WDM-PON for FTTx

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Introduction

WDM-PON is a general purpose and extremely efficient future-proof optical transport technology for use in Access and Metro transport networks. It enables highly efficient use of the outside fiber plant by providing point-to-point optical connectivity to multiple remote locations through a single feeder fiber.

![Figure 1. WDM-PON supports multiple services](image)

Figure 1 illustrates the general FTTx (Fiber-to-the-x) architecture using a WDM-PON (Wavelength Division Multiplexed Passive Optical Network). As can be seen in the figure, this general-purpose architecture can serve multiple applications for both the business and residential customer. This functionality is possible since each end point is connected to the central office through a dedicated bidirectional optical channel. This virtual point-to-point PON architecture enables large guaranteed bandwidths, bit rate independency, protocol transparency, graceful upgradeability, high QoS with excellent security and privacy.

Until recently, WDM (i.e. dense WDM) has been used only for long-haul and metro applications and was not thought to be economical for the access market. One reason for this
is that each remote site would have needed a unique transceiver (i.e. a wavelength-stabilized DFB laser) to match the WDM channel defined by the optical transport layer. These differently “colored” transceivers raised concerns regarding the high operational costs (installation, management and inventory) associated with managing each remote access location.

This limitation has been solved through the development of an innovative technology that has eliminated the need for complex wavelength-stabilized lasers [1, 2]. By utilizing an “optical injection seeding” technique, simple and identical Fabry-Perot lasers can now be used at all the remote ONU (Optical Network Unit) locations. Although all the transmitters are identical, each one operates at a different DWDM wavelength through the use of a novel automatic wavelength-locking technique. The term “wavelength-locked” WDM-PON will be used to describe a WDM-PON system that utilizes identical transceivers by means of automatic wavelength locking. In this paper we will review the concepts behind a wavelength-locked WDM-PON and will discuss a measurement instrumentation opportunity for this future-proof access architecture.

Comparison with Conventional WDM system

It is useful to first describe how a wavelength-locked WDM-PON differs from a more conventional long-haul WDM transmission system. Conventional WDM systems, as illustrated at the top of figure 2, typically carry unidirectional traffic over each fiber transmission link. This allows the use of unidirectional optical amplifiers that are normally required in long-haul applications. Therefore, bidirectional traffic requires two separate data links, one for eastbound traffic and another for westbound traffic. In contrast a WDM-PON provides the same functionality using only a single bidirectional data link. This is possible by using a cyclic or periodic AWG that can support both a separate upstream and downstream wavelength on each of its “n” output fibers. To achieve this functionality the AWG must be designed to operate on a high diffraction order (just as in a classical bulk-optics diffraction grating). By requiring only single fiber connections at each location, this simplified architecture becomes much more suitable for access network applications.

Another important difference is eliminating the need for “n” different laser sources (i.e. multiple wavelength-stabilized DFB lasers) at the “n” transceiver locations. By using automatically wavelength-locked FP-LDs (Fabry-Perot laser diodes), each remote transceiver can be identical and interchangeable with all the other remote transceivers. Identical transceivers are critical for minimizing inventory and management costs in an access network application. Wavelength locking of FP-LDs will be described in the following section.

Also of importance is the recent development of athermal AWGs that enable the remote node to be completely passive. Previously AWGs required heaters to keep their WDM channels locked onto the ITU wavelength grid. This active power requirement was acceptable in conventional long-haul applications since the AWGs (together with the temperature stabilized DFB lasers) could be located in temperature-controlled environments (i.e. central offices).
In summary, a wavelength-locked WDM-PON differs from a conventional WDM long-haul system by (i) enabling bidirectional transmission over each of its optical fibers, (ii) providing a point-to-multipoint architecture through a passive and environmentally hardened remote Mux/DeMux, and (iii) using identical and interchangeable automatically wavelength-locked FP-LDs.

Automatic Wavelength Locking in a WDM-PON

Figure 3 illustrates the operation of automatic wavelength locking in a WDM-PON system. An un-modulated BLS (Broadband Light Source) located at the OLT (Optical Line Terminal) in the central office is used to generate seeding signals for “locking” the wavelengths of the remotely located identical FP-LDs. The BLS seeding signal is transmitted downstream through the single feeder fiber into the passive remote node containing the athermal and cyclic AWG. At this location the BLS wavelength spectrum is divided or “sliced” into “n” narrowband DWDM (dense WDM) channels by the demultiplexing function of the AWG. Each spectral slice is then transmitted through a single distribution fiber and injected into a remotely located FP-LD. When the FP-LD is current modulated with the electrical data signal, the injected seed signal forces the laser to operate in a narrow wavelength range.
defined by the optical passband of the DWDM transmission link. This wavelength locking process can be easily understood when one realizes that the FP-LD basically acts as an optical amplifier that modulates, amplifies and reflects the injected BLS seeding signal. The FP-LD is not capable of free-lasing due to the gain saturation caused by the amplified seeding signal. This results in a stable narrow-band output data signal, free from any of the noise associated with mode-hopping found in standard free-running FP-LDs.

![Diagram]

Figure 3. Basic description of automatic wavelength locking

The lower right hand side of figure 3 shows the FP-LD wavelength spectrum before and after applying the seeding or “locking” signal. Without the application of the locking signal, the FP-LD lases in multiple wavelength modes (see top insert on the right). This spectrum is unsuitable for data transmission through the DWDM transmission link due to the generation of mode partition noise caused by the wavelength filtering of the AWG. After injection of the locking signal the multimode spectrum is transformed into a quasi single-mode signal (see bottom insert) similar to that of a DFB laser. This “DFB-like” signal is automatically aligned to the DWDM channel defined by the optical transport layer. This wavelength locking process results in a “plug and play” functionality where all the remote FP-LDs are identical and interchangeable but can operate at different wavelengths without the need of any complex control or locking circuitry.

Figure 3 also illustrates the bidirectional functionality of a WDM-PON. Simultaneously along with the downstream BLS signal, “n” independent downstream data wavelengths are transmitted in a different wavelength band (shown at bottom left of figure 3). Due to the cyclic nature of the AWG, both a spectral slice of the BLS and one downstream data wavelength are demultiplexed and sent to each remote ONU. Each ONU transceiver uses an identical dichroic band-splitting filter which separates the two bands, directing the downstream BLS seeding wavelength into the FP-LD and the downstream data wavelength into a standard optical receiver. The modulated upstream data signal generated by the
wavelength-locked FP-LD returns along the same optical path as the downstream BLS seeding signal.

System Description

Figure 4 shows a typical configuration for a wavelength-locked WDM-PON. Wavelength-locked FP-LDs are used at both the central office and the remote ONUs. All the ONU transceivers are identical and interchangeable. The central office OLT houses the BLS, a Mux/DeMux and the “n” downstream wavelength-locked laser sources.

![Wavelength-locked WDM-PON system configuration](image)

A single feeder fiber is used to connect the OLT to the environmentally hardened passive remote node. From the remote node, “n” distribution fibers are used to connect to “n” remote ONUs. In summary, over a single feeder fiber this WDM-PON architecture provides a dedicated and bidirectional optical point-to-point connection between “n” transceivers in the central office and “n” remotely located ONUs. There are no special requirements for addressing or managing the multiple remote ONUs.

One important advantage of the WDM-PON architecture is the ability to completely characterize all the optical fiber paths by using a single tunable-wavelength OTDR located at the central office [3]. This is possible since the different DWDM wavelengths provide a unique and low-loss optical path to each remote ONU which can be used to measure individual Rayleigh backscatter signals. This level of optical characterization is not possible in a more conventional TDM-PON (Time Domain Modulation) due to the remote node power splitter that prevents unambiguously identifying the backscatter signatures from the individual fibers after the power splitter. It is expected that a demand for wavelength-tunable OTDRs will emerge as WDM-PONs grow in popularity [4].
Summary

A wavelength-locked WDM-PON is an efficient and future-proof WDM transport architecture optimized for the access network. It provides a point-to-point optical connection over a shared fiber plant by allocating a pair of dedicated wavelengths for each ONU. To reduce both capital and operating costs, a newly developed optical seeding technique enables the use of automatic wavelength locking of identical low-cost Fabry-Perot laser diodes. The benefits of a wavelength-locked WDM-PON access system are; identical wavelength-independent DWDM ONT/ONUs, simple point-to-point dedicated connectivity, bit-rate and protocol independency, high security and privacy, simple future data-rate upgradeability, and complete fiber characterization through use of a wavelength-tunable OTDR.

References:


