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PERFORMANCE ANALYSIS OF ROADMS AT PEAK TRAFFIC IN ALL OPTICAL NETWORKS

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Reconfigurable Optical Add / Drop Multiplexer is a subsystem of All Optical Networks. In this paper we analyze the routing performance of ROADMs at peak traffic using Pascal distribution model. To evaluate wavelength routing capability of ROADMs of various architectures in dynamic optical network, a theoretical routing power model is considered. With simulation results, the routing power and blocking probability have been evaluated to achieve better performance and flexibility.

Key words: Wdm, Roadm, Blocking probability
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1 Introduction

As the transmission speeds and network demands are increasing, service providers and equipment vendors are trying to develop new technologies that will help them to build a network with enormous capacity and offer the services to the customers at lower costs. Wavelength-Division-Multiplexing (WDM) is generally regarded as the most promising technology for the backbone of future next-generation networks. Each WDM channel may be operated at whatever speed one desire, e.g., peak electronic speed of a few gigabits per second (Gbps). Transmissions on different wavelengths are coupled into a single fiber using wavelength multiplexers.

Optical technologies based on modern artifacts help the service providers to maximize their network capacity with reduced cost of bandwidth. This in turn leads to the growth of new sets of applications that set thriving thrust for more bandwidth. This positive feedback cycle for the demand on bandwidth pushes the service providers to the development of Reconfigurable All-Optical Networks (R-AONs). R-AONs combined with Dense Wavelength Division Multiplexing (DWDM) technology can help the service providers to meet the challenge of this surge of traffic demands and also to maximize the utilization of their existing network. R-AONs provide flexibility to the service providers, especially on the dynamic provisioning of their wavelengths that ultimately reduce the Capital- (CAPEX) and Operational-Expenditure (OPEX) of the overall network.

In order to achieve these reconfigurability and transparency over the AONs, service providers have been trying to integrate the service of Reconfigurable Optical Add/Drop Multiplexers (ROADMs) into their present network in combination with DWDM technology. The concept of reconfigurable optical add-drop multiplexers isn't new – in fact, ROADMs have been around for at least four years and have been part of a handful of vendors' WDM gear in both North America and Europe since 2002. Long-haul DWDM networks have nearly all been constructed with ROADMs in the past three years, setting the stage for a migration of this functionality into metro and regional networks as prices drop and network flexibility requirements escalate. The marketplace has long been rather wary of ROADMs – carriers have asked for more flexibility in their optical networks and simpler wavelength provisioning, monitoring, and management, but they have been loath to pay the price premium or invest in immature technologies. In addition, ROADMs are by their nature devices, not whole systems – a distinction that has led to some confusion in the marketplace about just what constitutes a ROADM system, when some vendors offer products with similar functionality based on different underlying device technologies.

2 Related work and Research

In this section we briefly reviewed the current research work in related with our work.

L. Eldada et al [1] developed the different optoelectronic technologies for use in ROADM subsystems and described their principles of operation, designs, advantages, and challenges. The technology platforms include PLC, MEMS and LCD in the four main ROADM subsystem types: WB, PLC, WSS and WXC.

M.D. Feuer et. al [2] introduced a new figure of merit, the global routing power R, which quantifies the flexibility of channel routing in a RWADM. Taken together with N, the number of input wavelengths accepted and K, the maximum no of wavelengths dropped, R provides a meaningful basis for comparing the network value of different RWADM designs. For OADM nodes supporting multiple services through optical transparency, as well as for OADM nodes with some unterminated add/drop fibers, the segmented routing power R_i is used. Moreover, for a specific ROADM architecture and an acceptable wavelength blocking probability, the minimum number of ROADMs required for accommodating a given traffic load has also been carried out in metropolitan optical ring networks [3].

L.E.N. Delbrouck et al [4]. a moment-matching technique, called Bernoulli–Poisson–Pascal (BPP) model is used, instead of attempting to focus on a specific traffic model. In the BPP model, an equivalent process is selected, based on the known moments of an offered traffic. This process is then used in the simulation of wavelength occupancy distribution. Moreover, suitably truncated product form combinations of these distributions can also be used to estimate the different levels of blocking experienced by two streams of traffic with different peakedness factors offered to the same trunk group. The main purposes of this paper to describe the procedure, illustrate its effectiveness, and also discuss some of its limitations.

S. Subramaniam et al [5]. a methodology for studying the benefits of wavelength converters for non-Poisson dynamic traffic is developed. The BPP model has been used by teletraffic engineers to characterize the non-Poisson nature of carried and overflow traffic from a trunk. The arrival occupancy distribution for this model has been derived and utilized it to analyze the effect of traffic peakedness on wavelength conversion benefits and call blocking performance.

J. Wagener et al [6]. 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.

Mohcene Mezhoudi et al [7]. Compare alternative ROADM network architectures through a study based on real LEC data. We show that optimally deployed higher-degree ROADMs with optical bypass and grooming can simultaneously reduce the cost of both the optical and SONET layers.

Han-You Jeong et al [8]. present a new analytical model that can give an accurate estimation of the blocking probabilities in wavelength-routed optical networks with heterogeneous traffic. By heterogeneous, they mean that each session offered to the network has its own traffic intensity and burstyness. In such cases, the blocking probability of a session is determined by the busy-wavelength distributions of the links seen at the arrival points of its calls. Thus, they first present two single-link models to estimate the arrival-point busy-wavelength distribution of a link with heterogeneous traffic: the full-population (FP) model and the reduced-population (RP) model.

Suresh Subramaniam et al [10]. makes the first known attempt to study wavelength-routing networks and the effects of wavelength conversion under dynamic non-Poisson traffic. An approximation that characterizes any non-Poisson traffic by its first two moments is utilized. The arrival occupancy distribution of busy wavelengths for this approximate 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, and also that wavelength conversion gain is insensitive to traffic peakedness over a large range.

The objective of this work is to study the performance analysis of Reconfigurable Optical Add/Drop Multiplexers under different configurations at traffic peakedness using Pascal model with different traffic parameters like routing power, blocking probability, delay, channel utilization and packets received.

3 ROADM

ROADMs can be defined as optical modules capable of adding/dropping or passing through (express) any or all wavelengths present in the DWDM signal with remote management capability. ROADM offers flexibility on the provisioning of wavelengths regardless of how the network changes. It effectively alleviates the need for service provisioning when new services are added to the network and offers flexibility to the service providers on the handling of churns.

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 .The past electrically controlled wavelength-routing flexibility provided reduces network operation cost, and the circumvention of the unnecessary O–E–O conversion at network nodes mitigates equipment cost, overcomes the transmission capacity bottleneck set by electrical signal processing, and relieves the burden on the electrical grooming switching at ingress and egress points of networks Over the past several years, considerable research and development effort has been expended on designing and fabricating ROADMs. Today, every major system vendor has a ROADM offering, and a large number of component vendors have announced ROADM products. Generally speaking, a ROADM can be treated as a device consists of a demultiplexer (DEMUX) and MUX pair, with equivalent optical switches sandwiched in between. The ROADM is comprised of two logical input ports, namely In and Add, as well as two logical output ports, namely Out and Drop.

3.1 Different categories of ROADM

The ROADM is comprised of two logical input ports, namely In and Add, as well as two logical output ports, namely Out and Drop [2]. According to their underlying switching technologies, existing ROADM architectures can be classified into three categories:

1) 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) [1], wavelength selective switches, and acousto-optic tuneable filters belong to this category.

2) 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) Category-III ROADM contains a single optical switch with only one add/drop wavelength.

Both broadcast-and-select-and vertically coupled semiconductors Bragg grating-based ROADMs belong to this category. ROADM wavelength-routing capability is based on an assumption that the wavelength occupancy probability is equal to one for all network states.

3.2 Wavelength-Routing Capability of ROADM

ROADM wavelength-routing capability is based on an assumption that the wavelength occupancy probability is equal to one 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. In this paper, it is to perform theoretical investigations on wavelength-routing capability of ROADMs of various categories in dynamic optical networks. A theoretical routing power model is developed, taking into account ROADM architectures and dynamic traffic.

4 Routing-Power Model for Dynamic Traffic

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. 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

$$R = \frac{Log(CN_{ROADM})}{Log(CN_{WDM})}$$

Where CN_{ROADM} is the number of connection states supported by a ROADM. 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.

To compute routing power by using the above equation for dynamic optical networks, we first derive an analytical formula of CN_{WDM}, 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

$$CN_{ROADM} = \sum_{\varphi=0}^{N_{wdm}} P_{\varphi} \binom{N_{wdm}}{\varphi}$$

Where φ is the state of the backbone network, i.e., the number of wavelengths being occupied simultaneously. $P\varphi$ is the wavelength occupancy probability in state φ. To calculate the routing power, the effective connection states CN_{ROADM} supported by a ROADM should also be made known, which depend significantly upon ROADM 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*j ROADM and the number of add/drop wavelengths of *K*j ROADM. The number of effective connection states supported by such a ROADM is given by

$$CN_{ROADM} = \pi_{j=1}^{N_{switch}} \left\{ \sum_{\varphi=0}^{K_{JROADM}} P'_{j\varphi} \binom{N_{jROADM}}{\varphi} \right\}$$

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

4.1 Wavelength Occupancy Distribution

Dynamic traffic can be specified by the arrival process, departure process, and bandwidth of its call [15]. 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 [11]. 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 model: smooth traffic if $Z < 1$
Poisson model: regular traffic if $Z = 1$
Pascal model: peak traffic if $Z > 1$

In this paper we have evaluated the performance analysis for category I & II for peak traffic using Pascal model

5 Pascal Model

In probability and statistics the negative binomial distribution is a discrete probability distribution. It can be used to describe the distribution arising from an experiment consisting of a sequence of independent trials, subject to several constraints. The Pascal distribution is the special case of the negative binomial distribution.

5.1 Wavelength Occupancy Distribution Using Pascal Model

Requirement of the network model that is arrival rate at the i^{th} path is equal to

$$\alpha_i = \alpha + (i-\alpha)\beta \text{ by } \alpha>0 \text{ and } 0<\beta<1$$

The probability equation can be calculated as follows

$$P_i = (1-\beta/\mu)^a (\beta/\mu)^i \binom{a+i-1}{i}$$

By given that $a = \alpha / \beta (1-\beta)$

$$\text{Mean:} \quad M = \alpha$$
$$\text{Variance:} \quad V = \alpha / (1-\beta)$$

By $\mu = 1$ and $z = 1 / (1-\beta) > 1$

From Markov chain process, we find that

$$\mu = 1$$
$$\alpha = M \text{ and } \beta = 1$$

6 Results and discussions:

In this section, the performance of ROADM for category-I & II is carried out with simulation study based on ns-2 network simulator for Pascal model [11&12].

The effect of dynamic optical traffic on the wavelength routing capability of category I & II ROADMs using high traffic model is examined in Figures 1 & 2 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. The traffic mean supported by the ROADM in the local network is $P_w K_{ROADM}$ with P_w being determined by the corresponding backbone traffic mean. The operating condition of $N_{WDM} = K_{ROADM} = 64$ is adopted.

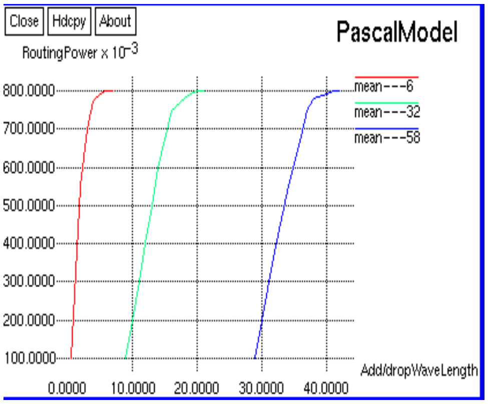

Figure 1. Routing Power of Category-I ROADM

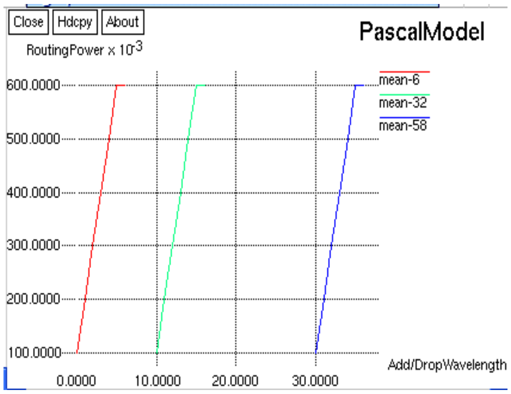

Figure 2: Routing Power of Category-II ROADM

From figures 1 & 2, this can be understood that, for a given backbone traffic mean, M_T there exists a minimum required number of add/drop wavelengths K_M below which *R* is zero.

The existence of the zero routing-power regimes is caused by K_{ROADM} that is not sufficiently large to accommodate the traffic in the backbone network. While if $K_{ROADM} > K_M$, R grows almost linearly with an increasing, and when K_{ROADM} is higher than the backbone traffic mean M_T, a relatively large R is obtainable. In particular, a further increase in K_{ROADM} results in ROADMs capable of offering the full wavelength routing capability. This can be understood by considering the fact that a large K_{ROADM} gives rise to a high traffic mean supported by the ROADM in the local network.

Considering the characteristics of the wavelength occupancy distribution if $K_{ROADM} << M_T$, the wavelength occupancy probability is very small, leading to the few number of effective connection states. Only when the traffic mean in the local network is comparable to that associated with the backbone network may the ROADM be able to provide some free wavelengths. Therefore, the full wavelength-routing capability is achievable when $K_{ROADM} >> M_T$. The blocking probability of ROADM is calculated by varying the number of hops for different arrival traffic rates. Since the increasable hops induce the blocking probability, it is increased as number of hops increases. The simulation results for blocking probability of category I & II for Pascal model is shown in the figure 3 and 4.

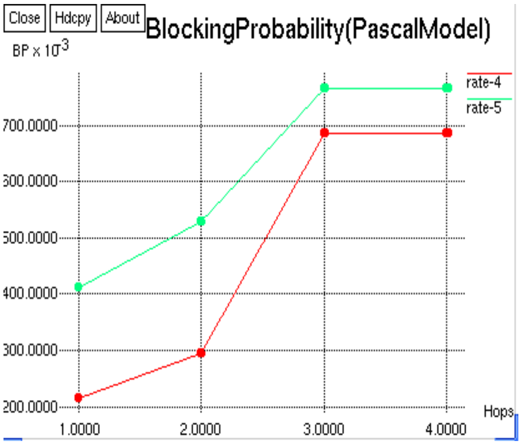

Figure 3: Blocking Probability Vs Hops of Category-I ROADM

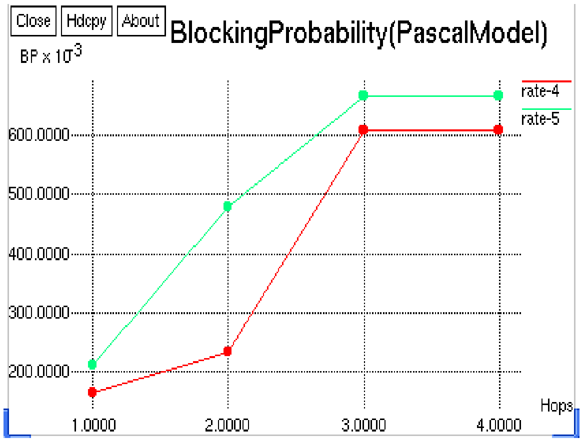

Figure 4: Blocking Probability Vs Hops of Category-II ROADM

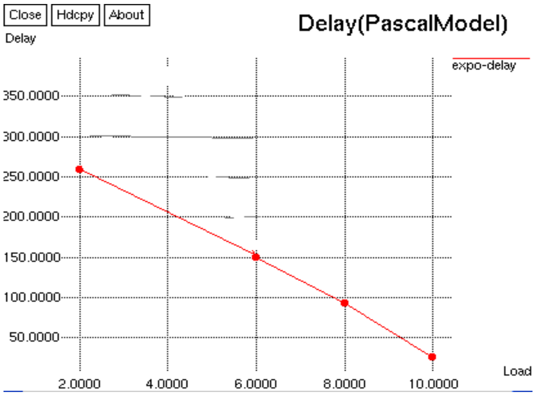

Figure 5: Delay Vs Load of Category-II ROADM for Pascal Model

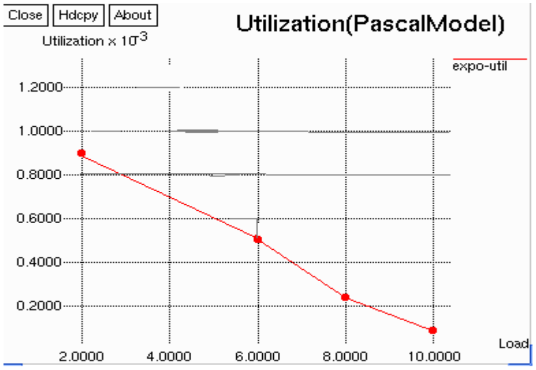

Figure 6: Utilization Vs Load of Category-II ROADM for Pascal Model

We have also evaluated QOS metrics delay, channel utilization and packets received for category – II ROADM for peak traffic. The simulation results are as shown in the figures5 and 6.

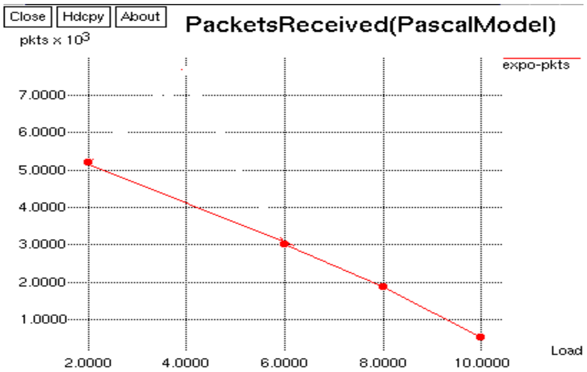

Figure 7: Packets Received Vs Load of Category-II ROADM for Pascal Model

We have observed through simulation results that Delay, channel utilization and packets received decreases as load increases.

7 Conclusion

Based on different architectural models category I & II, simulations are performed to explore the impact of peaky traffic ($Z > 1$) on the wavelength routing of ROADMs. This can be understood by considering the fact that a large K_{ROADM} gives rise to a high traffic mean supported by the ROADM in the local network. Since the increasable hops induce the blocking probability, it is increased as number of hops increases. We have observed through simulation results that Delay, channel utilization and packets received decreases as load increases. So the system is better and flexible which will be a new alternative choice for planning of communication network.

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