Network Design Method for Wavelength Routing Networks

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Abstract

Fiber-optic networks have been growing in terms of their scale and complexity with the enhancement of WDM technologies. This paper outlines how the network functionalities are designed focusing on wavelength routing via the wavelength transfer matrix method.

Introduction

Fiber-optic networks have been evolving in both core and access networks; the former use not only TDM (Time Division Multiplexing), but also WDM (Wavelength Division Multiplexing) technology for capacity enhancement and photonic routing functionality (e.g. GMPLS), and the latter is represented by FTTH (Fiber To The Home) and its extension of WDM-PON (Passive Optical Network).

Both networks are growing in terms of their scale and complexity. Wavelength counts have reached 100 in the core and the physical configuration of the network has made future access complicated [1].

In general, the network, (hereafter network means basically the physical network) consists of a variety of entities each with analog and/or digital characteristics. Here, analog (digital) implies continuous (discrete) signals. Therefore, it is essential to clarify and verify the network characteristics given network scale and complexity before their actual deployment or a protection route is needed.

Network simulators are powerful tools for designing and verifying network performance prior to deployment. Several network simulators e.g. Opnet, ns2, etc. have played important roles in the design of optical networks. However, they provide little support when we need to design new optical functions such as wavelength routing.

This paper first categorizes optical entities that comprise optical networks, and then introduces the wavelength transfer matrix (WTM) method to enable network design in terms of wavelength routing functionality. Its effectiveness is confirmed in a simulation tool.

Network entities

Regardless of the scale or complexity of a network, or it age, it consists of a variety of functional blocks, or entities with different attributes. In optical networks, an entity is a kind of black box with single/multiple input and output ports, and single/multiple wavelengths flow across the ports. TABLE I summarizes several optical entities together with major device examples. It is noted that entities are classified as source, sink, link, route, and switch. Here, attribute implies port count of port, wavelength count (channels), and analog/digital characteristics.

TABLE I OPTICAL NETWORK ENTITIES

Entity		Device example	Note
Source (So)	-single channel - multiple channels	- LD - LED - λ-converter -super continuum	
Sink (Si)		- PIN - APD	
Link (Li)	-multiple ports -single port	- splitter - combiner - optical amp. - DCF - attenuator - connector	
Rout (Ro)	- wave-length - port	- AWG - DMTF - FBG - circulator	- implies wavelength process
Switch (Sw)	- port	- mechanical - electrical - thermal	

When a new network is planned, several entities will need to be combined. The performance, functionality and availability of each link or end-to-end path are then evaluated to confirm whether they satisfy the required value(s) (QoS: Quality of Service) or not. Network simulation programs and/or emulation testbeds (hardware) are used for this purpose.

Wavelength Transfer Matrix (WTM) method

Input and output characteristics in terms of wavelength for network configurations consisting of several entities seem to be very complicated when the configuration consists of multi stage AWGs and optical loop back connections. An AWG seems to be the most complicated optical entity because it has a variety of attributes such as multiple ports, multiple wavelengths, possible loop connections between ports, and wavelength group routing. However, the wavelength transfer matrix (WTM) method makes it easy to understand and verify how any configuration works [2].

The following describes the application of the WTM method to the simple 4 x 4 AWG for easy understanding.

The output wavelengths of AWG port $\boldsymbol{O}$ are given by the product of wavelength transfer matrix $\boldsymbol{L}$ and input wavelength matrix $\boldsymbol{I}$ as

$$O = L \cdot I \quad (1).$$

When four nodes ***A-D*** are connected to ports 1-4 of the AWG, using, λ_1 –λ_4 as indicated in Fig.1, the output matrix $\boldsymbol{O}$ is given as

$$O=L\cdot I=\begin{pmatrix}\Lambda_1 & \Lambda_2 & \Lambda_3 & \Lambda_4\\ \Lambda_2 & \Lambda_3 & \Lambda_4 & \Lambda_1\\ \Lambda_3 & \Lambda_4 & \Lambda_1 & \Lambda_2\\ \Lambda_4 & \Lambda_1 & \Lambda_2 & \Lambda_3\end{pmatrix}\cdot\begin{pmatrix}A_1+A_2+A_3+A_4\\ B_1+B_2+B_3+B_4\\ C_1+C_2+C_3+C_4\\ D_1+D_2+D_3+D_4\end{pmatrix}=\begin{pmatrix}A_1+B_2+C_3+D_4\\ D_1+A_2+B_3+C_4\\ C_1+D_2+A_3+B_4\\ B_1+C_2+D_3+A_4\end{pmatrix} \quad (2),$$

where $\boldsymbol{X_k}$ is the wavelength $\boldsymbol{\lambda_k}$ from node ***X (A to D)***.

We define the product of element Λ_k and wavelength $\boldsymbol{\lambda_k}$ as

$$\Lambda_k \bullet \lambda_k = \lambda_k$$
$$\Lambda_k \bullet \lambda_l = 0 \quad (for \quad k \neq l) \quad (3).$$

For example, in (2), the first line of output, $\boldsymbol{A_1}$, $\boldsymbol{B_2}$, $\boldsymbol{C_3}$, and $\boldsymbol{D_4}$ corresponds to the wavelengths output to node ***A***.

This concept is slightly similar to the conventional digital process that uses the delta function [3]; it makes it easy to understand how wavelength routing proceeds even if the configuration is somewhat complicated.

Other examples show the effectiveness of using WTM for the design and verification of wavelength grouping; functionalities essential for confirming the hybrid use of CWDM (Coarse WDM) and DWDM (Dense DWM), wavelength-based VPN (Virtual Private Network) creation, and network management. The future wavelength abundant network will be required to handle bundles of wavelengths for easy processing and management. The WTM method can cope with this requirement. For details, please refer to [2] - [7].

Network design tool

In order to design actual networks with the WTM method, we need a computer based design interface similar to those of the CAD (Computer Aided Design) systems used in LSI (Large Scale Integration circuit) design. Such system is basically digital, but for our purposes the system should also support analog characteristics.

Some initial requirements of the design system are given in TABLE II:

Functional issues: Relationship of input wavelength and output wavelength should be determined for any port connection. This job might be done via the GUI (Graphical User Interface). The system should have WTMs for all optical circuits as a library and should update the WTM data as necessary.

Variables: As a variety of optical circuits such as AWG, WDM filter, switches, wavelength converter, circulator, will be used in WDM networks including wavelength routing networks, the design system should accommodate several parameters. They might include the number of input/output ports, the number of wavelengths, the number of bundles for wavelength grouping, FSR (Free Spectral Range), and wavelength spacing.

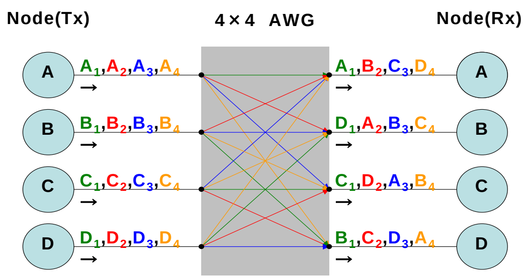

Fig. 1. Input and output wavelengths routed by 4 x 4 AWG. X_k from node X (A to D) corresponds to λ_k (k=1 to 4)

TABLE II
REQUIREMENTS OF NETWORK DESIGN SYSTEM (TENTATIVE)

Item	Requirement
Functionality	- Port connectivity in terms of wavelength - WTM library for several entities - User friendly GUI
Variable	- # of input ports - # of output ports - # of wavelengths - Wavelength grouping - FSR - Wavelength spacing

Conclusions

As optical networks are still growing through the emergence of new technologies e.g. wavelength routing, network design must also be enhanced to handle advanced concepts and provide user-friendly tools for easy functional allocation and verification.

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