability to provide gain and modulation in the same time rejects the need for additional amplification, while the wide amplification bandwidth of the SOA implies wavelength independence [4].

3. TRANSMISSION EXPERIMENT

The setup for transmission experiment is depicted in Fig. 2a and some of its parameters are given in Table 1.

The CO (a. k. a. headend) consists of two lasers generating accordingly λ_1 and λ_{1+FSR}. Next, one of wavelength channels is modulated with 1.25 Gbit/s data downstream in a Mach-Zehnder Interferometer (MZI). The channels are coupled into the feeder fiber by a 2:1 coupler and a circulator. The complete output power is monitored by an in-line power meter situated before the circulator and the measured value is corrected for the losses introduced by the circulator. The receiver part of the headend consists of an Arrayed Waveguide Grating (AWG), step attenuator for Bit Error Rate (BER) measurement, 90/10 splitter to measure the exact received optical power and a commercially available 1.25 Gbit/s receiver.

The remote node consists of an Optical Add/Drop Multiplexer (OADM), which is a simplified version of the WR from Fig. 1b supporting up to 4 add/drop channels. Due to low return loss of the OADM resulting in a degradation of the Signal-to-Crosstalk Ratio (SCR) two OADMs were applied together with circulators to provide adding and dropping operations separately. That way the reflected power is blocked by the circulator. Due to high insertion loss of each OADM a Semiconductor Optical Amplifier (SOA) in each direction is used. OADM and SOA are polarization dependent, so polarization controllers are inserted to maintain the maximum transmission. The dropped and added signal powers are monitored by in-line power meters. High insertion loss, low return loss and polarization dependent loss of the OADM leave a room for improvement.

The ONU consists of a 50/50 splitter and a downstream part and upstream part. The downstream part is similar to the headend receiver part and consists of an optical bandpass filter, a step attenuator, 90/10 splitter and a commercial 1.25 Gbit/s receiver. The upstream part consists of an AWG, polarization controller and an MQW-RSOA [5] for data modulation and amplification. The tuneable filter in the downstream part is required due to the FSR of the OADM, which is unintentionally not an integer multiple of the ITU-T wavelength grid channel interval.

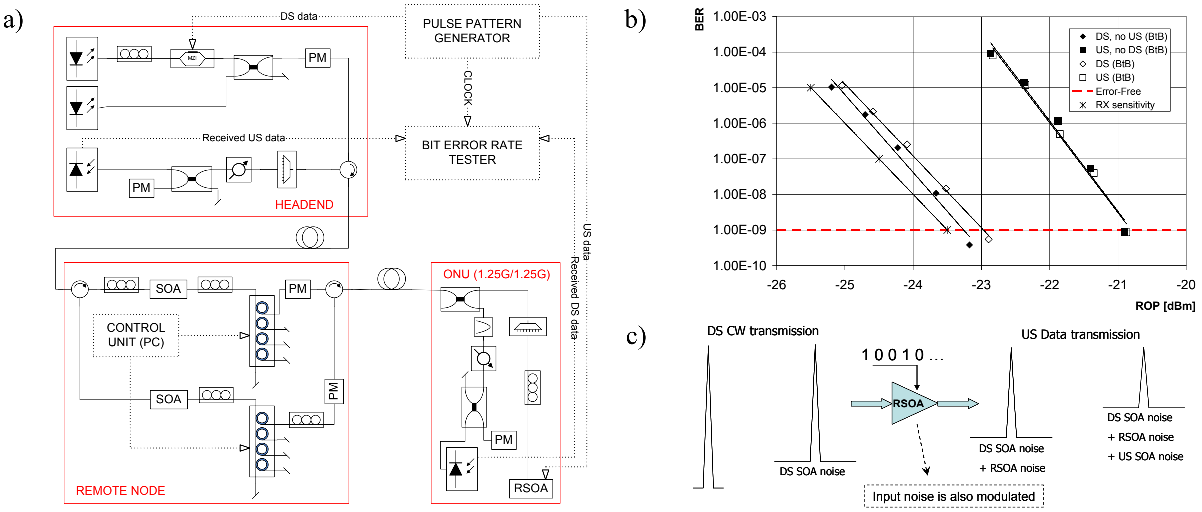

Figure 2. Transmission experiment setup a), results of the experiment b) and noise accumulation diagram c)

If no upstream signal is present, the Back-to-Back (BtB) measurement result show 0.2 dB power penalty in the received downstream signal. This is justified by the presence of the Amplified Spontaneous Emission (ASE) noise, which is not completely filtered at the ONU receiver (optical filter bandwidth is 2.6 nm). When an upstream signal is also transmitted a negligible power penalty can be seen (less than 0.2 dB) with respect to the previous case, which is due to polarization instability in the setup. The upstream received signal reveals around 2 dB power penalty (the same), which can be justified by two factors. The first one is the difference of the

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performance of the RSOA as a modulator and the MZ modulator which was used in the reference measurement. The former has much lower electrical bandwidth (1.5 GHz) than the latter one (9 GHz). The low electrical bandwidth of the RSOA is a result of career lifetime in the active area, which causes a longer falling edge of the eye diagram and consequently eye symmetry degradation. The second factor is the ASE noise coming from the three cascaded SOAs which the signal experiences while going through the RN, ONU and RN again. The CW signal, which enters the RSOA, is influenced by the noise from an SOA in the RN. Such signal is consequently modulated in the RSOA, which means that the noise from the first SOA is also modulated. Finally, it goes back via RN where it is amplified again and the noise level increases even more, Fig 2c. This is not the case for the downstream data channel, as this signal experiences only one SOA at the RN. The influence of the noise accumulated in the cascade of optical amplifiers has been discussed in [2].

Table 1. Transmission experiment parameters a) and power budget for the applied setup b)

a)

Setup parameter	Value	Unit
Channel 1 (DS) wavelength	1554.64	nm
Channel 2 (DS/US) wavelength	1559.00	nm
PRBS (DS and US)	2^{23}-1	
Fiber span	0.0	km
OADM FSR	4.3	nm
OADM return loss (depending on the port)	~15.0	dB
OADM insertion loss (depending on the port)	~14.0	dB
RSOA bias current	27.9	mA
RSOA RF current	40.0	mA
Rx sens. @ BER = 10^{-12} (Headend and ONU)	-23.5	dBm

b)

	Power budget	Ch1 (DS)	Ch2 (DS/US)
DOWNSTREAM	CO laser out. pow. [dBm]	5.5	-2.5
	CO total loss [dB]	10.0	6.0
	RN input power [dBm]	-4.5	-8.5
	RN total loss [dB]	20.5	20.5
	RN gain [dB]	14.0	14.0
	ONU input power [dBm]	-11.0	-15.0
	ONU total loss [dB]	5.5	5.0
	ONU Rx power [dBm]	-16.5	n. a.
UPSTREAM	ONU gain [dB]	n. a.	20.0
	ONU total loss [dB]	n. a.	5.0
	RN input power [dBm]	n. a.	-5.0
	RN total loss [dB]	n. a.	20.5
	RN gain [dB]	n. a.	13.0
	CO total loss [dB]	n. a.	4.5
	CO Rx power [dBm]	n. a.	-17.0

The received optical power at the ONU receiver and the CO receiver is -16.5 and -17.0, respectively. After reserving the measured power penalty of 2 dB in upstream transmission one obtains enough power budget for a fiber span of around 20 km, respectively, when fiber attenuation of 0.2 dB/km and the receiver sensitivity of -23.5 dBm is taken into account as mentioned in Table 1b.

A well-known limitation in bidirectional systems is the Rayleigh Backscattering (RBS), which severely influences the Signal-to-Noise Ratio (SNR). However, on one hand in this setup the fiber length at which accumulated RBS power is the highest (typically 25 – 30 km) is not yet reached, and on the other hand there are cost-effective solutions to mitigate the backreflection by optical signal linewidth enhancement, which were shown in [6, 7].

4. SWITCHING TIME MEASUREMENT

The measurement setup to determine the switching time is illustrated in Fig. 3a). The CW signals are inserted using a circulator after the ROADM to avoid backreflections of the signals. Both CW signals are modulated instantaneously at the RSOA. The data is generated by PC1. Only one channel passes through the ROADM. The wavelength router is controlled by PC2 which can switch the microring between two adjacent channels on the ITU-T frequency grid. Media-converters are used for opto/electrical conversion.

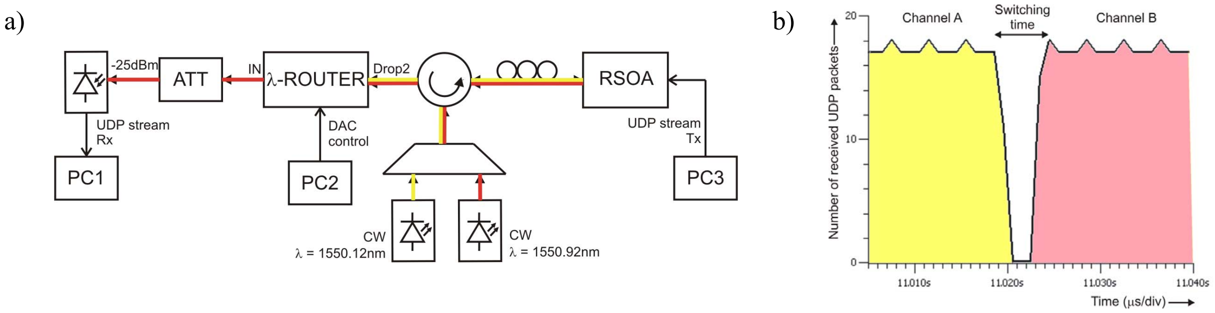

Figure 3. Measurement setup for determining the switching time of the ROADM a) and results b)

The switching time is defined here as the time it takes to achieve maximum throughput again when a microring has to tune from one channel to the other, spaced at a distance of 50 GHz in the frequency domain. The measurement is done at 200 Mbps using UDP packets of 1470 bytes. 200 Mbps is chosen for this experiment, because it is the highest data rate achievable without spontaneous packet loss. Switching time is measured by

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monitoring the received UDP packets at PC3, while tuning the Drop2-ring from 1550.12 nm (channel A) to 1550.92 nm (channel B). A graph of the switching time is shown in Fig. 3b). The switching time is determined to be approximately 6 ms measured at the ethernet layer. This will inherently lead to packet loss. However, when examining voice, a time critical service, it will not disturb or disconnect the conversation, since the obtained packet loss consists maximum 20 ms of voice data, which will not be notified by the user. For other applications, retransmission of the packets will take place after time-out.

5. CONCLUSIONS

We have demonstrated a bidirectional access network link providing a user with symmetrical downstream and upstream bandwidth of 1.25 Gbit/s per wavelength channel. The complete BtB transmission experiment and switching time measurement have been presented. The results show negligible power penalty due to polarization instabilities in the downstream transmission and 2 dB power penalty is readable in the upstream transmission due to the relatively low electrical bandwidth of the RSOA and the ASE noise accumulation.

The results prove the concept of a reconfigurable access network which can provide an end user with on-demand bandwidth.

ACKNOWLEDGEMENTS

This work is part of the Freeband BB Photonics project (http://bbphotonics.freeband.nl).
Freeband is sponsored by the Dutch Government under contract BSIK 03025.

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