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Routing Capability and Blocking Analysis of Dynamic ROADM Optical Networks (Category - II) for Dynamic Traffic

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***Abstract*—**Reconfigurable optical add/drop multiplexers (ROADMs) can be classified into three categories based on their underlying switching technologies. Category I consists of a single large optical switch; category II is composed of a number of small optical switches aligned in parallel; and category III has a single optical switch and only one wavelength being added/dropped. In this paper, to evaluate the wavelength-routing capability of ROADMs of category-II in dynamic optical networks,the dynamic traffic models are designed based on Bernoulli, Poisson distributions for smooth and regular types of traffic. Through Analytical and Simulation results, the routing power of cat-II of ROADM networks for two traffic models are determined.

***Keywords*—**Fully-Reconfigurable Optical Add-Drop Multiplexers (FROADMs), Limited Tunability in Reconfigurable Optical Add-Drop multiplexers (LROADM), Multiplexer/De-Multiplexer (MUX/DEMUX), Reconfigurable Optical Add-Drop Multiplexers (ROADMs), Wavelength Division Multiplexing (WDM).

I. INTRODUCTION

IN high speed long-haul network backbones and metropolitan and local area networks, wavelength division multiplexing (WDM) has been proven to be a successful technique, which, however, only provides a medium for physical lightpath connectivity. Future optical networks will also require the WDM transport layer to deliver advanced functionalities such as automatic wavelength provisioning and optical restoration. Due to their unique features, including dynamic reconfigurability, great connectivity, forecast tolerance, bit-rate/ protocol transparency, and efficient assignment of connections between sources and destinations without the need of optical–electrical–optical (O–E–O) conversion, reconfigurable optical add/drop multiplexers (ROADMs) have emerged as one of the mainstream platforms for the practical implementation of cost-effective advanced optical networks .

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II. ROADM NETWORKS

The first phase of optical networking was mainly focused on increasing the capacity of point-to-point links and relied on advances in optical amplifier and multiplexer/de-multiplexer (MUX/DEMUX) technologies [9]. The second (current) generation of optical networking primarily focuses on the dynamic reconfiguration of the optical layer, without the use of opto-electrical/electro-optical conversion. From the perspective of scalability, data-plane electronics have been synonymous with bit-rate limitations and increased power consumption. Migration of dynamic networking capabilities into the optical layer, where such limitations can be avoided, is key to evolving the scalability of data transport networks. Reconfigurable Optical Add/Drop Multiplexers (ROADM) are the primary enablers for this migration.

In this paper, Bernoulli and Poisson models are designed for various traffic types to calculate the Wavelength Occupancy Distribution of ROADMs of category-II in dynamic optical networks. The rest of this paper is organized as follows: Section III briefly presents the related work done. Section III gives the Wavelength-Routing Capability of ROADMS of different Categories. Section IV presents the design models for Wavelength Occupancy Distribution. Section V gives the Routing-Power Model for Dynamic Traffic, Section VI presents the results of analysis and concluded in Section VII.

III. RELATED WORK

J. Wagener et al [1] to evaluate the blocking probability in a banded FOADM system and compared that to the more flexible ROADM counterpart, which has no stranded bandwidth. T. Hsieh, et al [2] examine the use of limited tunability in reconfigurable optical add-drop multiplexers (LROADM). L-ROADMS can add or drop from only a subset of adjacent wavelengths on the network and are less costly than fully-reconfigurable optical add-drop multiplexers (FROADMS). Suresh Subramaniam et al [3] model that characterizes any non-Poisson traffic by its first two moments is utilized. The arrival occupancy distribution of busy wavelengths for this model process is derived and is used to analyze the effects of wavelength conversion. The model predicts that traffic peakedness plays an important role in determining the blocking performance.Louay Eldada [4] different optoelectronic component and module technologies that have been developed for use in ROADM subsystems, and describe their principles of operation, designs, features, advantages, and challenges.

IV. Wavelength Routing Capability of ROADMs of Different Categories

A. Dynamic Wavelength Routing

The ROADM is comprised of two logical input ports, namely In and Add, as well as two logical output ports, namely Out and Drop [9]. According to their underlying switching technologies, existing ROADM architectures can be classified into three categories:

1. A category I ROADM consists of a single large optical switch with the number of add/drop wavelengths of ≥ 1. ROADMs based on micro electro mechanical systems(MEMS) , wavelength selective switches , and acoustooptic tuneable filters belong to this category.
2. A category II ROADM is composed of a number of small optical switches aligned in parallel. ROADMs based on arrayed waveguide gratings and multiport optical circulator-fiber Bragg gratings are in this category.
3. A category III ROADM contains a single optical switch with only one add/drop wavelength. Both broadcast-and-select- and vertically coupled semiconductor Bragg grating-based ROADMs belong to this category.

ROADM wavelength-routing capability are based on an assumption that the wavelength occupancy probability is uniform for all network states. But this is not true in real network deployment scenarios. So ROADMs implemented in dynamic optical networks will exhibit significant differences in the network performance, which, however, have not been reported [9].

V. Wavelength Occupancy Distribution

Dynamic traffic can be specified by the arrival process, departure process, and bandwidth of its call [10]. Here, it is assumed that each call occupies the entire bandwidth of a channel. In this paper, instead of attempting to focus on a specific traffic model, use is made of a moment-matching technique, called Bernoulli–Poisson–Pascal (BPP) model [7],[3]. In the BPP model, based on the known moments of an offered traffic, an equivalent process is chosen, which yields the same moments. The equivalent process is then utilized to simulate the wavelength occupancy distribution. The advantages of the BPP model include simplicity, ease in obtaining matching parameters, and relatively good accuracy.

If m and v are the mean and variance of the number of simultaneously occupied wavelengths in a dynamic optical network, respectively, the traffic peakedness can be defined as $Z = v/m$.

The Traffic models are applied to the following types of dynamic traffic:

Bernoulli: Smooth ,if $Z < 1$
Poisson : Regular, if $Z = 1$
Pascal : Peaked, if $Z > 1$

A. Bernoulli Model

A Bernoulli process is a discrete-time stochastic process consisting of a finite or infinite sequence of independent random variables $X_1, X_2, X_3, \ldots$ such that

for each i, the value of X_i is either 0 or 1;

for all values of i, the probability that $X_i = 1$ is the same number P .

Given a Bernoulli process defined on a probability space $(\Omega, \Pr)$,then associated with every is a sequence of integers.

1. Wavelength Occupancy Distribution Using Bernoulli Model

To use the Bernoulli model to describe traffic statistics, four hypotheses are made as follows: 1) The call arrival process is a conditional Poisson process with network state-dependent rates; 2) each call holds a wavelength on each link of its route, and the call holding times is exponentially distributed and independent of the arrival process; 3) one wavelength is assigned randomly to a new wavelength request from a wavelength pool and 4) any released wavelength is returned to the wavelength pool.

In the Bernoulli traffic model, the state-dependent arrival rate of a wavelength request in network state φ rφ, for an optical network consists of the number of wavelengths of n, is governed by

$$\gamma_\varphi = \begin{cases} \beta(n-\varphi), \varphi = 0,1,2,...., \mathrm{n} - 1 \\ 0, \qquad \varphi \geq \mathrm{n} \end{cases} \tag{1}$$

where $\beta(>0)$ is the traffic parameter. The corresponding wavelength occupancy probability can be expressed as

$$P_\varphi = \left(\frac{\beta}{\beta+\mu}\right)^\varphi \left(\frac{\mu}{\beta+\mu}\right)^{(n-\varphi)} \binom{n}{\varphi} \tag{2}$$

$$\varphi = 0,1,2,..., n$$

where μ is the wavelength request departure rate. Based on (2), the mean m and the variance v of the number of simultaneously occupied wavelengths can be obtained, which have the forms of

$$m - \frac{n\beta}{(\beta+\mu)} \tag{3}$$

$$v = \frac{n\mu\beta}{(\beta+\mu)^2} \tag{4}$$

For simplicity but without losing generality, we set $\mu = 1$. It can be seen from (1)–(4) that the wavelength occupancy distribution can be obtained, provided that m and n are known.

B. Poisson Model

A Poisson process is a sequence of events ``randomly spaced in time."

- The rate λ of a Poisson process is the average number of events per unit time (over a long time).

1. Properties of a Poisson Process

- For a length of time t, the probability of n arrivals in t units of time is

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \quad (5)$$

- For 2 disjoint (non-overlapping) intervals, (S_1, S_2) and (S_3, S_4) $(i.e\ S_1 < S_2 <= S_3 < S_4)$, the number of arrivals in (S_1, S_2) is independent of the number of arrivals in (S_3, S_4) .

2. Interarrival Times of a Poission Process

- Pick an arbitrary starting point in time (call it **0**).

- Let τ_1 = the time until the next arrival

$$P(\tau > t) = P_0(t) = e^{-\lambda t}$$

So

$$F_\eta(t) = P(\tau_1 \le t) = 1 - e^{-\lambda t} \text{ and } f_\eta(t) = \lambda e^{-\lambda t}$$

τ_1 has an exponential distribution.

Let τ_2 = the time between the first and second arrival

- We can show that

$$P(\tau_2 > \tau_1 + t | \tau_1 = \delta) = e^{-\lambda t} \text{ for s, t} > 0$$

- independently of τ_1 !
- Similarly define τ_3 as the time between the second and third arrival; τ_4 as the time between the third and fourth arrival; . . .

The random variables $\tau_1, \tau_2, \tau_3, ..., \tau_n, ...$ are called the interarrival times of the Poisson process.

The interarrival times, $\tau_1, \tau_2, \tau_3, ...$, are independent of each other and each have an exponential distribution with mean $1/\lambda$.

3. Wavelength Occupancy Distribution Using Poisson Model

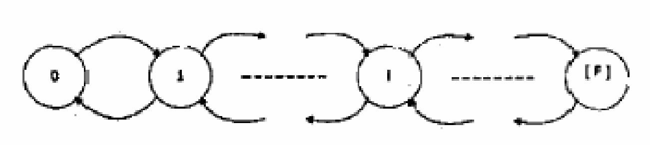

Fig. 1 Markov Chain Process for Poisson arrival distribution

The proportion of each wavelength:

$$P\frac{(i)}{k} = \frac{(\lambda_i T)^k}{K!} = \frac{\frac{L^k{}_i}{K!}}{\sum_{L=0}^{w} \frac{L^t{}_i}{l!}} \quad (6)$$

when *Ai* denoted the arrival traffics rate in the system at each hop path , T denoted the average duration of a connection , *k* denoted wavelengths on the i[th] hop path, *Li* denoted the average offered traffics on the i[th] hop path and i denoted number of each hop paths.

VI. Routing Power Model for Dynamic Traffic

A. Definition of Routing Power

The wavelength-routing capability of ROADMS of different categories can be quantified by counting the number of individual connection states that can be established by using the ROADMS. Each of those connection states can be represented by a connection vector with elements equal to one or zero, depending on whether the corresponding wavelength is dropped or expressed [8]. An expressed wavelength is the wavelength that just passes through the ROADMS without being added dropped. For unidirectional ROADMS that do not have wavelength conversion functionality, routing power is defined as [8]

$$R = \frac{\log(CN_{ROADM})}{\log(CN_{WDM})} \quad (7)$$

Where CN_{ROADM} is the number of connection states supported by a ROADMS. CN_{WDM} is the number of connection states required by an optical network for achieving the full wavelength routing capability, i.e., any incoming wavelength can be added or dropped to any output channel.

B. Routing Power for Dynamic Traffic

To compute routing power by using (7) for dynamic optical networks, an analytical formula of CN_{WDM} is first derived, which should be regarded here as the number of effective connection states. If the backbone network has N_{WDM} WDM wavelengths, the number of effective connection states required by the backbone network for achieving the full wavelength-routing capability is given by

$$CN_{WDM} = \sum_{\varphi=0}^{N_{WDM}} P_{\varphi} \binom{N_{WDM}}{\varphi} \quad (8)$$

where φ is the state of the backbone network, i.e., the number of wavelengths being occupied simultaneously. P_φ is the wavelength occupancy probability in state φ.

To calculate the routing power, the effective connection states CN ROADMS supported by a ROADMS should also be made known, which depend significantly upon ROADMS architectures and underlying switching technologies.

For a category II ROADMS involving *N*switch optical switches aligned in parallel, it is defined that the *j*th optical switch has the number of input wavelengths of *N*jROADM and the number of add/drop wavelengths of *K*jROADM. The number of effective connection states supported by such a *ROADM* is given by

$$CN_{ROADM} = \prod_{j=1}^{N_{switch}} \left\{ \sum_{\varphi=0}^{K_{jROADM}} P'_{j\varphi} \binom{N_{jROADM}}{\varphi} \right\} \quad (9)$$

where $P'_{j\varphi}$ is the wavelength occupancy probability in the local network corresponding to the *j*th optical switch.

By substituting (8) and (9) into (7), we get the following analytical routing-power expression for category-II ROADMs.

$$R = \frac{\log \left\{ \prod_{j=1}^{N_{switch}} \left[\sum_{\varphi=0}^{K_{jROADM}} P'_{j\varphi} \binom{N_{jROADM}}{\varphi} \right] \right\}}{\log \left[\sum_{\varphi=0}^{N_{WDM}} P_{\varphi} \binom{N_{WDM}}{\varphi} \right]}. \quad (10)$$

When *N*switch = 1 (10) gives the routing power of cat-II ROADMs.

VII. Results

To gain an insight into the impact of dynamic traffic on the wavelength-routing capability of category-II ROADMs, first numerical simulations are undertaken on the routing-power characteristics. The effect of dynamic optical traffic on the wavelength routing capability of category II ROADMs using all the 2 models are examined in Fig. 2 and Fig. 3 where routing power versus the number of add/drop wavelengths is plotted for different traffic-mean values of 6, 32, and 58 in the backbone network.

Next, the blocking probability is compared with number of-hops for changing arrival traffic rates. Since the increasable hops induce the blocking probability, it is increased as no. of hops increases. The results for all the 3 models are given in Fig. 4 and Fig. 5.

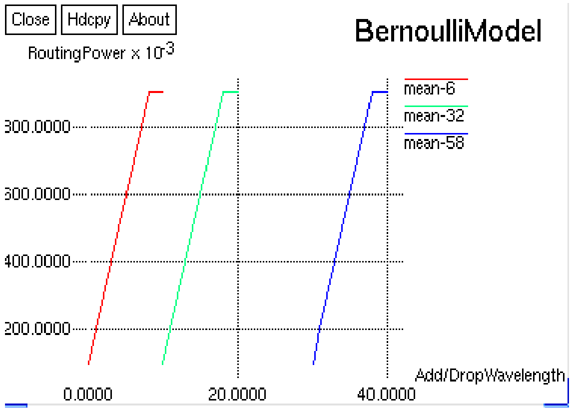

Fig. 2 Routing Power of Category-II ROADM for Bernoulli Model

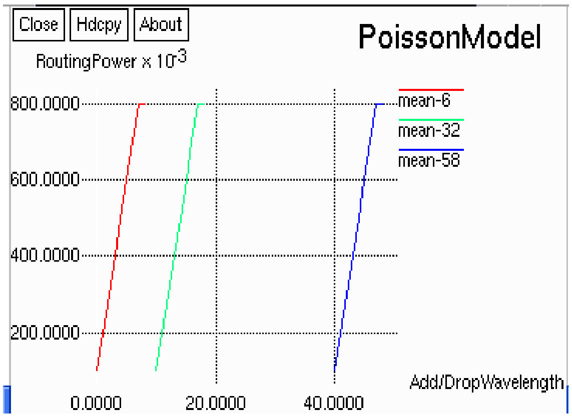

Fig. 3 Routing Power of Category-II ROADM for Poisson Model

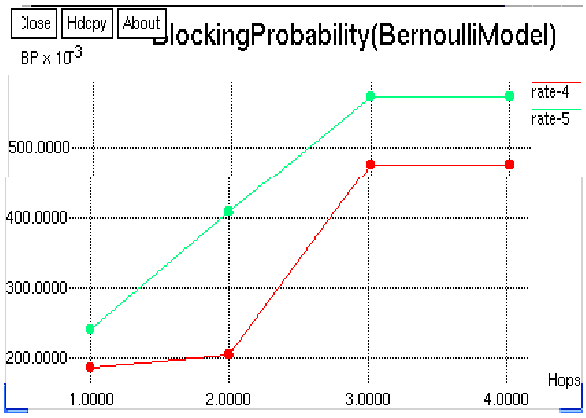

Fig. 4 Blocking Probability Vs Hops of Category-II ROADM for Bernoulli Model

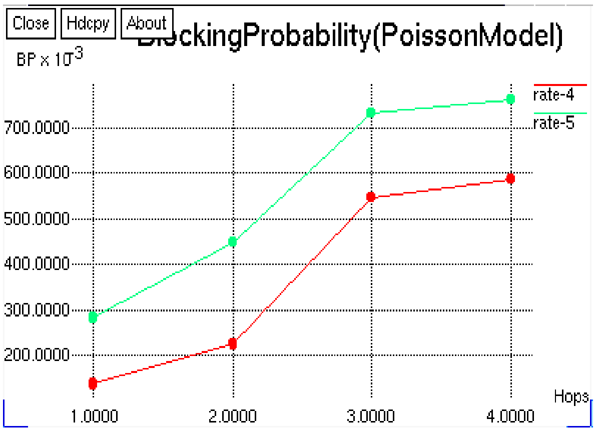

Fig. 5 Blocking Probability Vs Hops of Category-II ROADM for Poisson Model

VIII. Conclusion

Existing ROADMs have been classified into three categories: Category I consists of a single large optical switch; category II is composed of a number of small optical switches aligned in parallel; and category III has a single optical switch and only one wavelength being added/dropped. To describe the wavelength-routing capability of ROADMs of various categories in dynamic optical networks, a theoretical routing-power model has been developed, taking into account ROADM architectures and dynamic traffic. The ROADM wavelength occupancy probability is not same when implemented in dynamic optical networks. In this paper, to evaluate the wavelength-routing capability of ROADMs of category II in dynamic optical networks, Bernoulli and Poisson models for various traffic types has been developed and analysed.

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