Evaluating the Reach of Multiwavelength Optical Networks

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Introduction – In multiwavelength optical networks, a purely optical connection will traverse many different components: fibers, amplifiers, (de)multiplexers (MUX/DMUXs) and switches, accumulating distortion, Amplified Spontaneous Emission (ASE) noise and interference as it propagates. The above is one of the negative aspects of optically transparent networks. The study of the above impairments and other physical effects is needed in order for the network designer to determine the limits of transparency. As the size and complexity of these networks increases, analytical performance evaluation becomes increasingly cumbersome leading the way for an increased use of computer simulation. Although important for point-to-point studies, conventional time/frequency-domain simulation approaches to networks with thousands of components prove to be extremely time-consuming. On the other hand the use of *wavelength-domain simulation* greatly reduces computation time by using a coarse resolution in the frequency domain [1]. This allows for evaluating the signal, ASE noise [2] and linear optical crosstalk [3] at every point in the network. The system performance is roughly estimated in terms of optical Signal-to-Noise Ratio (SNR). Moreover, based on information provided by the wavelength-domain, simplified time-domain simulations can be performed for specific paths in the network, in order to generate signal waveforms, study the various crosstalk generation mechanisms and estimate network performance degradations based on error probabilities. The above simulation approach can also be useful for studying the performance of WDM optical self-healing rings where the proper operation of protection switching is of vital importance.

The trade-off associated with the above efficient simulation technique is that certain impairments which depend on the phase information can not be studied (dispersion, non-linear effects) and are thus excluded from this work.

Case Studies and Discussion – Using the wavelength-domain tool, we present three case studies that illustrate the impact of network impairments. Figure 1 presents the study of ASE noise accumulation through a cascade of Wavelength-Add/Drop Multiplexers (WADMs) [2]. Eight equally spaced externally modulated wavelengths propagate through a cascade of equidistant WADMs. Two wavelengths are dropped and added at each WADM node according to a periodic add/drop plan, and only wavelength 5 is allowed to propagate through the whole WADM chain. The MUXs/DMUXs within each WADM are composed of Multilayer Interference (MI) filters modelled as third-order Butterworth filters. Figure 2 presents the Power Spectral Density (PSD) after 50 WADMs. Clearly the optical SNR for wavelength 5 is the worst, although it stays above the required 20 dB (for a Bit Error Rate (BER) of 10^{-9}). Using the above system model, maximum allowable laser misalignment tolerances can be obtained by calculating the electrical SNR level necessary to achieve the above BER at various bit rates at an ideal direct detection ASK receiver. In [4] it was shown that for laser misalignments of up to 30 GHz, the signal at wavelength 5 in the above example can go through more than 50 WADMs, whereas for laser misalignments equal to 40 GHz, it can only traverse 24 nodes.

It is well known that when a signal passes through a large number of cascaded optical filters, the bandwidth of the filter's equivalent transfer function is much narrower than the bandwidth of each individual filter [5]. In addition, laser and filter misalignments due to temperature, aging and manufacturing cause an additional bandwidth narrowing and the combined effect causes signal distortion. A realistic simulation study of filter-induced distortion based on measurements of the transfer function of commercial MI filters shows that transmission through 100 MUX/DMUXs (Fig. 1) is possible as far as this individual impairment is concerned [6]. However, requirements on the passband flatness, passband ripple and other filter parameters should be considered in order to achieve such performance. Figure 3, shows the output eye-diagram after a chain of 100 MI filters for a laser misalignment of 30 GHz from the filter center-frequency. The induced 13.5 dB excess loss can be compensated by the amplifier gain and servo-controlled attenuators (Fig. 1) in

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the chain, however, the 0.65 dB distortion-induced loss will cause a penalty in the network performance [6].

Figure 4 presents the study of linear optical crosstalk in a Wavelength Selective Cross-connect (WSXC) mesh topology. The common-channel linear crosstalk accumulating in the signal path λ_8 (bold line in Fig. 4) is collected using wavelength-domain simulation of the entire mesh network. Time-domain simulations are then run on the above selected signal path only, thus increasing the efficiency of the simulation. A combination of Monte Carlo simulations and semi-analytical method is used to calculate the BER at receiver 8. The effects of varying the individual switch crosstalk level as well as changing the switching fabric architecture are investigated. The above simulation can be used effectively to set crosstalk level requirements for various switching fabrics used in large and complex WDM networks by calculating power penalties [3].

Figure 5 presents a WDM ring network with shared fiber protection network configuration. A critical aspect of the performance of such network is the proper activation of the protection switching mechanism shown in the inset of Fig. 5. Optical amplifiers are present on both the working and the protection fibers. We use wavelength-domain simulation to compare optical methods for detecting fiber cuts in the above ring. As will be explained, detecting total optical power or power in a channel is not adequate, but differential measurements provide the necessary information.

In the conference we will expand on the above case studies and show how simulation can be used effectively to evaluate the performance of WDM optical networks.

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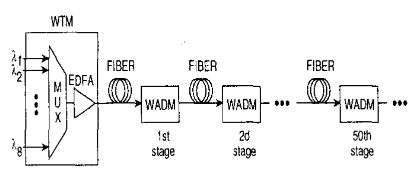

Figure 1: Block diagram of a cascade of 50 WADMs.

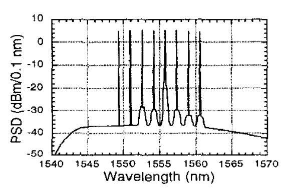

Figure 2: Power Spectral Density in dBm/0.1 nm after the 50 WADM cascade.

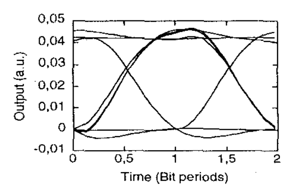

Figure 3: Eye-diagram after transmission through 100 optical filters for 30 GHz laser misalignment [6].

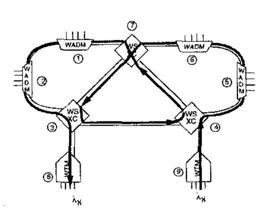

Figure 4: Block diagram of the WSXC mesh topology with the worst crosstalk path denoted by a bold line.

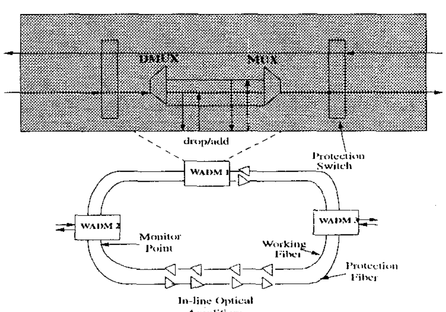

Figure 5: A schematic view of a working fiber/protection fiber pair in a WDM ring [7].