Wavelength-Domain Simulation: an efficient technique for the design of Multiwavelength Optical Networks

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Abstract

This paper reviews a simplified computer representation for the optical signals and network components in the optical transport layer of multiwavelength optical networks. This representation can be used for efficient steady-state and transient power-budget computations.

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Introduction – Efficient computer-aided design of the optical transport layer of large-scale multiwavelength optical networks requires an abstract and simplified computer representation for the optical signals and network components.

This paper reviews the wavelength-domain representation of optical signals and network components. In this representation, optical signals are characterized by their carrier wavelength and average power exclusively and not by their temporal waveform, as is customary in simulation of analog and digital communication systems [1]. In addition, the constituent parts of the network are fully characterized by their loss or gain as a function of wavelength.

In the following, the key assumptions and concepts of wavelength-domain representation are summarized and an example of implementation is presented.

Principles – It is assumed that the constituent parts of the optical transport layer do not alter the shape of the signal waveforms (quasi-transparent components). Signal distortion due to linear or non-linear effects is ignored. The action of the network components consists in a simple scaling of the signal power by a multiplicative factor (gain or loss).

The constituent parts of the network are described by step-like transmittance transfer functions (Fig. 1). The wavelength axis is discretized into N wavelength bins. The choice of the wavelength bin size is arbitrary and depends on the desired accuracy. Typically, the wavelength bin bandwidth is several times the bit-rate. The central wavelengths of these wavelength bins define a grid. In Fig. 1, only five nodes of the wavelength grid are shown. The gain or loss is assumed to be approximately constant within a single wavelength bin but may be different for signals at adjacent wavelength bins. The gain or loss may also vary as a function of time but this variation is slow compared to the bit period (quasi-static components). The phase transfer functions of the network components are discarded.

The representation of the optical signals differs depending on if they occupy one or several wavelength bins (narrowband or wideband optical signals respectively). For simulation purposes, we define three different types of optical signals, namely optical signals produced by laser sources (narrowband), ASE noise (wideband), and interference (narrowband). Each type is represented separately. 1) Optical signals produced by laser sources are fully characterized by a pair of numbers (carrier wavelength, average power) and are represented by a single point in the (wavelength, power) space. 2) ASE noise is represented by a set of N pairs of numbers (i.e. values of the average power at the nodes of the grid). 3) Interfering terms originating from the same laser source as an optical signal and recombining with it after propagation through different optical paths (i.e. multipath optical crosstalk) are represented as distinct narrowband optical signals in the same wavelength bin as the optical signal. The modulation, phase and polarization of all types of optical signals is ignored.

For illustration purposes, Fig. 2 shows the wavelength-domain representation of an optical signal produced by a laser source contaminated by ASE noise and six multipath interferers. Similar to Fig. 1, only five nodes of the wavelength grid are shown. All signal power is concentrated into the third wavelength bin (black column). ASE noise power is distributed into all five wavelength bins (white columns). The six multipath interferers, denoted by x_1-x_6, are represented by distinct gray columns in the same wavelength bin as the optical signal.

A WDM signal composed of M individual optical signals is represented in the wavelength-domain by a set of M 3-D graphs similar to Fig. 2, one for each different laser source.

As optical signals, ASE noise, and optical crosstalk pass from one module to the other, their average powers at the N grid nodes are multiplied by the corresponding values the gain/loss of the modules. It is thus possible to evaluate the average powers of optical signal, ASE noise, and optical crosstalk at every point of the network.

The above simplified representation is advantageous in terms of execution speed compared to other, more accurate representations [1]. The price to pay is that all distortion impairments can not be studied in the wavelength-domain.

MONET wavelength-domain simulation tool – A general purpose simulation tool based on the above representation was implemented in the context of the Multiwavelength Optical Networking (MONET) project [2]. This tool can compute the optical signal, ASE noise and linear optical crosstalk power spectra at all points in the network in both steady-state and transient regime.

Fig. 3 shows the organization of the optical library of the MONET wavelength-domain simulation tool. An indicative list of modules is given on the right side in Fig. 3. The modules of the optical library are divided into three hierarchical categories, namely Network Elements, Network Element Components, and Elementary Units. Each module is implemented using different designs, technologies, and simulation models, and can have uni- or bi-directional fiber interfaces, steady-state or dynamic properties, and so forth. Modules can be combined in any order to simulate various WDM network topologies.

A modeling example of a uni-directional four Wavelength Add-Drop Multiplexer (WADM) ring topology is shown on the left side of Fig. 3. The WADMs are represented by circles. At the next hierarchical level, the architecture of a simplified Wavelength Add-Drop Multiplexer (WADM) [2] is shown. The depicted WADM consists of two EDFAs (1), a multiplexer/demultiplexer (MUX/DMUX) pair (2), 2x2 optical switches for signal adding/dropping (3), and variable attenuators for power equalization (4). At the lowest hierarchical level, the structure of the EDFAs is shown. In this particular example, the EDFAs are identical single-stage forward-pumped amplifiers, composed of two isolators (5), a laser diode (6), a wavelength selective coupler (WSC) (7), and a strand of Erbium-Doped Fiber (EDF) (8).

The MONET wavelength-domain simulation tool was used in the past to study automatic gain control in Erbium-doped fiber amplifiers (EDFAs) and EDFA chains [3], network topologies [4], [5], and network functionalities [6], [7]. To illustrate the computing capabilities of the MONET wavelength-domain simulation tool, sample results will be presented at the conference.

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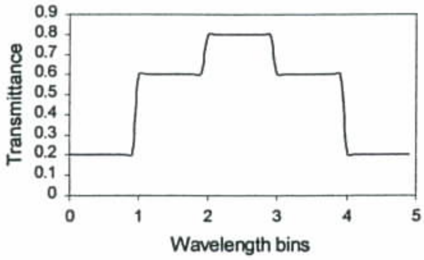

Fig. 1 Wavelength-domain representation of an optical component.

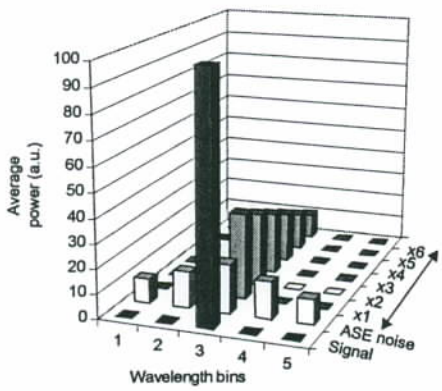

Fig. 2 Wavelength-domain representation of an optical signal contaminated with ASE noise and interference.

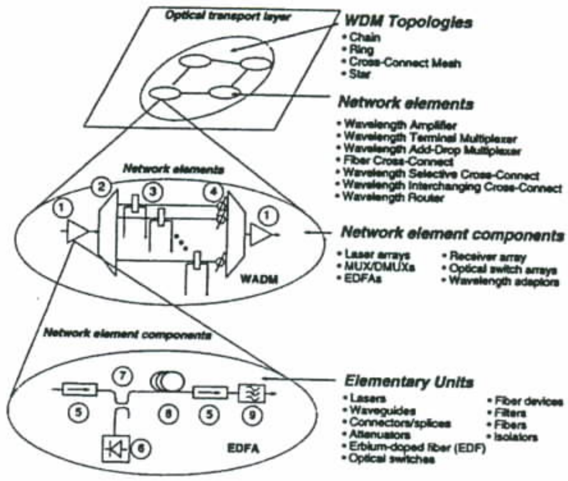

Fig. 3 Hierarchical organization of the MONET wavelength-domain simulation tool.