Wavelength-Converted Long-Reach Reconfigurable Optical Access Network

Nguyen-Cac Tran,[1] Eduward Tangdiongga,[1] and Ton Koonen[1]

[1] COBRA Research Institute, Eindhoven University of Technology, P.O. Box 513, Eindhoven, 5612 AZ, The Netherlands

Next generation optical access networks should not only increase the capacity but also be able to redistribute the capacity on the fly in order to manage more fluctuated traffic patterns. Wavelength reconfigurability is the instrument to enable such capability of network-wide bandwidth redistribution since it allows the dynamic sharing of both wavelengths and timeslots in WDM-TDM optical access networks. However, reconfigurability typically requires tunable lasers and tunable filters at the user side, resulting in cost-prohibitive optical network units (ONU). In this paper, we propose a novel long-reach reconfigurable architecture based on the concept of cyclic-linked flexibility to address the cost-prohibitive problem. The network-wide bandwidth redistribution capability is archived, even though ONUs are equipped only with legacy GPON and XPON transceivers.

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 use 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.

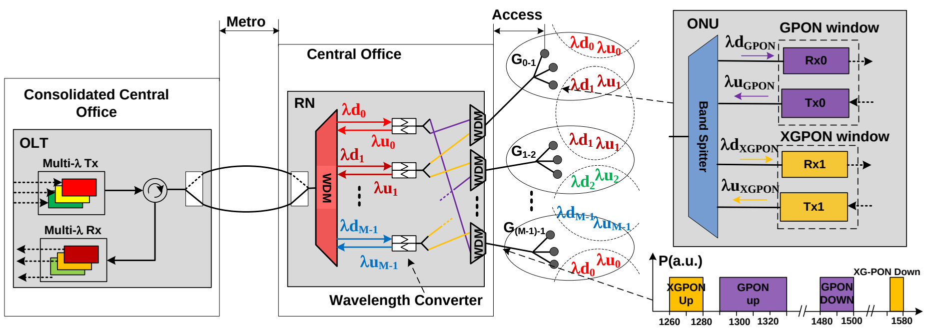

Fig. 1. Schematic representation of wavelength-converted long-reach architecture to support central office consolidation and direct migration for current PON deployments

In this paper, we propose a wavelength-converted long-reach reconfigurable optical access network WCL-Access 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, WCL-Access is able to achieve performance close to fully flexible networks where ONUs could be relocated to any wavelength in the system.

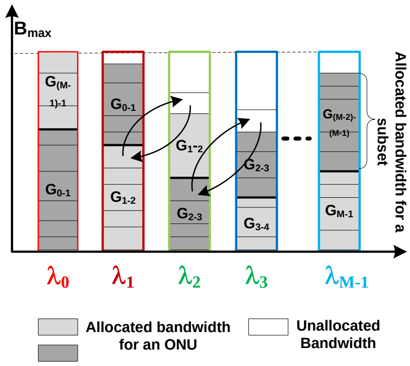

Fig. 2. Concept of bandwidth rearrangement where unallocated bandwidths are shifted toward a hot spot

WCL-Access Architecture

The proposed architecture is shown in Fig. 1 in which the OLT is located in the consolidated central office while the remote is located in the distributed central office. The network between the two central offices is the metro section in which DWDM wavelengths are used to establish light-paths between the OLT and the RN. These wavelengths are then converted to either GPON-window wavelengths or XGPON-window wavelengths. These wavelengths are converted, split and combined to form the cyclic-linked configuration. For example, the wavelength λd_0 is converted to the GPON downstream wavelength and the corresponding GPON upstream wavelength is converted to the wavelength λu_0. The two GPON wavelengths are split and combined with other two XGPON wavelengths, which are obtained by converting λd_1 and λu_1 to feed group $G_{0\text{-}1}$ of ONUs. Thus, ONUs in $G_{0\text{-}1}$ interface with GPON and XGPON wavelengths, however, they are actually serviced by (λd_0, λu_0) and (λd_1, λu_1) in the metro section. Similarly, $G_{1\text{-}2}$ is serviced by (λd_1, λu_1) and (λd_2, λu_2), and so on to constitute the cyclic-linked flexibility structure.

One of the advantages of this architecture is that the wavelength pairs are cyclically linked among ONU groups which allow system-wide allocated bandwidth rearrangement as visualized in Fig. 2. For convenience in the figure, (λd_x, λu_x) wavelength pair is denoted as λ_x. For example, group $G_{0\text{-}1}$ demands more bandwidth which neither λ_0 nor λ_1 can provide. Thus, the system performs bandwidth rearrangement by relocating one or more ONUs in $G_{1\text{-}2}$ from λ_1 to λ_2, hence virtually the available (unallocated) bandwidth from λ_2 is shifted to λ_1 in order to provide to G_1. Available bandwidth from a wavelength can reach any other wavelength by several shifting steps because in general available bandwidth from a wavelength can be shifted to any adjacent wavelengths. Therefore, by rearranging feature the performance of WCL-Access is close to that of fully reconfigurable networks where available bandwidth is shifted directly towards the hotspot wavelength.

The ONU transmits and receives only GPON and XGPON wavelengths that allows to have to use transceivers similar to ones designed for standardized PONs, promising cost-effectiveness. The same design of ONU can be used in every branch guaranteeing the wavelength-agnostic property since only GPON and XGPON wavelengths are present in the access section. Note that although using the GPON window, it not necessarily to use GPON line rates. The access section is based on power splitter which is compliant with current PON deployments. The compliance allows network migration without touching the outside plant.

Cost per user

Although the wavelength converter is shared among users in the same branch, it eventually increases the cost per user. Therefore, it is important to justify this increment and to compare with the conventional architecture. The conventional reconfigurable

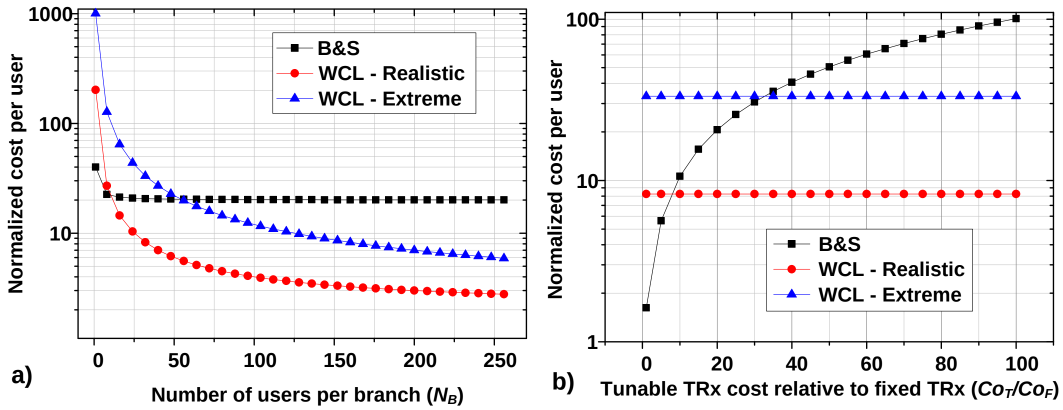

Fig. 3. Cost comparison between WCL-Access and conventional long-reach Broadcast-and-Select, cost is normalized to conventional PON TRx (Co_F), a) cost per user as a function of number of users per branch, b) cost per user as a function of

long-reach PONs employs optical amplifiers such as EDFAs to compensate the power loss and tunable transceivers at the ONU for wavelength reconfigurability. Therefore, the cost difference between two architectures can be evaluated by different devices used in the RN and the ONU.

Let Co_F, and Co_C denote cost of a fixed transceiver and cost of the wavelength converter in the WCL-Access architecture, respectively. In this architecture, the ONU employs two fixed transceivers and the wavelength converter services one ONU group and includes a converter for downstream and another for upstream. Let Co_T and Co_A denote cost of the tunable transceiver and cost of the optical amplifier module in the conventional Broadcast-and-Select architecture, respectively. In this architecture, ONUs employ tunable transceivers and one optical amplifier is used for each ONU group. Assume that cost of other modules is the same for both architectures, we can derive cost per user Cu_{WCL} and $Cu_{B\&S}$, which do not take into account common costs, for the WCL-Access and Broadcast-and-Select architecture in Eq. 1 and Eq. 2, respectively

$$Cu_{WCL} = 2Co_F + \frac{Co_C}{N_B} \qquad \text{(Eq. 1)}$$

$$Cu_{B\&S} = Co_T + \frac{Co_A}{N_B} \qquad \text{(Eq. 2)}$$

where N_B is the number of ONUs per branch.

The cost per user as a function of number of users per branch N_B is shown in Fig. 3.a) in which the cost per user is normalized to cost of a fixed transceiver Co_F. We assume that cost of the tunable transceiver Co_T is 20 times higher than cost of the fixed transceiver Co_F, cost of the amplifier Co_A is the same as cost of the tunable transceiver Co_T. There are two cases for cost of the wavelength converter in which Co_C is 200 times and 1000 times higher than Co_F. The first case represents a realistic cost while the second case represents an extremely high cost for the wavelength converter. The result shows that from the level of 16 ONUs per branch the WCL-Access requires a lower cost than the conventional Broadcast-and-Select in the realistic estimation while from the level of 56 ONUs per branch in the extreme estimation. Therefore, 64 ONUs per branch can guarantee the WCL-Access solution is cheaper than Broadcast-and-Select solution even in case that cost of wavelength converter is extremely high. This achievement is due to the fact that cost of the wavelength converter is shared among large number of users.

The assumption that Co_T is 20 times higher than Co_F is practical since the tunable TRx is not only wavelength tunable and long-reach operable but also much lower in the production volume than the conventional fixed TRx. However, one still can question what if cost of the tunable TRx can be reduced relatively to the fixed TRx. In order to address the question, cost per user as a function of Co_T to Co_F ratio is shown Fig. 3.b). In this estimation, the number of user per branch is kept to be 32 ONUs. In the realistic estimation, the Broadcast-and-Select solution is more costly than the WCL-Access solution when the ratio is 10 or higher. In the extreme estimation, the cost crossing between two solutions occurs when the ratio is around 35 times. Therefore, much reduction in cost of the tunable TRx needs to be made before the Broadcast-and-Select can be more cost-effective. This comparison highlight the advantage of using mass-produced optical transceivers, thus low-cost, in the design of WCL-Access architecture.

Conclusions

WCL-Access architecture is the long-reach implementation for the cyclic-linked flexibility concept. The implementation requires wavelength converters in the distributed central office. The use of wavelength converters adds extra cost but enable several advantages: completely decouple of the metro and the access section in terms of wavelength plan and signal impairments, conventional CWDM or PON transceivers can be used in the ONU, no wavelength tuning is required at the colorless ONU, and scalable in terms of number of wavelengths and ONUs.

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