Chapter 15
Network Performance Analysis with Nonlinear Effects

ABSTRACT

The nonlinear Bit Error Rate (BER) performance of dense Wavelength Division Multiplexed (WDM) Manhattan Street Networks with deflection routing was obtained using a semi-analytical model. The chapter’s results show that nonlinear effects impose significant performance penalties on dense WDM networks, both in terms of maximum hops attainable and average BER, and should be taken into account when modeling such networks. Simple techniques such as optimal amplifier positioning can mitigate some of the nonlinear penalties.

INTRODUCTION

Transparent all-optical cross-connected networks work entirely within the optical domain, by employing optical cross-connects (Castanon, Tonguz, & Bononi, 1997). A common network topology for multihop, wavelength division multiplexed (WDM), packet switched networks is the Manhattan Street (MS) Network (Maxemchuk, 1987; Forghieri, Bononi, & Prucnal, 1995). A model of the MS Network without optical buffers and wavelength conversion (also called Hot-Potato), employing deflection routing was presented in (Forghieri, Bononi, & Prucnal, 1995). This model was

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used to estimate the average network bit error rate (BER) performance in the presence of linear noises (Castanon, Tonguz, & Bononi, 1997). However, the impact of nonlinear effects within the fiber interconnection links is often neglected because the WDM signal spectral density is normally low for networks (Castanon, Tonguz, & Bononi, 1997) unlike for point-to-point links (Kahn & Ho, 2004). Nowadays, as network capacity increases through the use of dense WDM, nonlinear effects will become important.

In this chapter, the impact of nonlinear effects on the BER performance of dense WDM, cross-connected networks using the Hot-Potato MS Network with deflection routing as the case study is investigated. A semi-analytical model, combining the hop distribution and node model with nonlinear Schrödinger equation (NLSE) based simulation of the fiber interconnections is used to evaluate the nonlinear BER performance.

**SYSTEM MODEL**

The Hot-Potato MS network with deflection routing is described using the deflection probability \( p(g) \) given the packet generation probability or network load \( g \) (Forghieri, Bononi, & Prucnal, 1995). Using \( p(g) \), the hop distribution \( P(n) \), which is the probability density function of the number of hops, \( n \) required to travel to the destination can be obtained. The process of obtaining \( P(n) \) and \( p \) for given values of \( g \) is elaborated in (Forghieri, Bononi, & Prucnal, 1995), and is not repeated here. In addition, the BER of the packets depends on the node (cross-connect) structure and the fiber link between nodes. The node structure used is shown in Figure 1(a).

All transmitters are assumed to transmit with the same average power, \( P_{TX} \), which is the signal power of a WDM channel. Each signal consists of a pseudorandom bit sequence (PRBS) of 16384 bits where the modulation format is RZ-OOK (return-to-zero-on-off-keying) with 50% pulse duty cycle and a bit rate \( B_r \) of 42.656 GHz. We consider a high capacity, dense WDM network where the spectral density (spectral efficiency) is high at 0.4, corresponding to a channel spacing of 107 GHz. The WDM demultiplexers are modeled as second order Gaussian filters centered at the WDM channels’ center frequencies. The total node loss is

\[
L_{\text{total}} = L_{\text{DEMUX}} L_{\text{coupler}} L_{\text{add/drop}} L_{\text{switch}} L_{\text{MUX}}
\]

(Castanon, Tonguz, & Bononi, 1997). The receivers are direct-detection receivers followed by a fifth order Bessel postdetection electrical filter. The main switch introduces crosstalk noise, because a portion of an output link signal leaks onto the
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