Comparative Performance Study of WDM Packet Switch for Different Traffic Arrival Approach

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***Abstract*— Optical packet switching is a promising technology, which can integrate both data and optical network. In this paper, we present a comparative study of various traffic arrival approaches in WDM packet switches. The comparison is made based on packet loss rate and average delay under uniform and self-similar Pareto traffic. Computer simulations are performed in order to obtain the switch performance metrics. Study shows that burstiness of data traffic has a strong negative impact in the performance of WDM packet switches.**

***Index Terms*— Average Delay, Optical Packet Switching (OPS), Packet Loss Rate (PLR), Pareto Traffic.**

I. INTRODUCTION

IN recent years, with the exponential growth of Internet traffic and Multimedia applications, the requirements of higher bandwidth for communications are rapidly increasing day-by-day. The requirements of increasing bandwidth could be satisfied by Wavelength Division Multiplexing (WDM) technology. Optical packet switching (OPS) is one of the potential candidates that can fully utilize the bandwidth efficiently. OPS offers connectionless networking and very fine granularity. Besides higher bandwidth, it also provides a high speed data rate, format transparency and configurability [1].

One of the major inventions in the field of optical communication is Erbium-Doped Fiber Amplifier (EDFA) [2, 3] that is an optical amplifier capable of amplifying multiple channels simultaneously in optical domain. This also led to the widespread deployment of Wavelength Division Multiplexing. This technology has enabled to send hundreds of wavelengths to a single fiber and EDFA is capable to amplify all the multiplexed optical channels together rather than individually. WDM technology has added a new dimension in optical networks. It has made the deployment of All-Optical Network (AON) possible [4], which eliminates the processing bottleneck in electronic domain. Therefore, it can be assumed that all-optical networks will replace the traditional networks in the near future.

One of the critical factors in implementing optical networks is to design the architecture of optical switch/router, which is responsible to perform the switching operation at a high speed. Ideally, all the operations inside the node would be performed in optical domain. Although data (payload) remains in optical domain however, in practice, header processing and control operation are performed in electronic domain. Therefore, today's optical switches are not entirely optical. It is due to the immaturity of optical memory storage technology [5]. Although optical networks and components have been developed rapidly and many research works have been done so far. However, still there are some potential unsolved problems. Among them the most critical factor is packet contention [5].

Contention resolution is one of the key issues in optical packet switching network. When the packets are being switched, contention occurs at a switching node whenever two or more packets try to leave the switch fabric on the same output port, on the same wavelength, at the same time [5]. In traditional electrical packet switched network, contention is resolved utilizing random access memory (RAM). However, due to lack of optical RAM technology in optical packet switching network, various techniques have been introduced in order to resolve contention. These are: wavelength conversion, deflection routing, and optical buffering.

Among the above three approaches, optical buffering based on fiber delay lines (FDLs) is the simplest and the most widely used cost-effective solution for contention resolution [6, 7]. In [8] and [9], a slotted WDM packet switch using fiber delay lines was proposed and analyzed under both uniform and bursty traffic. Output buffering approach was implemented in the proposed switch to resolve contention. Shared tunable wavelength converter (TWC) based optical switch architecture is proposed in [10], where TWCs are shared among all input channel. A significant reduction of the number of required TWC was reported in the switch. However, such structure cannot make efficient use of scarce output FDLs, because at a given instant not all FDLs are used. In [11], feedback shared buffering based optical packet switch architecture is proposed utilizing the advantage of WDM loop buffer memory. The proposed switch is built on a simple routing algorithm. However, the architecture of the switch is very complex and it suffers from severe circulation limits. Both

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fiber delay lines (FDLs) and electronic buffer based hybrid buffering optical packet switch is proposed in [12]. The major idea of implementing electronic buffer in the proposed architecture is that it provides various time delay values which might be effective for contention resolution. However, electronic buffer is not very effective for contention resolution in optical packet switching network as it requires converting of optical packets to electrical packet, store, and re-convert the signal back to optical domain. Therefore, it is a very slow and time consuming process.

In this paper, we present a comparative analysis of different traffic arrival approaches in optical packet switches. In most cases, the performance of WDM packet switches is investigated under Poisson or Markovian arrival process. However, it is discovered that Ethernet traffic and World Wide Web (WWW) traffic possess self-similar behavior. Therefore, it is important to study the performance of optical packet switch under such kind of self-similar traffic.

The rest of the paper is organized as follows. A brief introduction of generic optical packet switch is highlighted in Section II. Section III describes self-similar Pareto traffic model. The comparative study is done through computer simulations in Section IV. Finally, Section V concludes this paper with some conclusive remarks.

II. GENERIC OPTICAL PACKET SWITCH

A typical optical packet switch is illustrated in Fig. 1, which consists of a set of multiplexers/demultiplexers, an input interface, a switching fabric with associated optical buffers (i.e., fiber delay lines), an output interface, and a control unit. The function of each component varies on whether synchronous (slotted) or asynchronous (unslotted) switch is deployed.

At first, the packets arriving on an input fiber are demultiplexed into individual wavelengths and then sent to input interface. The input interface delineates incoming packets in order to identify the beginning and end of each packet, extracts packet header and forwards headers to control unit for further processing and, converts packet payloads from an external WDM transmission wavelength to an internal wavelength. It is also responsible for packet synchronization and alignment of packets with switching time slots. The switch control unit processes the header information, determines an appropriate output port and wavelength for the packet, and instructs the switch fabric to route the packet accordingly. The switch fabric establishes optical connection between input and output, which can be one-to-one, one-to-many or many-to-one. It is responsible for performing switching operation for packet payloads in optical domain.

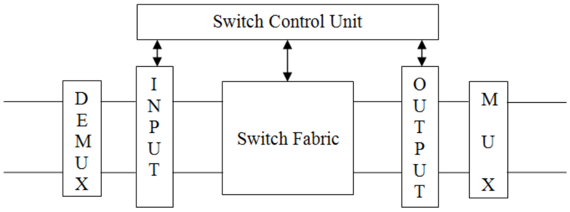


Fig. 1. A Generic block diagram of optical packet switch

The output module delineates and resynchronized optical packets, reattaches newly processed headers to the associated payloads, and converts an internal wavelength to an appropriate external WDM transmission wavelength before sending packets to the multiplexer. It is also responsible for output power level equalization.

III. SELF-SIMILAR PARETO TRAFFIC MODEL

The term self-similar was first coined by Mandelbrott [13] and was implemented for the modeling of geological and hydraulic problems [14]. The self-similarity defines a characteristic associated primarily with fractals and chaos. Fractals are objects that appear similar at all levels of magnification. Typically, the performance of switch is analyzed under Poisson or Markovian arrival process. It is found that these models are adequate to generate data traffic. However, generating data traffic using these models is found inadequate. In real world, the traffic streams are often characterized as bursty in nature. Most of the application level data units (ADU), such as video frame, arrive consecutively in a burst are strongly correlated by having the same destination address. Therefore, it is better to model traffic by Pareto or exponentially distributed statistics. In this paper, we study a heavy-tailed truncated Pareto distribution, which is considered as an effective model for bursty traffic in real networks [15, 16].

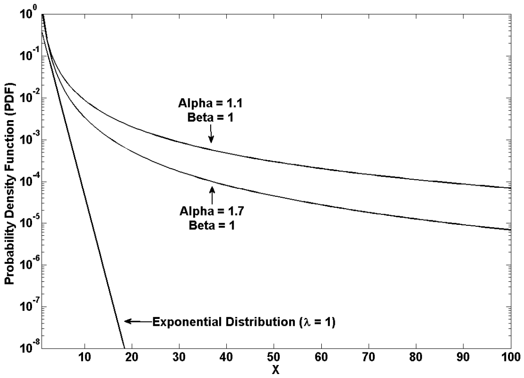


Fig. 2. Comparison curve between Self-similar Pareto distribution and exponential distribution

In this model, self-similar traffic is generated, contains fixed-length packets with packet duration equal to a time slot. ON-OFF Pareto model [17] is used to generate traffic where an input port alternates between ON and OFF period. During ON periods, packet arrives in bursts, which are separated by OFF periods. ON and OFF periods are Pareto distributed random variables, which are heavy-tailed. Since fixed length packets are used in this paper, therefore ON periods represent packet train size, i.e., the number of packets arrives contiguously. No packets are generated during OFF or idle periods. The probability density function for a Pareto distributed random variable x is given by:

$$f(x) = \alpha\beta^{\alpha} x^{-(\alpha+1)}, \; x \geq \beta \text{ and } \beta \quad 0$$

With mean

$$E(x) = \frac{\alpha\beta}{\alpha - 1}$$

Where, α is shape parameter (tail index), and β is the minimum value of x. When $\alpha \leq 2$, the variance of the distribution is infinite. When $\alpha \leq 1$, both variance and mean will be infinite. The lower value of α, the probability of obtaining extremely large value of x is higher. Therefore, in order to obtain self-similar process (heavy-tailed distribution), the value of α should be between 1 and 2, ($1<\alpha<2$). Fig. 2 illustrates a comparison curve between Pareto distribution with different α and exponential distribution. It is found that the tail of the Pareto curve is more consistent and decays much more slowly than the exponential distribution.

The formula in order to obtain computer-generated random variable that follows truncated Pareto distribution is given by:

$$x = \frac{\beta}{U^{\frac{1}{\alpha}}}$$

Where, U is uniformly distributed random value within range [0, 1].

In order to generate packet trains during ON period, a set of parameters are used which are denoted by α_{on} and β_{on}, where α_{on} represents tail index or shape parameter and β_{on} represents burst size (packet train) during ON period. Therefore, mean ON time of a source is given by:

$$E_{on}(x_{on}) = \frac{\alpha_{on}\beta_{on}}{\alpha_{on} - 1}$$

Similarly, a set of parameters α_{off} and β_{off} are used in order to obtain OFF period. The mean OFF period of a source is given by:

$$E_{off}(x_{off}) = \frac{\alpha_{off}\beta_{off}}{\alpha_{off} - 1}$$

In real time, it is very often desirable to generate synthetic traffic to a predefined load. The generated traffic load on a specific source is defined as the mean size during ON period over the mean size during ON and OFF period. Therefore, traffic load to a specific source is given by:

$\rho = \frac{E_{on}}{E_{on} + E_{off}}$, where α_{on}, α_{off}, and β_{on} are predefined and β_{off} is calculated in order to obtain specific traffic load, ρ.

IV. RESULTS AND DISCUSSIONS

It is assumed that we have an existing optical packet switch called two-stage OPS, which is illustrated in Fig. 3 [18]. Note that we deploy a 32 × 32 of two-stage OPS in order to perform our simulation and comparative study. The switch consists of two types of switches: main switch and auxiliary switch. The main switch consists of N input fibers and $(N + M + O)$ output fibers. Therefore, the main switch requires $N \times (N + M + O)$ switching fabric. Among them, M and O output fibers of the main switch are connected to auxiliary switch I and auxiliary switch II respectively as input through feed-forward fiber delay lines. The K output fiber of auxiliary switch I is connected to auxiliary switch II as input. Thus, the switching dimension of auxiliary switch I is $M \times (N + K)$. The auxiliary switch II requires $(K + K + O) \times (N + K)$ switching fabric. It consists of K feedback FDLs that are shared among all of its input ports.

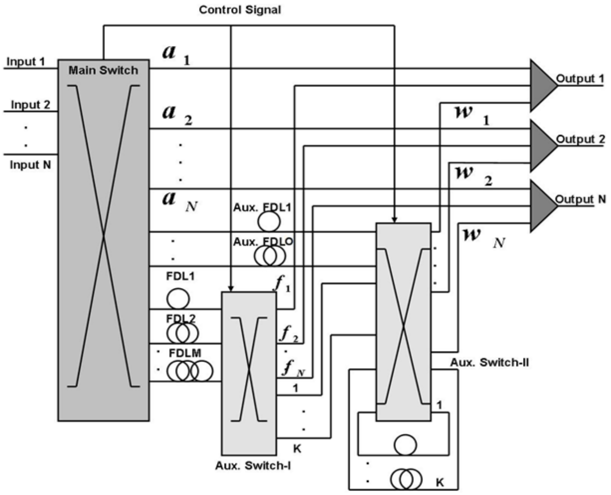
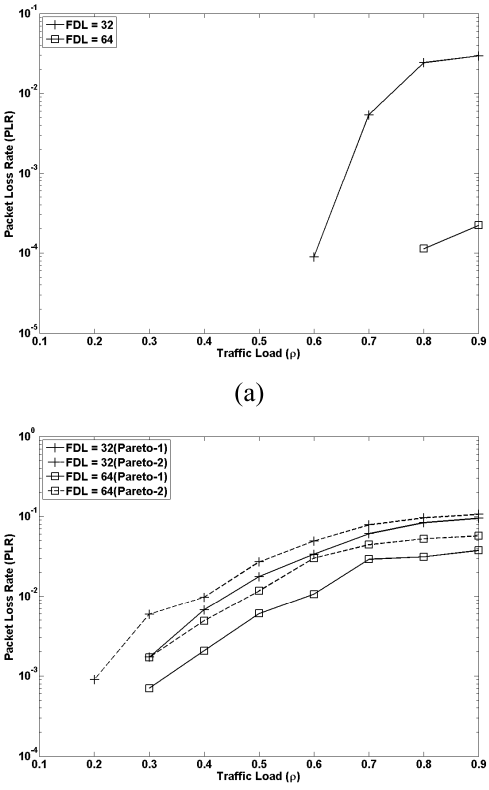


Fig. 3. Two-stage shared fiber delay line optical packet switch [18]

We conduct our simulation study for fixed length optical packets under different traffic load. The simulation run consists of 1000 time slots. The major performance parameters of this simulation study are: (1) packet loss rate (PLR), and (2) average delay. Two data traffic models are considered in simulation to justify the influence of different traffic in performance of OPS: Poisson traffic and Pareto traffic, which is described in

Section III. In Poisson traffic, it is assumed that packet arrives according to Poisson process with rate λ_n. Traffic is uniformly distributed to all switch output and packet length is one time unit.



(a)

(b)

Fig. 4. Packet loss rate versus traffic load; (a) Poisson traffic with rate λ_n, (b) Pareto traffic with α_{on} = 1.3, α_{off} = 1.5, β_{on} = 1 for Pareto-1 and β_{on} = 2 for Pareto-2

Fig. 4 shows packet loss rate (PLR) with respect to traffic load for different number of FDLs. Fig. 4(a) illustrates the performance of the switch under Poisson traffic. From Fig. 4(a) it is found that PLR increases as the traffic load increases. However, with the increase in the number of FDLs, PLR decreases significantly. Therefore, it can be concluded that FDLs play a vital role in order to improve the performance of switch. Fig. 4(b) measures the PLR under Pareto traffic. Two Pareto curves are generated, which are denoted as Pareto-1 and Pareto-2 in Fig. 4(b). In simulation, we consider that α_{on} = 1.3, α_{off} = 1.5 for self-similarity, and β_{on} = 1 and 2 for Pareto-1 and Pareto-2 respectively. The other parameter β_{off} is calculated in order to obtain a given traffic load. From Fig. 4(b), it is observed that PLR is higher for Pareto-2 than for Pareto-1 due to the effect of β_{on}. Like Fig. 4(a), the increment of number of delay lines reduces PLR. However, comparing with Fig. 4(a), it is found that Poisson traffic shows lower PLR, whereas, Pareto traffic has much higher PLR under any traffic load. The impact of increasing the number of delay lines is lower for Pareto than for Poisson traffic. Under heavy traffic load of 0.8 (ρ = 0.8), it is found that PLR for Poisson traffic for 64 FDLs (M = 64) is about 10^{-4}, whereas for Pareto traffic, PLR is certainly very higher, where the difference is more than about the factor of 10^2.

Fig. 5 shows the average delay of the switch under different traffic load. It is known that average delay is more likely to increase as the traffic load increases due to buffering of optical packets. It is because, as the traffic load increases, the contention is more likely to occur. Therefore, the more packets need to buffer to resolve contention. However, it is observed that average delay for Pareto traffic decreases after it reaches at a certain traffic load. It is because, under heavy load, due to the unavailability of free FDL packet drop rate increases. From Fig. 5, we observe that average delay is higher for Pareto-2 than for Pareto-1. We also found that Poisson traffic produces lower average delay comparing with Pareto traffic.

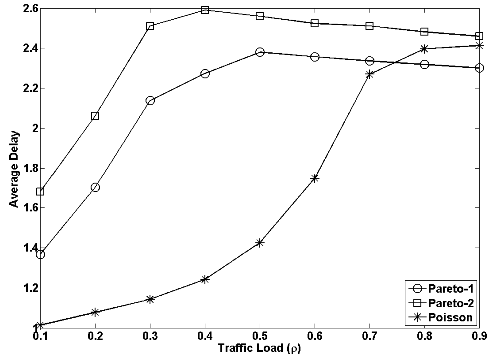


Fig. 5. Average delay versus traffic load under Pareto traffic (α_{on} = 1.3, α_{off} = 1.5, β_{on} = 1 for Pareto-1 and β_{on} = 2 for Pareto-2) and Poisson traffic with rate λ_n

In this study, we found that bursty traffic limits switch performance for the both performance metrics discussed in this paper. Burstiness of data traffic could be a vital obstacle to enhance switch performance. The performance of WDM packet switches could be greatly improved by reducing the burstiness of data traffic. Therefore, it can be concluded that if possible, it is advisable to avoid the generation of burst of packets all destined for the same output port.

V. CONCLUSIONS

In this paper, we have investigated and analyzed the performance of optical packet switch under different data traffic. Through simulation with various types of data traffic, it is found that the performance of WDM packet switches could be greatly influenced by arrival traffic. It is observed that the burstiness of data traffic has a strong negative impact on the switch performance. Therefore, we conclude that, if possible, it is recommended to avoid the generation of bursty traffic all destined for the same output port.

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