Passive OADM Network Element for Hybrid Ring-Tree WDM/TDM-PON

Josep Prat [(1)], Jose Lazaro [(1)], Philippe Chanclou [(2)], Sergio Cascelli [(3)]

[(1)] Universitat Politécnica de Catalunya, Jordi Girona 1, 08034 Barcelona, Spain, jprat@tsc.upc.edu
[(2)] FT/Orange, Lannion. [(3)] Italian Ministry of the Economic Development – Communications, Rome

Abstract *The operation of a ring-tree WDM/TDM-PON and the enabling OADMs remote nodes performing the hybrid interface are described and specified, validating the capacity and functionality of the NGPON architecture.*

Introduction

PON access networks are commonly implemented in tree configuration, with diverse splitting ratios and split locations. In search of enhanced performances and functionalities for the next generation (NGPON), a more sophisticated hybrid ring-tree topology has been proposed and demonstrated[1-3]. In terms of multiplexing, the feasible practical approach consists of an overlay of WDM in the ring and TDM in the tree section. The former adopts the technology developed for metro networks and the later is highly compatible with the chip-sets and MAC of last generation PONs. This hybrid topology offers basic resilience, better fibre utilization, distributed flexible higher splitting ratio, extended reach and, in general, a transparent solution to metro-access convergence. The general scheme, implemented in the FP7 Sardana project[4], is sketched in Fig. 1, showing the ring, feeder and drop sections. In this work, its operation and the obtained features of the enabling network element are described.

Basic operation of the PON and the RNs

In the external fibre plant of the PON, the new key element that enables the hybrid architecture is the add&drop remote node (RN); its main function is to interface the WDM ring and the TDM access trees, thus implementing passive cascadeable Optical Add/Drop Multiplexers (OADMs) of specific wavelength channels and enabling the ring protection function. Another requirement is for it to be passive, in the sense of not requiring electrical power feeding inside of the Optical Network Elements (ONEs) involved with respect to the low OPEX feature of the external fibre plant of a PON. Because of the ring protection, the RN internal topology requires to be symmetrical from both sides of the ring (left and right sides) and, being static, has to allow the transmission to/from the tree OADM port (D in Fig.2) of the selected channel/s. Because of this fundamental feature of the network and the RN, the bidirectional transmission in the PON is to operate as follows:

1. Downstream: the OLT transmits each wavelength channel through one side of the ring; in case of cut, the OLT switches to the other side (1:1 protection). 1+1 protection is not possible because it would cause coherent interference at the drop.
2. Upstream: the up signal is transmitted through both directions of the ring, and the OLT selects one for detection (1+1 protection).

This implies that in upstream the protection mechanism (located at the OLT) can be faster than in downstream, where both the ONU and the OLT have to react, after a monitoring/signalling operation.

In the RN, the above requirements are obtained by means of a central 3dB 2x2 coupler in diversity configuration, in conjunction with the devices described below.

In each RN, 1, 2 or some more few wavelengths can be extracted (the extraction of all wavelengths would reduce the ring to the dual feeder protection defined in ITU G.983). Because of the 2x2 diversity coupler, the most efficient drop in terms of per channel optical power efficiency, is to extract 2 wavelengths at each RN.

The above requirements lead to a general definition of the RN as a fixed network element in the functional scheme of the PON, so as indicated in Fig. 2, and specified by the spectral attenuations between the L, R and D ports.

Power budget

The tree section of the PON is adopted from the standard PON, now at allocated wavelength; with the ring, there is higher freedom in placing the splitting elements and the 3 fibre sections. The difference in power budget with the new architecture is due to the bypass losses and add/drop loses of the RNs:

$$\Delta PB = (i\text{-}1)\ Pass\text{-}Loss + Drop\text{-}Loss$$

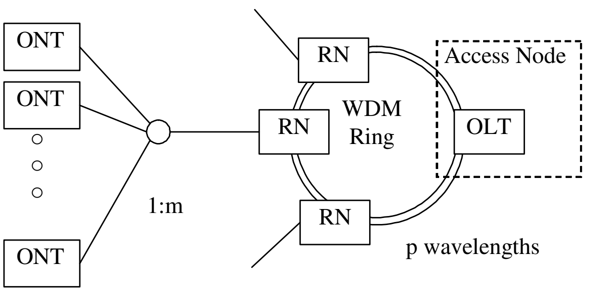

Fig. 1: Ring-tree PON scheme.

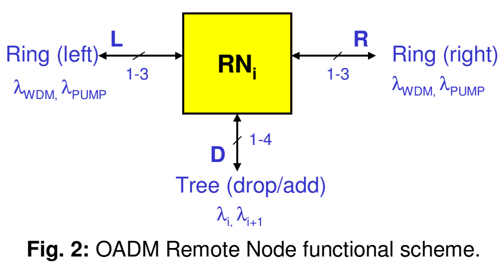

Fig. 2: OADM Remote Node functional scheme.

The consequent decrease in the distance range and/or in the splitting ratio, specially in the worst case of fibre cut, can be overcome in this network adopting any of the following approaches:

a) Enhancing the OLT/ONU equipment from e.g. GPON Class B+ (28dB) to Class C+ (32dB) or even higher, for example by using optical amplifiers at the OLT. The increase of the associated cost is compensated by the higher sharing factor of this PON, as the amplifier covers the full band, in DWDM.
b) Reducing the tree splitting ratio, in a factor of 4 or 8, thus increasing equally the guarantied bandwidth to each ONU, and considering the wavelength domain as in the overall splitting ratio of the PON.
c) Adopting an optical amplification of the signal in the RN, remotely pumped from the OLT (ROPA) to preserve the passiveness of the PON. This technique has been used in repeater-less optical submarine systems (ITU-T G.973) and in PONs too.

Added features

In the implemented Sardana network, optical amplification is effectively used to compensate the RN losses, the splitting ratio up to 1024 ONUs, and to further extend the distance reach, up to 100 Km. Therefore, Erbium doped optical fibre (5 m to 15 m) is inserted inside the RN (in the drop path and/or the in-line paths) and a percentage of the pump power circulating along the ring is extracted in both directions with low loss 1550/1480nm mux. With the above said amplification, the RN is no longer static in terms of power budget calculation, and has a more complex non linear dependency on the status of both system and signals. For all of the above, the proper dimensioning of the network, the design of the RNs and the powers associated to the signals become key issues of this PON.

Another network key aspect is the ONU technology. At this regard, for provisioning uniformity in the WDM PON, a colourless design is preferred. This is obtained with tuneable ONU or with reflective ONU. While the first is not yet mature for PONs and requires double spectrum management, the second suffers from Rayleigh backscattering (RBS). Notwithstanding the above said difficulties, both the above mentioned technologies can be used in the hybrid architecture. If reflective ONU is used, a simply way to combat RBS consists of doubling the ring fibres, using one ring for downstream and another for upstream. The feeder fibre can be also doubled, depending on the scenario. The drop fibre is kept single since it is the most cost-sensitive section of the PON. Other solutions involve enhanced-tolerance modulation formats.

Optionally, the pump light could be transported via a third ring fibre to reduce the RN pass loss, but this may not desirable in practical scenarios and restricts the obtained extra Raman amplification.

Example design and specifications

With the above considerations, several designs have been implemented. Figure 3 shows the RN with 2 drop wavelength (2 trees), bidirectional remote amplification in the drop and for reflective ONUs. Wavelength extraction is done by means of two thin-film OADMs at alternated 50GHz channels. The natural amplification transients with the dynamic burst-mode operation of the PON are cancelled in this RN thanks to the crossed direction-wavelength design, to avoid the RBS of the ROPA. The specified (from the overall power budget and penalties) and measured values of the RN characteristic parameters are reported in Table I.

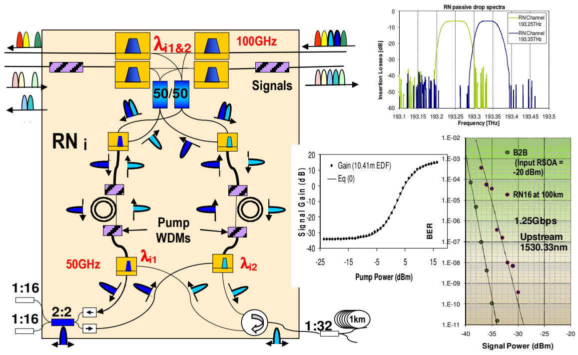

Fig. 3: RN implementation scheme (pump connections not shown for clarity, although pump muxs included), spectral response, gain as a function of the pump power and BER.

Table I. Specification and measured values of the RN.

Parameter	Target	Measured prototype
Wavelength Ch.	ITU 50GHz, (1530 – 1570 nm)	ITU 50GHz (alternating ch,)
Pass IL (/ with pump)	0.6dB / 1.2dB	0.53dB / 1.0dB
Drop Insertion loss	6 - 8 dB	6.1 dB
Drop selectivity	>25dB	>35 dB
Wavelength drift	< 0.1 nm	< 1.2 pm/ºC
Return loss	> 30 dB	32 dB
Pump Wavelength	1470 - 1490 nm	1480 nm
Pump power	10 - 19 dBm	10 dBm
Gain (drop)	10 - 18 dB	14 dB
Noise Figure	4 - 6 dB	4.2 dB
Burst-mode penalty	0.5 dB	< 0.5dB

Conclusions

The designed RNs enable the resilient ring-tree network operation, at BER<10^{-10} with 16 RNs (2 implemented and the rest emulated), with a total 1024 splitting ratio, validating so the operation of the NGPON architecture.

This work was supported by the European FP7 SARDANA Project and BONE Network of Excellence.

References

1 L.G.Kazovsky et al., JLT, Nov. 2007.
2 K.-D. Langer et al, Proc. NOC’2005, 68-75.
3 J.A. Lazaro et al, OFC’2008, OThL2.
4 www.ict-sardana.eu