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Demonstration and field trial of a resilient hybrid NG-PON test-bed

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ABSTRACT

A multi-layer next generation PON prototype has been built and tested, to show the feasibility of extended hybrid DWDM/TDM-XGPON FTTH networks with resilient optically-integrated ring-trees architecture, supporting broadband multimedia services. It constitutes a transparent common platform for the coexistence of multiple operators sharing the optical infrastructure of the central metro ring, passively combining the access and the metropolitan network sections. It features 32 wavelength connections at 10 Gbps, up to 1000 users distributed in 16 independent resilient sub-PONs over 100 km. This paper summarizes the network operation, demonstration and field trial results.

1. Introduction

Current developments on new FTTH network architectures and technologies aim at enabling universal end-to-end communications with substantial increase in terms of bidirectional capacity, connected users and distance reach, as well as incorporating enhanced scalability, resilience, security, metro-access convergence, service integration and other key functionalities. The main limiting conditions are related to the reuse of a common infrastructure and the cost efficiency with respect to the currently deployed Passive Optical Networks (PON) systems. With this basic requirements, several candidates for Next-Generation PONs (NG-PON) are nowadays being investigated and proposed, using different multiplexing domains (CWDM, DWDM, TDMA, SCM, CDMA or hybrids, like TWDM, selected for NG-PON2), modulation formats (duobinary, OFDM, xPSK, etc), devices and architectures [1]. The ideal candidate has not been consensually identified yet, that could offer the appropriate balanced levels of performances, complexity, scalability and compatibility.

Until now, the different PON generations have scaled up in digital rate by means of optical TDMA multiplexing, as enabling fine bandwidth granularity; but as 10 Gbps rate has been reached, the device requirements and power efficiency indicate the need for other multiplexing domains. Among them, being the optical wavelength spectrum the dimension offering the vastest bandwidth, many research initiatives have shown the convenience of exploiting WDM, alone or in combination with other multiplexing domains to obtain the required bandwidth amount and bandwidth granularity simultaneously.

On the other hand, intensive research has been also devoted to the extension of the distance-reach, and to the efficient integration of the access network with the metro or core network, in order to: simplify the overall network operation, consolidate dispersed active Central Offices, reduce operation costs and provide service to disperse rural areas [2].

In terms of topology architecture, there has been few novel proposals; the tree-based PON is still dominant in the proposals for NG-PON. However, advantages like better fiber utilization, protection, add&drop granularity are subject to be obtained with a different architecture.

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A novel extended architecture combining DWDM and TDMA was proposed and implemented, as a NG-PON candidate in the recent European "SARDANA" project (Scalable Advanced Ring-based passive Dense Access Network Architecture) [3,4], The hybrid ring-tree DWDM/TDMA-PON test-bed has proven the feasibility of a transparent passive approach of what is today known as metro-access convergence. It consists of the organization of the optical distribution network as an aggregation of TDM access trees passively connected through a metropolitan WDM bidirectional ring, via cascadable add&drop Remote Nodes, in order to operate as a resilient all-optical TDM-over-WDM overlay. The proposed topology concentrates the electronic equipment at a unique Central Office (CO), whilst simplifying the customer premises equipment and the external optical plant with respect to the WDM-PONs where every user uses a wavelength-selected laser (not colorless), as will be shown in Sections 3 and 4.

In this paper, the rationale, the constitutive novel elements and the results of the test-bed demonstration are presented. It is organized as follows: Section 2 describes the new architecture of the SARDANA network, in Section 3 the key subsystems and techniques that enable the PON operation are presented, Section 4 describes the network tests performed in the demonstration set-up and field trial, and Section 5 discusses on the cost and energy efficiencies.

2. Network architecture

In search of high scalability and trunk protection, an alternative architecture of the conventional TDM or WDM PON tree is implemented, by combining a WDM bidirectional ring and the TDM access trees, interconnected by means of cascadable remote nodes (RN), as depicted in Fig. 1. A RN drops two wavelengths of the metro ring and reinserts them after being remodulated at the colourless ONUs, as will be explained in Section 3.1.

The ring+tree topology can be considered as a natural evolution from the conventional arrangement, where metropolitan and access networks are connected by heterogeneous O/E/O transceivers and routers at the interfaces between the FTTH OLTs and the metro network nodes, towards an integrated Metro-Access network. In this case, covering similar geographical area, users and services, but concentrating the electronic equipment at one CO, implementing an all-optical passive alternative, and operating as a resilient TDM over WDM overlay. Depending on the scenario, the ring+tree mixed topology optimizes the usage of fiber infrastructure in the ODN, especially for rural areas, and also offers enhanced scalability and flexible distribution, as new RNs can be installed in addition, as it will be analyzed below. The central ring provides resilience capability and distributed add&drop with a minimal number of links, as being the most common topology in current metropolitan networks. With the proposed design of the Remote Nodes (RN), there are two possible OLT-ONU paths; in case of a fiber failure, the data links are reconfigured and restored, with centralized optical switching at the OLT. This feature becomes more important as the capacity of the access network scales to the high number of served users; with the hybrid multiplex, the fiber congestion at the CO is reduced, as 4 fibers are required per about 250–2000 users, and it is compatible with scenarios as in urban areas where new fiber deployment can suppose a very high cost, but a limited number of dark or free fibers can be still available.

In the design of the physical layer, the optical and electro-optical subsystems are aimed to be highly transparent to the protocol, coding and bit rate, of existing PON standards. With respect to these, the optical parameters are changed (for example the wavelength band), but the chipset is kept compatible with the ITU-T G.984 GPON family, for a smooth migration and interoperability. The GPON standard was taken as a first reference point, this being also the more stringent in specifications than IEEE 802.3ah EPON, and scaled to XGPON1.

For the full network demonstration, a 10G/2.5G MAC, based on FPGA, performing the SXGPON (SARDANA 10G PON), in line with XGPON1 GTC (GPON Transmission Convergence) of ITU-T G.987 standard, but with few variants like the capability for longer reach, was developed in the project supporting advanced new broadband multimedia services. Even though the systems are primarily designed to operate with the XGPON1 protocol, the transceivers are implemented to be optical and 2R transparent to also provide simultaneous connectivity to different standards like GPON, XGPON, EPON and 10GEPON for point to multi-point and 1G Ethernet and 10G Ethernet for point to point (pure WDM-PON). To enable this connectivity as simple as possible, with minimum adaptation, the SARDANA interface is optical, with the corresponding media converter and 2R regeneration and wavelength transponder, when it is not built in the client system. It allows these systems to be transported over SARDANA, with its optical transmission characteristics, in terms of wavelengths, powers, routing, protection, etc.

SARDANA can thus be regarded as a transparent optical layer operating at the wavelength domain transparently that acts as traffic collector of existing access systems, and using the existing metro/access optical passive infrastructure. The corresponding multi-operability model in terms of OLT and ONU interfaces is shown in Fig. 2a with the equipment scheme, and an example of physical PON distribution on the basis of remote nodes and assigned wavelengths per operators is drawn in Fig. 2b. This metro ring PON extension can be considered as a neutral network layer that can be shared by different operators (Service Operators, IP Connection operators or PON equipment operators) in equal terms, with a high level of transparency, to guarantee their independency. In contrast with the unbundling at layer 2 or layer 3, unbundling at the physical layer can provide a more open solution for multi-operability, specifically in the wavelength domain, inside the bandwidth of the optical amplifiers. For this purpose, the ring-tree topology of SARDANA provides an extra degree of freedom to allocate Remote Nodes or wavelengths to groups of users in an operation flexible way thanks to the very low bypass losses of the RNs. The ring infrastructure, with the protection feature, can thus be shared by a huge number of users, minimizing the usage of trunk cable.

Longer term proposals to extend the dynamicity of the traffic control have been contributed, by means of online upstream scheduling and wavelength assignment [5] or using Optical Burst Switching for the PON in transparent connection to the core network [6], exhibiting efficient throughput in different traffic conditions.

3. Key subsystems

The implementation of the network encompasses a number of technical challenges in the three key subsystems: the passive Remote Node (RN) of the Optical Distribution Network (ODN), the colorless Optical Network Unit (ONU) and the Central Office (CO). Along the research, although several solutions have been investigated, the decision on the selected one for network demonstration is made on the basis of cost efficiency and robustness, leaving more complex advanced solutions for longer-term research.

3.1. Remote nodes

The RN is a key element of the SARDANA network and many of the performances and functionalities of the network depend on its