Plug-and-Play Optical Node Architectures and Their Built-in Optical Fiber Characterization Techniques

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Plug-and-Play Optical Node Architectures and Their Built-in Optical Fiber Characterization Techniques

Rongqing Hui[1] and Andrea Fumagalli[2]
1 : Dept Electrical Engineering and Computer Science, The Univ. of Kansas, Lawrence KS 66044
2 : Eric Johnsson School of Eng. and Computer Science, The Univ. of Texas at Dallas, Richardson TX 75083

Abstract *Cost-effective plug-and-play optical (PPO) nodes may enable a new generation of self-configuring and simple-to-deploy optical networks. Three possible PPO node architectures are discussed in the paper along with their built-in opitcal fiber characterization techniques.*

Introduction

The deployment of optical networks is in part delayed by two factors: the excessive cost of optical node equipment and the highly complex procedure of design, installation and maintenance of the overall network. To circumvent the cost and complexity burden of extant optical networks, the authors proposed to design *ad-hoc* optical networks that use cost-effective self-configurable optical nodes [4]. Such nodes will look like today's fast Ethernet hubs and switches, providing however, several orders of magnitude higher bandwidth, and larger geographical network coverage. Any user will be able to connect such nodes with existing fibers by a simple plug-and-play operation. Once connected, the plug-and-play optical (PPO) nodes will be able to communicate with one another, finding the characteristics of surrounding optical links and looking for cost-effective ways to provide reliable and optimized optical circuits to the end user's applications and interfaces. This self-configuring property of the PPO nodes will be essential to make the node installation procedure easy, and to adjust the optical data flows to both varying traffic patterns and changing conditions of the optical physical layer, e.g., introduction and removal of PPO nodes, aging of optical components and soft failure of network elements. This paper discusses three possible PPO node architectures and their built-in techniques to characterize some linear and nonlinear properties of the input/output optical fiber pairs.

Three node architectures and their functionalities

A PPO node requires simplicity of configuration and integratibility of its components. On the other hand, in order to self-determine the network connectivity and transmission characteristics, a PPO node needs to provide sufficient functionalities. The tradeoff between the PPO node complexity, cost, and functionalities is discussed using three possible architectures.

PPO node 1. The simplest PPO node makes use of a low-cost and low-speed optical transceiver at each input/output fiber pair. The transceivers can establish and verify connections between the PPO node and its neighboring nodes. Identification information will be carried by the optical signal shared between the connected nodes. By regulating the optical output power of each transmitter, the loss of each fiber pair can be evaluated through the measurement of the received optical power at the other end.

PPO node 2. A more sophisticated PPO node makes use of both a superluminescent LED (SLED) at the transmitter and a tunable optical filter at the receiver. The wide spectrum SLED is modulated by a sinusoid signal. At the receiver, the relative RF phase shift of the sinusoid is detected at multiple wavelengths selected by the tunable filter. Chromatic dispersion of the optical fiber can then be evaluated using conventional techniques. Thanks to its tunable filter, PPO node 2 can also evaluate the optical signal-to-noise-ratio (OSNR) of the link when the fiber pair involves optical amplifiers.

PPO node 3. Another possible PPO node architecture (shown in Fig.1) makes use of a tunable laser diode and employs coherent detection to determine chromatic dispersion, nonlinearity and PMD of the fiber pairs. Depending on the state of the 1x2 optical switch, the tunable laser can be used as either transmitter or local oscillator of the coherent detection at the receiver.

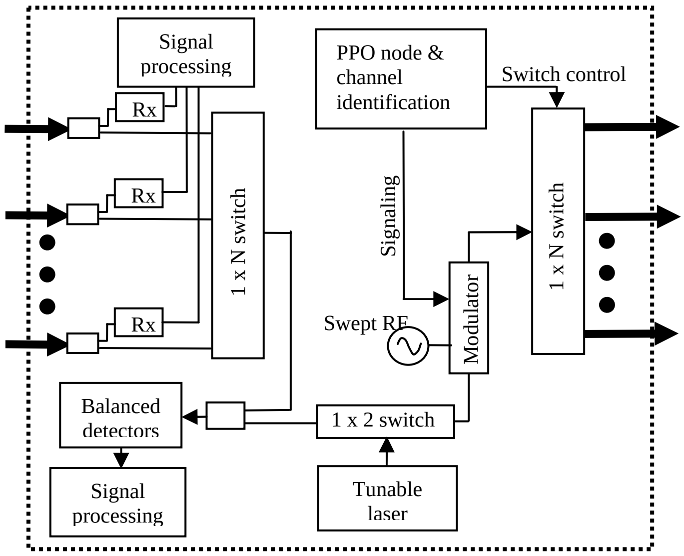

Fig.1, PPO node using a tunable laser diode

The PPO node identification and channel information is modulated into the optical signal and sent to the receiving PPO nodes. At the receiving PPO nodes, each input fiber port has a low cost and low speed receiver. These receivers will monitor the optical signal connectivity between PPO nodes.

To find additional fiber system information, a linearly swept RF source is used to drive the modulator. The frequency response of the fiber system can then be measured by a coherent detection optical receiver. Synchronization is not required in this measurement as the modulation frequency can be found at the receiver by evaluating the modulation sidebands with the local oscillator performing coherent spectrum analysis.

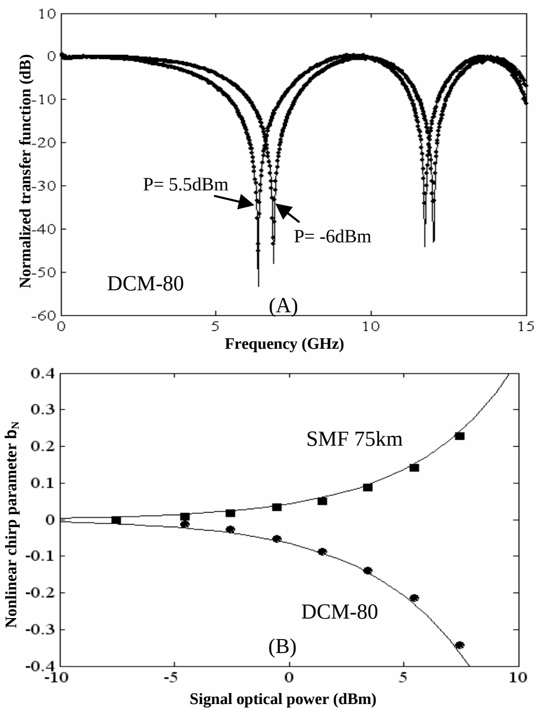

Fig. 2, (A) Example of transfer function in a system with a dispersion compensating module (DCM-80) (B): Nonlinear chirp parameter b_N versus signal optical power for DCM-80 and 75km SMF. Dots: measured, continuous curves: calculated

The normalized frequency response of a fiber system can be expressed as [1]:

$$H(f) \propto \cos\left(\frac{\pi\lambda_0^2 D f^2 L}{c} - \tan^{-1}(b)\right)$$

Where D is chromatic dispersion, L is the fiber length, c is speed of light, λ_0 is the wavelength and $b = b_L + b_N$ is defined as an equivalent chirp parameter. b_L represents a linear chirp, which can be created by the optical modulator, while $b_N = \pm 2\gamma P/\alpha$ is a nonlinear chirp, which is determined by the fiber nonlinear coefficient γ, attenuation coefficient α, and signal optical power P. The ± option in b_N denotes the sign of fiber chromatic dispersion.

Fig.2(A) shows an example of measured frequency response in a dispersion compensating fiber (DCF). Note that the response notches move to lower frequencies when the input optical power is increased.

When the optical power is small, both b_L and D can be evaluated as follows

$$b_L = \tan\left(\frac{\pi\nu_{0,l}^2}{\nu_{1,l}^2 - \nu_{0,l}^2} \mp \frac{\pi}{2}\right) \quad \text{and} \quad DL = \frac{c}{\lambda^2\left(\nu_{1,l}^2 - \nu_{0,l}^2\right)}$$

where $\nu_{0,l}$ and $\nu_{1,l}$ are the 0^{th} and the 1^{st} order of notch frequencies in the linear system.

When the optical power is increased, the 1^{st} notch moves to $\nu_{0,f}$. Once this frequency shift is measured, the nonlinear chirp parameter can be found as

$$b_N = \frac{\left(1+b_L^2\right)\tan(u)}{1-b_L\tan(u)} \quad \text{with} \quad u = \pi\left(\frac{\nu_{0,f}^2 - \nu_{0,l}^2}{\nu_{1,l}^2 - \nu_{0,l}^2}\right)$$

Fig.2(B) shows the measured value for b_N using both a standard SMF (squares) and a DCF (circles) versus the signal power. The continuous curves represent the calculated values when using the following parameters: L = 75.74km, α = 0.21dB/km, D = 15.614 ps/nm/km and γ = 1.2974 $W^{-1}km^{-1}$ for the SMF, and L = 14.19 km, α = 0.47 dB/km, D = -92.636 ps/nm/km and γ = 3.534 $W^{-1}km^{-1}$ for the DCF. The values of dispersion, length and attenuation are independently verified via OTDR measurements.

In a system with N optical spans, the nonlinear chirp effect has to be weighted by the dispersion of each span. The effective nonlinear chirp parameter can be expressed as [2],

$$b_N \approx \frac{2}{\sum_{i=1}^{N} D_i L_i} \sum_{i=1}^{N} \frac{\gamma_i P_i}{\alpha_i}\left(\sum_{k=i}^{N} D_k L_k\right)$$

It is known that in fiber systems, both self-phase and cross-phase modulations originate from nonlinear phase modulation. The phase modulation is then converted into intensity modulation or time-jitter through fiber dispersion. Therefore, nonlinear chirp b_N is a good indicator for the degree of nonlinearity in the fiber system. It must be noted that the same coherent detection capability at the PPO node may be used to monitor the performance of the optical network once the optical traffic is established, including time-varying PMD. This process is described in [3].

Conclusion

The fiber characterization process described in this paper is a key step in realizing self-configuring and simple to deploy optical networks, whereby optical fiber resources are discovered and characterized by PPO nodes. Three possible PPO node architectures were discussed. By means of a tunable laser, a PPO node may be able to characterize both linear and nonlinear properties of the input/output fiber pairs.

References

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