Feasibility of DWDM-upgraded PON for FTTBusiness and demonstrator.

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The aim of the wavelength division multiplexing (WDM) upgraded access project was to study all aspects pertaining to the evolution of existing passive optical networks (PON) and to take those evolution aspects into account for the future-safe deployment of such optical access networks. APON technology is mature and commercial products are available today. In order to serve future needs of high-end users, DWDM techniques could be used to upgrade already installed APONs. The results of the feasibility study of DWDM overlay PON based upon a power splitter are presented and discussed. A demonstrator with Gigabit Ethernet over DWDM-upgraded PON has been built.

Introduction

For fiber-to-the-x (FTTx) architectures, ATM passive optical network (APON) is accepted as a well-suited technology, giving a good compromise between performance and cost. Pushed by the full-service access network (FSAN) initiative, APON technology is mature and commercial products are available today. PON systems have been standardized in ITU-T G.983.1, followed by a wavelength plan for an upgrade of PON defined in [1]. In order to serve future needs of high-end users, dense wavelength division multiplexing (DWDM) techniques could be used to upgrade already installed APONs.

WDM can transform a point-to-multipoint PON network into a virtual point-to-point network. A logical point-to-point network is present in a broadcast PON, in which a network termination (NT) only reads the channels or packets intended for it. The virtual link, as opposed to the logical point-to-point character, allows a subscriber to enjoy several advantages, such as increased privacy, efficiency, serevice segregation and format transparency. These attributes of the physical level distinguish WDM PONs from TDM PONs and help to make PONs future proof.

A DWDM upgrade is a more cost-effective way to offer point-to-point services via an existing PON than installing additional fibers. Furthermore, an operator can upgrade the PON with the DWDM solution from the central office. While for a point-to-point connection, there is a need to go into the field to connect the fibers.

We have studied in detail the DWDM upgrade of APON based upon a power splitter [2]. This evolution has been chosen because it is the most promising in terms of flexibility. The new users and/or the users requiring a higher bandwidth can be added to the existing system one by one, without requiring any work in the field. The performed simulations are described, and the results are discussed. Based on this feasibility study, a demonstrator is built.

Feasibility of DWDM overlay PON

Fig.1 shows the architecture of a DWDM upgrade PON based upon a power splitter. At the central office, Line Terminations (LT) are the interfaces between the core network and the access network.

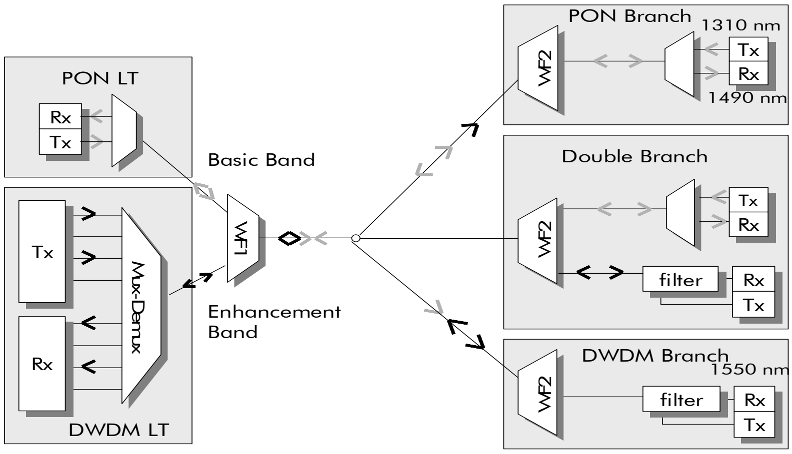

Figure 1: DWDM overlay PON based upon a power splitter.

The optical distribution network (ODN) is composed of a feeder section divided by power splitters into drop sections. It forms a point-to-multipoint connection.
At the DWDM LT, DWDM sources at different wavelengths, situated between 1539 nm and 1565 nm [1], also called the enhancement band, generate downstream signals. Those signals are multiplexed into one single fiber via a wavelength multiplexer. In the opposite direction, the same component demultiplexes the DWDM upstream signals.
The PON LT board generates the APON downstream signal in the band 1480 nm - 1500 nm, called the basic band [1]. The APON downstream signal is multiplexed into the feeder section with the DWDM signals via a coarse WDM (CWDM) multiplexer (Wavelength Filter WF1). In the opposite direction, the same component separates the PON upstream signal from the DWDM upstream signals.
At the NT side, a CWDM filter (WF2) separates the enhancement band from the basic band. A DWDM filter selects the DWDM downstream signal destined to the specific NT. A DWDM source generates the DWDM upstream signal at a wavelength belonging to the enhancement band (but different from the ones of the downstream signals). The PON NT board generates the PON upstream signal (situated between 1260 nm and 1360 nm [1]). Every user can have either a PON NT and/or a DWDM NT.
Simulations have been performed in order to determine feasible architectures in terms of maximum ODN loss, constraints on the dynamic range of the ODN, and component requirements. Worst cases have been considered: the components parameters could vary from a minimum value to the value announced by their specifications, in line with [1].
The maximum ODN loss is limited on one hand by the power budget of the upstream and downstream paths, and on the other hand by linear crosstalk inherent to the DWDM demultiplexer, being an arrayed waveguide grating (AWG). Since a signal to interference ratio (SIR) higher than 7 dB gives a power penalty due to the linear crosstalk smaller than 1 dB [2], a SIR higher than 10 dB was chosen as acceptance criterion. The different interference contributions at the DWDM LT and NT receivers

have been identified and simulated, taking into account the parameters of the involved components. Component requirements (e.g. isolations of WF1 and WF2 for 1310 nm and 1490 nm) have been computed.

The minimum ODN loss has been fixed at 10 dB. Fig.2 illustrates the noise contributions arriving at the LT DWDM Rx versus the number of used DWDM channels. The following parameters have been assumed: AWG insertion loss varying from 3.5 dB to 5 dB; AWG adjacent crosstalk is 30 dB; AWG non-adjacent crosstalk is 40 dB; AWG directivity is 55 dB; DWDM filter isolation at 1550 nm is 22 dB; DWDM filter directivity is 45 dB; Rx sensitivity is -23 dBm (typical value for a PIN diode at 1.25 Gbit/s); average optical output power at DWDM LTs and NTs varies between –1 dBm and +2dBm.

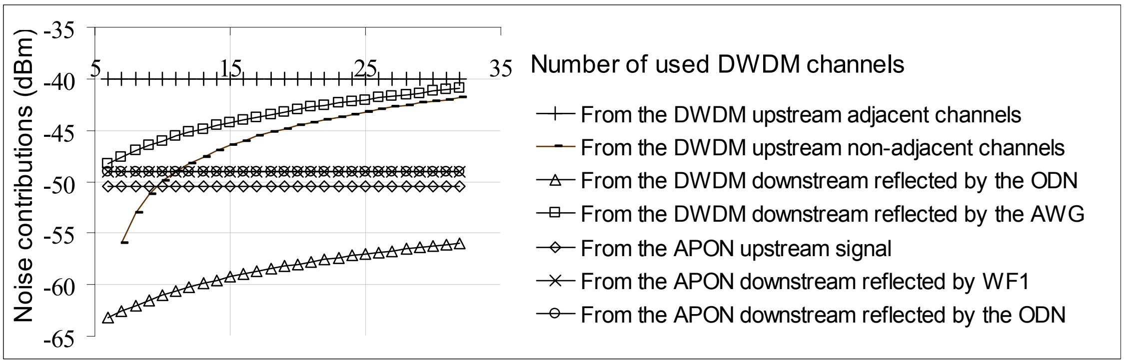

Figure 2: Noise contributions at the DWDM LT Receiver.

Fig.2 shows that the most important contribution (-40 to –37 dBm) is the noise coming from the upstream DWDM channels (adjacent and non-adjacent ones), and particularly from the two adjacent channels. The second contribution (up to –40 dBm) comes from the downstream DWDM channels, being reflected mostly by the AWG. Note this contribution is of lower importance if the number of involved DWDM channels is low (only –47 dBm). A third contribution (-46 dBm) is due to the APON downstream signal, being equally reflected by WF1 and by the ODN. A small contribution (-51 dBm) comes from the APON upstream signal.

The same exercise was performed for the noise arriving at the NT DWDM Rx. The only noise contribution to be dependent on the number of used channels is the DWDM downstream signals (log curve). It is the largest contribution, reaching –32 dBm for 32 channels. Other contributions are from the DWDM upstream channels (-43 dBm), mostly reflected by the DWDM filter; from the PON upstream signal (-45 dBm), mostly reflected by WF2; and from the PON downstream signal (-47 dBm).

The results have been computed considering worst cases, thereby considering specifications of current commercial components have been used. Other components with improved characteristics could be used to optimize the performances of the system in a given configuration.

Linear crosstalk appears mainly in the DWDM upstream link. The AWG adjacent crosstalk, the dynamic range of the optical output power at the NT, and the number of channels are dominating parameters, followed by the AWG directivity, and, when the number of channel is higher than 8, its non-adjacent crosstalk.

Concerning the performances of the DWDM downstream signals, the most important parameter is the DWDM filter isolation in the 1550 nm window.

The simulation results can be used to determine feasible architectures in which GigE (Gigabit Ethernet) point-to-point services are overlaid to APON. The presented case assumed a receiver having a sensitivity of –23 dBm (typical PIN diode), and the maxium ODN loss (for the DWDM links) is 13.5 dB. Better results can be obtained with other components. Assuming a sensitivity of –26 dBm, the maximum ODN loss is 16.5 dB, which corresponds e.g. with a PON of maximum 7.6 km and a split of 1:8 for the DWDM users. Maximum 4 users in a cluster of 8 users can hence be hooked up to a GigE service with two wavelengths to support the bi-directional transmission. The clusters of 1:8 can of course be grouped to one BPON LT by an additional splitter in the central office. When an APD based receiver is used for the GigE link, the sensitivity can be as low as –30 dBm. The maximum ODN loss would then be 20.5 dB, which corresponds to a PON cluster of maximum 8 km and a split 1:16 [3].Note the computed maximum losses apply to the DWDM branches and do not affect the initial PON system.
Alternating the upstream and downstream DWDM wavelengths leads to a significant reduction of the linear crosstalk and hence to a much higher (up to 8 dB, depending on the considered configuration) maximum ODN loss. However, this is only true if the crosstalk is the limiting factor. When the ODN dynamic range is limited by the power budget, the wavelength arrangement has no influence.

Conclusion

We have studied the feasibility of a DWDM upgraded PON. The results of the simulations show that with components available today, a PON can be upgraded with up to 16 DWDM users. This upgrade does not perturb the existing PON, but the maximum possible ODN loss for the DWDM users are reduced to 13.5 dB, 16.5 dB or 20.5 dB (in the cases considered here above) compared to 25 dB for the one of the PON users. A demonstrator is built and BER measurements are performed in order to highlight the influence of the basic band on the enhancement band and the influence of the crosstalk on the quality of the signal. These measurements will prove the proper operation of the system under certain conditions. Furthermore, the demonstrator includes a Gigabit Ethernet link over the DWDM overlay PON, in order to demonstrate the high performances reachable by such a system.

References

[1] ITU-T G.983.3, “Broadband optical access system with increased service capability by wavelength allocation”, February 2001.

[2] C. Bouchat, C. Dessauvages, F. Fredricx, C. Hardalov, R. Schoop, P. Vetter, “WDM-upgraded PONs for FTTH and FTTBusiness”, Proceedings of Optical Hybrid Access Network (OHAN) 2002, 231-238, Florence, Italy, June 2002.

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