

## 1.25 - 10 Gbit/s reconfigurable access network architecture

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## 1.25 – 10 Gbit/s Reconfigurable Access Network Architecture

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### ABSTRACT

In this paper we propose a novel reconfigurable access network architecture which enables the bidirectional transmission of 1.25 – 2.5 Gbit/s. Optical Network Units (ONUs) are equipped with a Reflective Semiconductor Optical Amplifier (RSOA) and Remote Nodes (RNs) are based on microring resonators – both contribute to network transparency and flexibility. We also propose ONU upgrade to serve 10 Gbit/s per end-user. Next to the theoretical description and transmission simulations some principle measurement results are presented which show the feasibility of the concept.

**Keywords:** reconfigurable access network, FTTx, reflective semiconductor optical amplifier, optical add-drop multiplexer, microring resonators, Michelson interferometer.

### 1. INTRODUCTION

Recent statistics show the increase of broadband penetration (Fig. 1). The number of broadband subscribers in the OECD countries increased 33% from 136 million in June 2005 to 181 million in June 2006. This growth increased the broadband penetration rates in those countries from 11.7 in June 2005 to 15.5 subscriptions per 100 inhabitants one year later [1].

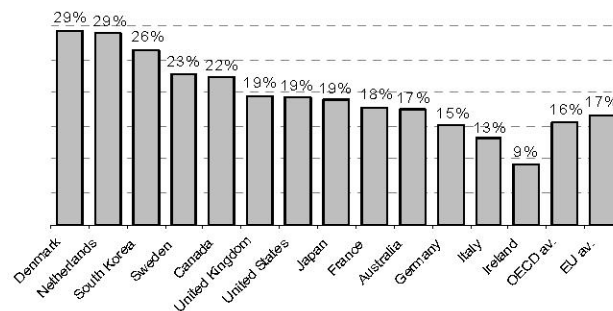


Figure 1. Broadband subscribers per 100 inhabitants.

The increasing bandwidth demand for existing and future applications drives the research on access network technologies. This research includes the development of cost-effective devices, the improvement of network architectures towards reconfigurability and migration scenarios from TDM-PONs to WDM/TDM-PONs [2-6].

The network architecture proposed in this paper provides the user with congestion-free access and virtually unlimited bandwidth. The research incorporates cost effective solutions for an optical add drop multiplexer and a fully integrated ONU. This enables the network operator to easily and remotely reconfigure the capacity distribution according to the varying users' demands.

### 2. 1.25-2.5 Gbit/s NETWORK ARCHITECTURE

The network consists of the distribution part in the ring topology and point-to-point connections between RNs and ONUs (Fig. 2a) [7]. The design of the distribution part provides redundancy. It means that the physical topology does not determine whether the downstream or upstream should go along upper or lower branch of the ring, since bidirectional single fiber transmission is applied. Detailed description of the network architecture is shown in [5] and [7]. Here, we focus on two major elements in this network: the Wavelength Router (WR) and the optical network unit.

The WR is a matrix of microring resonators which are thermally tuned [8]. The example of an 8-port WR is given in Fig. 2b and the scheme of operation is given in Fig. 2c. The ring is coupled into two waveguides with a four port configuration (two inputs and two outputs). A broadband input at port 1 is dropped on port 4, when the ring is in resonance for  $\lambda_{\text{drop}}$ , the wavelength. The remaining non-resonant wavelengths are transferred to port 2. Waveguides are situated orthogonally to allow the microring resonators to be placed in a matrix array. This way single wavelength channel can be dropped to one or more ports providing unicasting and multicasting

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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. 2d. 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.

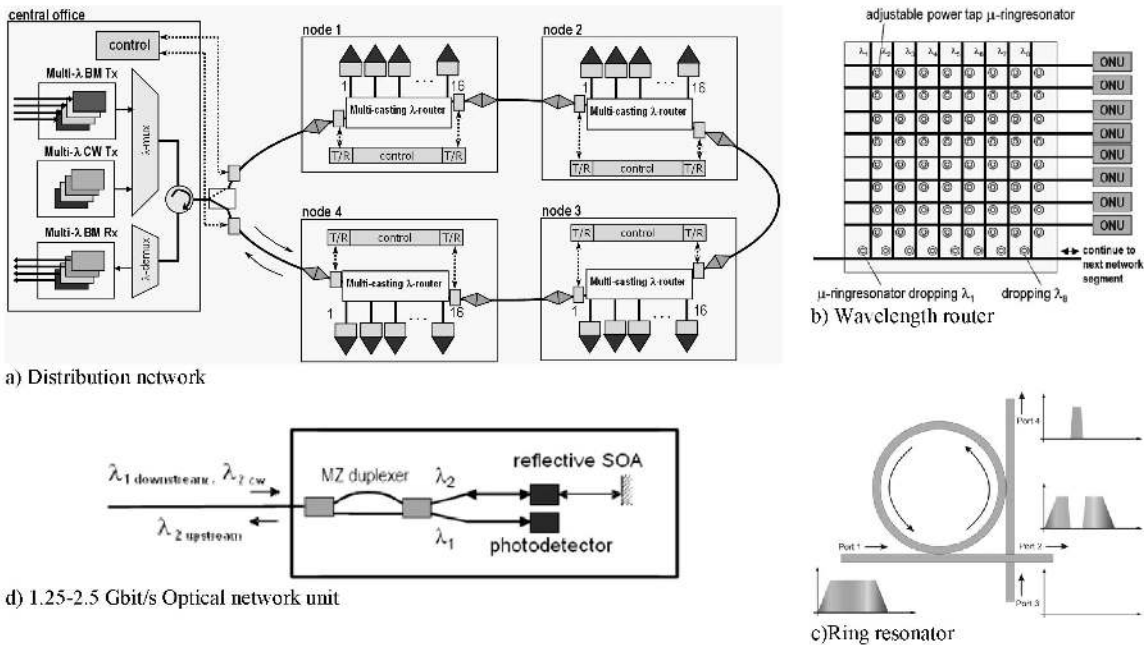


Figure 2. Network Architecture.

2.1 Wavelength Router Design AND Measurements

The WR is a structure composed of microring resonators which are tuned to a specific wavelength through current applied to the heaters. The static performance of a one-dimensional WR (one row of ring resonators) with four add/drop ports is given in Fig. 3a. In this measurement light from a broadband source was injected into the common input of the WR (without tuning) and the output of each drop port was plotted. The 3dB-passband of the drop port is around 0.3 nm.

Principle dynamic measurements were also performed. One of the microring resonators was tuned to drop a 1305 nm 1.25 Gbit/s channel with a PRBS of 2<sup>31</sup>-1. As expected, no significant power penalty was observed. The microring resonators technology enables much higher bitrates [9]. Thus, the network upgrade to 10 Gbit/s, discussed later in this paper, does not concern the WR.

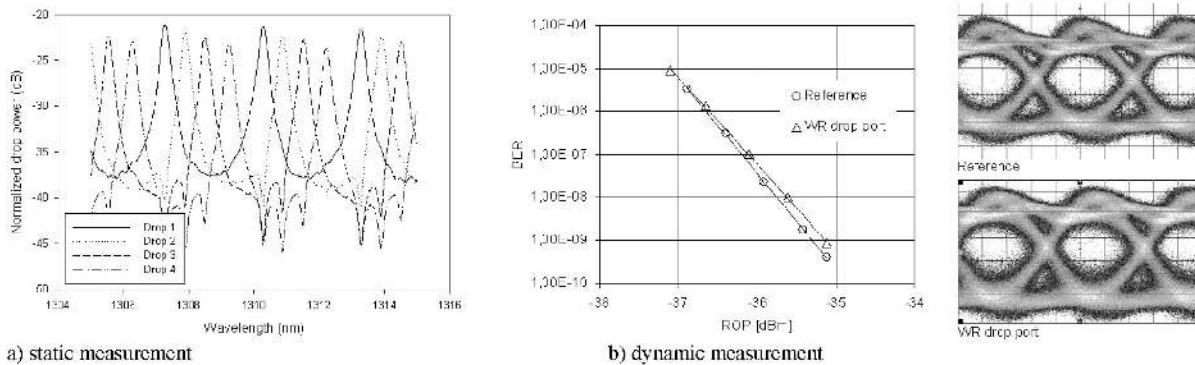


Figure 3. Wavelength router measurements.

### 2.2 RSOA Simulations and Measurements

Based on the performance of a commercially available MQW-RSOA [10] a virtual model of RSOA was designed and simulated in order to check its suitability in high bitrate access network. The eye diagrams were measured with a standard photodetector followed by 15 GHz low-pass filter. The results are shown in Fig. 4a-4e together with the measured eye diagrams.

For given bitrate the simulated eye diagrams show a good match with the corresponding measured ones. However the pattern effect is not well represented in the simulations due to the limited amount of simulated bits, whereas in the measurements a  $2^{31}-1$  PRBS was used. The highest extinction ratio is obtained when the logical zero level current is below the transparency current. This leads to a quicker falling edge, while the rising edge will become slightly slower. Therefore, the SOA also shows possible limitations to the frequency of the modulation signal. Due to the high rise and fall times, which show a behavior characteristic for the SOA, the extinction ratio is reduced for higher RF signal frequencies. However, for higher modulation frequencies, a higher bias current improves the performance of the device. The symmetry of the eye and the eye-opening become more important, here [11]. For higher bias current the pattern effect decreases and the crossing of the rising and trailing edge becomes more centered (Fig. 4e). The eye-opening increases until a maximum value is reached. After reaching this value, the eye-opening decreases because of larger saturation in the gain-current characteristic.

The described behavior gives 2.5 dB, 5.2 dB and 5.7 dB power penalty at BER equal to  $10^{-9}$  for 1.25 Gbit/s, 2.0 Gbit/s and 2.5 Gbit/s, respectively.

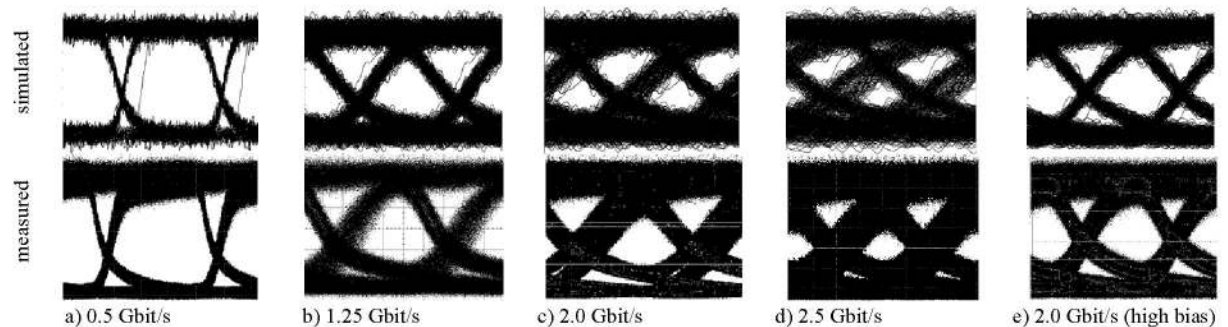


Figure 4. Eye diagrams received at RSOA output.

Network simulations were performed including the designed RSOA model for 1.25 Gbit/s. The virtual model of the WR includes filtering characteristics together with loss parameters of the microring resonators structure. In the simulations a fiber break is assumed between the last node and the CO so all signals go via upper branch. The downstream and upstream signals follow the longest lightpath, as shown in Fig. 5a. The simulations were performed for three capacity distribution cases: the uniform case (every channel feeds the same amount of users per RN), the worst case (one channel feeds all users in the network) and the best (one channel feeds one user in the network). From the point of view of the power budget (distances, insertion losses etc.) the downstream and upstream transmission is identical. However, more critical is the upstream transmission since the OSNR at the ONU output is much worse than the one at the CO output and it depends on the ONU input OSNR of CW carrier. Also the parameters of eye diagram of the transmitted upstream are crucial, as described previously.

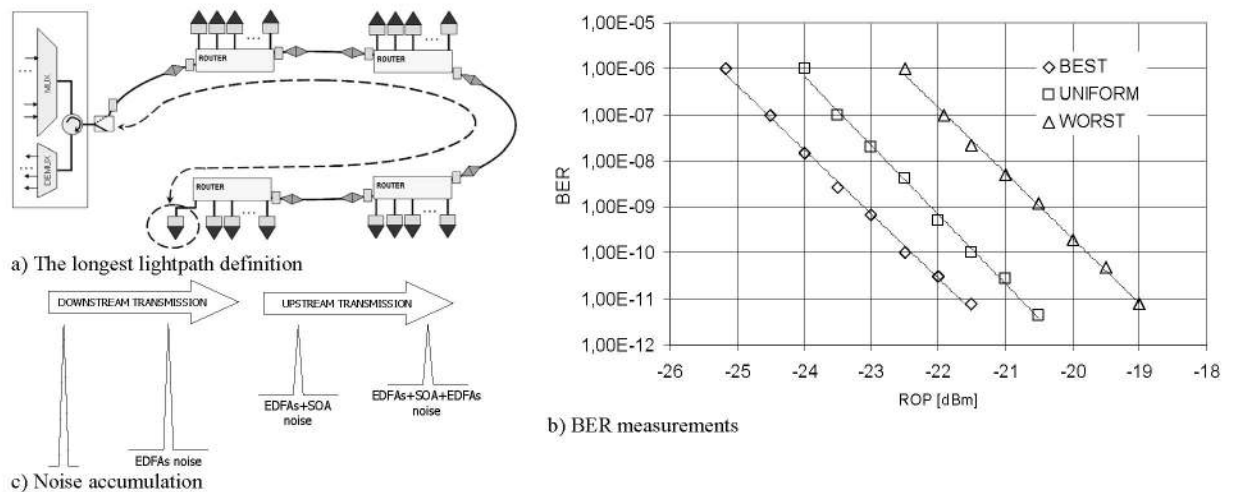


Figure 5. 1.25 Gbit/s RSOA-based network simulations.

The results, given in Fig. 5b, show power penalty in the received optical power of the upstream signal. This is due to the different amounts of ASE noise coming from the cascade of optical amplifiers as showed in Fig. 5c. 1.0 dB and 1.7 dB of power penalty was observed for the uniform and best capacity distribution case with respect to the best capacity distribution case.

Some device reflections were taken into account, however the value of reflected power is kept on the noise level and does not perform any visible influence on data streams. No FWM or other nonlinearities were observed, because of relatively short distances and low signal power involved.

### 3. 10 Gbit/s OPTICAL NETWORK UNIT

For the bitrates above 2.5 Gbit/s another ONU architecture was studied. The new design is based on Michelson Interferometer (MI) and it incorporates conversion of phase modulation to amplitude modulation. The incoming optical power is split into two equal paths. The application of the voltage causes the difference in refractive index and thus a shift in the relative phase between the two paths. Then the beams are reflected and go back to the coupler. Based on the degree of phase shift, light from two segments interferes at the recombining Y-junction destructively or constructively and the continuous signal is amplitude modulated. For best destructive interference the induced phase shift must be  $180^\circ$  at the recombination junction yielding a logic 0. Constructive interference yields a logic 1 and it happens when the phase shift is  $0^\circ$ .

A virtual model of MI-based ONU was designed (Fig. 6a) and simulation for different bitrates were performed (Fig. 6b-6d). In the simulation setup an 0.8 nm optical filter was used followed by the 15 GHz receiver. When comparing to the eye diagrams in Fig. 4, the upgraded device show great potential in high speed modulation. The rising and falling slopes do not limit the performance of the device as in case of RSOA.

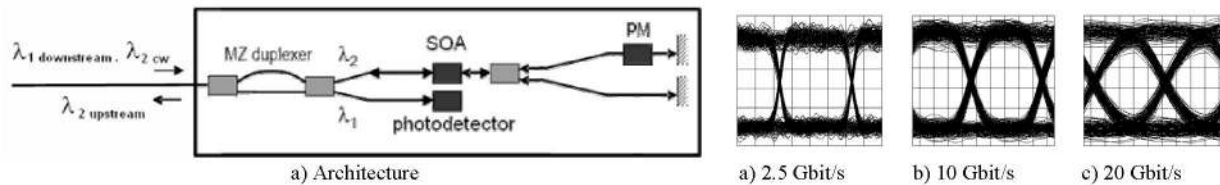


Figure 6. MI-based optical network unit.

### 4. CONCLUSIONS

We proposed reconfigurable access network architecture which is capable of handling 1.25 – 2.5 Gbit/s to the user. Optical network units equipped with RSOA and remote nodes based on microring resonators provide network transparency and flexibility. A proposition of ONU upgrade to 10 Gbit/s is shown by a Michelson Interferometer component. Transmission simulations and principle measurement results prove the feasibility of the concept.

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