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A 10 Gb/s Passive-Components-based WDM-TDM Reconfigurable Optical Access Network Architecture

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Abstract: We propose a cost-effective, reconfigurable optical access network by employing passive components in the remote node and dual conventional optical transceivers in ONUs. The architecture is demonstrated with bidirectional transmission at 10 Gb/s.

OCIS codes: (060.4510) Optical communications; (060.4250) Networks

1. Introduction

Due to fast-growing bandwidth demands, optical access networks are widely replacing copper-based access network technologies. To match the growth pace of user demands, emerging optical access networks have to evolve by increasing the transmission bit rate per wavelength and also the number of wavelengths per fiber. On the other hand, intelligent features such as optical reconfigurability, have been introduced to efficiently utilize increased network capacity [1]. Reconfigurable optical access networks could be classified based on the location where network reconfigurability is handled: at the remote node (RN) by wavelength routing [2-4] or at the optical network units (ONUs) by wavelength selection [5]. In these previous works, optical active components are used in RN for wavelength routing using ring resonators [4] or in ONUs for wavelength selection using tunable filters and tunable lasers [5]. The usage of these components raises issues of network cost and reliability. Therefore, despite the benefits of flexible bandwidth distribution, the reconfigurable optical access is not attractive yet for the network operator.

In this paper, we propose for the first time a passive-components-based reconfigurable optical access network or PROAN in which ONUs could be relocated in a subset of two wavelength pairs (each pair contains a downstream and an upstream wavelength). However, these subsets overlap in order to enable flexible bandwidth rearrangement. By this rearrangement mechanism, PROAN is able to achieve performance close to fully flexible networks where ONUs could be relocated to any wavelength in the system.

2. Passive-components-based reconfigurable architecture

Fig. 1 shows the proposed architecture in which optical line terminal (OLT) transmits two wavelength bands. The lower band contains M continuous wave (CW) wavelengths for upstream (US) reflective modulation at the ONU side and the higher band contains M data-modulated wavelengths for downstream (DS) transmission. Each US wavelength has a corresponding DS one where the spectral distance is one free spectral range (FSR) of the arrayed waveguide grating (AWG) in the RN. As a result, the wavelength pair appears at the same port of the AWG. The output of the AWG is split into two branches, one branch combines with previous-index wavelength pair and the

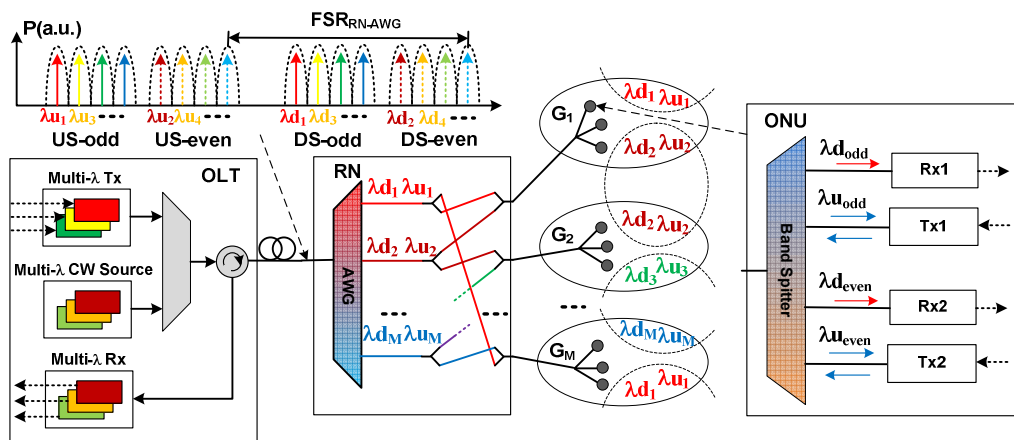


Fig. 1. Representative cyclic reconfigurable optical access architecture in which wavelength pairs are demultiplexed and then cyclically combined at the remote node

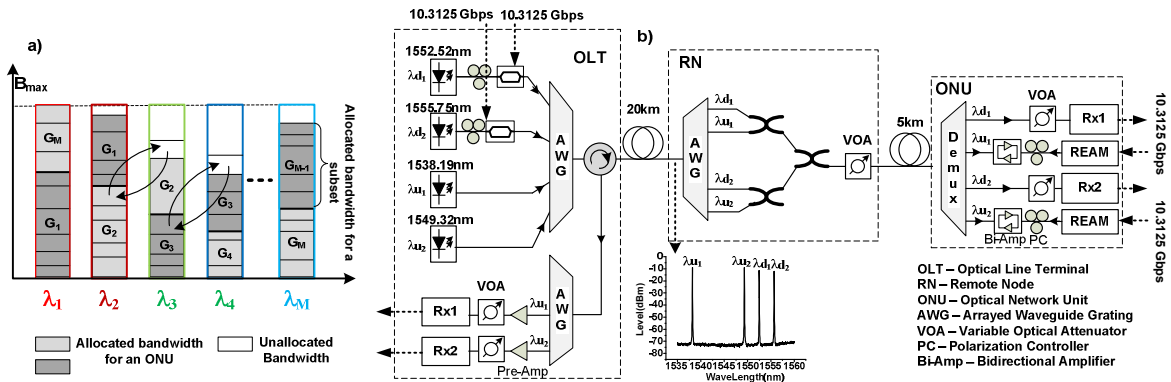


Fig.2. a) Concept of bandwidth rearrangement where unallocated bandwidths are shifted toward a hot spot, b) Experimental setup demonstrating cyclic reconfiguration, as a subset of the system described in Fig. 1

other branch combines with next-index wavelength pair in an interleaving and cyclic manner. For example, wavelength pair $(\lambda_{d1}, \lambda_{u1})$ is split and combined with wavelength pairs $(\lambda_{dM}, \lambda_{uM})$ and $(\lambda_{d2}, \lambda_{u2})$. The following pair $(\lambda_{d2}, \lambda_{u2})$ is split and combined with $(\lambda_{d1}, \lambda_{u1})$ and $(\lambda_{d3}, \lambda_{u3})$ as depicted in Fig.1. Thus, each RN output port could serve one subgroup of ONUs with two wavelength pairs by employing a power splitter.

Since the US band is further divided into odd-index and even-index sub-bands and the same for the DS band, the band splitter at the ONU side is designed to demultiplex four sub-bands to separate ports. Therefore, an ONU is able to demultiplex four received wavelengths to the appropriate ports because no wavelength falls to the same sub-band. The ONU electrically selects to operate on one wavelength pair or even both of them. This configuration allows ONU to be colorless while avoiding the use of tunable filters and tunable lasers at the ONU which are less stable and more costly.

One of the advantages of this architecture is that the wavelength pairs are cyclically interleaved among ONU subgroups which allow system-wide allocated bandwidth rearrangement as visualized in Fig.2.a. For convenience in the figure, $(\lambda_{dx}, \lambda_{ux})$ wavelength pair is denoted as λ_x . For example, subgroup G_1 demands more bandwidth which neither λ_1 nor λ_2 can provide. Thus, the system performs bandwidth rearrangement by relocating one or more ONUs in G_2 from λ_2 to λ_3 , hence virtually the available (unallocated) bandwidth from λ_3 is shifted to λ_2 in order to provide to G_1 . Available bandwidth from a wavelength can be shifted to any adjacent wavelengths. Therefore, by rearranging feature the performance of PROAN is close to that of fully reconfigurable networks where available bandwidth is shifted directly towards the hotspot wavelength.

In addition, the dual-transceiver allows the ONU to be relocated to new wavelength in a make-before-break mechanism during rearranging process. Hence, interruption of on-going services is completely avoided. Consequently, network reconfiguration is transparent to upper layers.

3. Experimental demonstration and discussion

The proof-of-concept experimental setup shown in Fig.2.b consists of two wavelength pairs $(\lambda_{d1}, \lambda_{u1})$ and $(\lambda_{d2}, \lambda_{u2})$. The DS wavelengths λ_{d1} (1552.52 nm) and λ_{d2} (1555.75 nm) are externally modulated by 10.3125 Gb/s non-return-to-zero (NRZ) $2^{31}-1$ pseudorandom bit sequence (PRBS) and multiplexed together with CW US seeding wavelengths λ_{u1} (1538.19 nm) and λ_{u2} (1549.32 nm). These wavelengths are specified by ITU-T 100GHz-spacing wavelength grid and selected from available DFB laser sources in our laboratory. The launching power towards the OLT-AWG is 0 and 3 dBm for DS wavelengths and US wavelengths, respectively. After transmission over 20km standard single mode fiber (SMF), they are demultiplexed at the RN by a commercial 32-port 100GHz-spaced C-band AWG with 2.5 dB insertion loss. Then λ_{d1} and λ_{u1} are combined using a 2x2 3dB coupler and the same for λ_{d2} and λ_{u2} to emulate cyclic property of the proposed AWG. The two pairs are then combined again to be a RN output port. The variable optical attenuator (VOA) in the RN emulates the losses associated with a splitting ratio of 1:8. After further transmission over 5km from RN to ONU, the wavelengths are demultiplexed by a 16-port 200GHz-spaced C-band AWG in which two DS wavelengths are routed to the avalanche photodiode (APD) receivers and two US wavelengths are routed to the reflective electro-absorption modulator (REAM). US wavelengths are modulated by 10.3125 Gb/s NRZ $2^{23}-1$ PRBS and propagate back to OLT. We use a bidirectional amplifier which provided a gain of 20dB for each direction before the REAM to compensate for 8-dB REAM insertion loss and transmission loss.

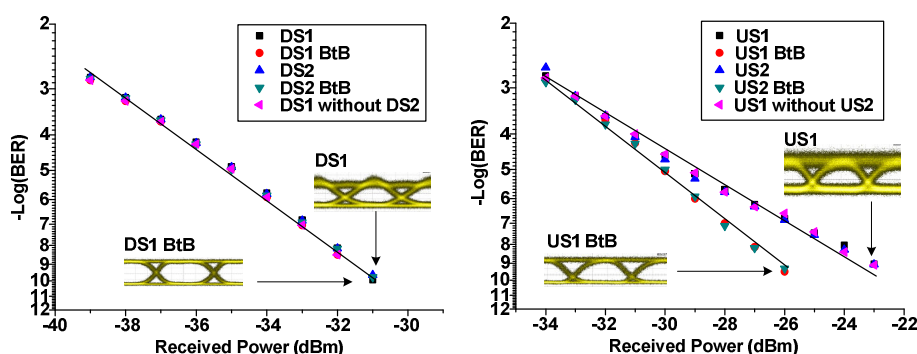


Fig.3. Receiver performance for downstream (left) and upstream (right) channels

The total link loss for each direction is 30 dB while a total loss of 31 dB for downstream results in error-free transmission providing a margin of 1 dB. This margin could be improved by increasing the launching power however, the launching power for DS wavelengths is maintained at 0 dBm to avoid nonlinear interchannel cross talk. In the upstream direction, the bidirectional amplifier is used since the REAM provided no gain but 8-dB insertion loss. However, the external amplifier could be removed if an REAM-SOA (semiconductor optical amplifier) reported in [6] is used instead of REAM. To achieve error-free transmission, a pre-amplifier has to be used in front of upstream receivers in OLT since without it the minimum achievable error rate is 10^{-7} .

Results in Fig.3 shows four measurement cases in each direction including the case when only channel 1 (λ_{d1} , λ_{u1}) is working. In all DS cases in Fig.3(left), the error performance is identical to the baseline optical back to back (BtB) performance. The performance of DS1 without DS2 is coincided due to good isolation in the passive components. For US performance shown in Fig.3(right), all transmission cases suffer a power penalty of 2.5 dB to get error-free performance which is due to backscattering from the seeding wavelength transmission.

In the proposed architecture, a DS wavelength should have a US wavelength spaced by one FSR to exploit the cyclic property of the AWG at RN. This requirement is somewhat restrictive in terms of wavelength planning especially when coexistence with traditional PONs is considered. This requirement could be relaxed in the proposed architecture if the 2x2 3dB couplers are used to combine the wavelength pairs as suggested in the experimental setup. As the coupler also acts as splitter to provide two branches for interleaving combination, no additional power loss is introduced.

4. Conclusion

In this paper, we presented a passive-components-based reconfigurable WDM-TDM optical access network. The RN is designed to be completely passive and a tunable transceiver at ONU side is avoided by using a band-splitter and dual-transceiver. Although an ONU is allowed to be relocated between only two wavelength pairs, the system still attains superior flexibility by allocated bandwidth rearrangement mechanism. The architecture is demonstrated experimentally with error-free 10 Gbps bidirectional transmission. The physical performance was shown to be tolerable.

We continue to explore some aspects of the proposed architecture including wavelength planning, efficient integration of optical components at the ONU side, and implications on the MAC layer. We believe that the proposed concept is a feasible proposal for the optical access community which up to now has been reluctant to adopt reconfigurability because of its complexity and expensiveness.

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