

Performance Evaluation of Hybrid Buffering Optical Packet Switch for Pareto Traffic

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Abstract— Optical packet switching is an emerging technology, which provides enormous bandwidth for Internet traffic. In this paper, we investigate the performance of hybrid buffering optical packet switch with fixed-length packets under self-similar Pareto traffic, for a more realistic traffic. The performance is evaluated in terms of packet loss rate and average delay by means of simulation experiments. Usually, the performance of WDM packet switches is investigated under Poisson or Markovian arrival process. Therefore, in order to show the influence of different traffic, the performance of the switch under Pareto and Poisson traffic are compared in this paper. Moreover, from economical view, the optical cost of the switch architecture is assessed based on fiber-to-chip coupling to estimate hardware complexity, scalability.

Keywords— optical packet switching; packet loss rate (PLR); delay; Pareto traffic; Poisson traffic

I. INTRODUCTION

Driven by increasing internet data traffic, the next generation communication networks are expected to stipulate higher bandwidth for communications. The requirements of higher bandwidth could be satisfied by wavelength division multiplexing (WDM) technology. In order to utilize the full fiber capacity, optical burst switching and optical packet switching have been proposed as switching paradigm in optical domain as it eliminates the processing bottleneck in electronic domain [1]. Besides higher bandwidth, it provides a high speed data rate, format transparency and configurability.

In general, optical packet contains two segments: header and payload. Both header and payload is separated (time or wavelength domain) and thus, bit rate independent. The header is encoded at lower bit rate, and contains information such as source address, destination address, etc. The payload actually contains the client data. It should be transparent to channel speed, as well as to the format of client data [2]. At the input of the switch, packets may arrive either synchronously or asynchronously, and may have same or variable lengths. However, in previous study it is found that, packets of same length arrive synchronously and have better performance. It is because in asynchronous network, chances of contentions are higher comparing with the synchronous technology [3].

One of the major drawbacks in optical packet switching network is contention. It 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 [4]. In traditional electrical packet switched network, contention is resolved using store-and-forward routing technique, where the packets losing in contention are buffered in large numbers and sent out later when desired output port is free. It is possible because of the availability of random access memory (RAM). Since optical RAM technology is not available in optical packet switching network, therefore, various techniques have been introduced to resolve contention. These are: wavelength conversion, deflection routing, and optical buffering.

In this paper, we will focus on optical buffering approach based on fiber delay lines (FDLs) for contention resolution as it is the simplest and the most widely used cost-effective solution [5, 6]. In [7] and [8], 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 [9], 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 [10], 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, architecture of the switch is very complex and it suffers from severe circulation limits. Both fiber delay lines (FDLs) and electronic buffer based hybrid buffering optical packet switch is proposed in [11]. 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 most cases, the performance of WDM packet switches is investigated under Poisson or Markovian arrival process.

Although these models could generate ample voice traffic, however, they are found inadequate for data traffic. It is found that Ethernet traffic and World Wide Web (WWW) traffic possess self-similar behavior. Therefore, in this paper, we investigate the performance of our previously proposed hybrid buffering optical packet switch [12] in terms of packet loss rate and average delay under self-similar Pareto traffic. Our study shows that the performance of WDM packet switches could be greatly influenced by traffic generation model. We also determine the optical cost of the switch in order to analyze the complexity of the switch architecture.

The rest of the paper is organized as follows. Section II describes the node architecture and scheduling mechanism of hybrid buffering optical packet switch. The self-similar Pareto traffic model is discussed in Section III. The simulation results are given and analyzed in Section IV. The optical cost of the switch is determined in Section V. Finally, Section VI concludes this paper.

II. HYBRID BUFFERING OPTICAL PACKET SWITCH

The hybrid buffering optical packet switch is designed with the aid of two types of switches: 1. Main switch, and 2. Auxiliary switch, refer to Fig. 1 [12]. The main switch employed in the switch is a typical node used in synchronous optical packet switching (OPS) network. On the other hand, auxiliary switch is a simple cross-connect. It is assumed that the switch fabric is non-blocking and operates synchronously with fixed length packets arriving on the N inputs in a time slotted fashion. Although non-blocking switch fabric is considered, however, contention may still occur due to uncoordinated arrival of optical packets. In order to resolve contention, shared fiber delay line (FDL) based optical buffering approach is considered, where a set of buffers are shared among all input or output ports. Two types of FDLs are considered to resolve contention: 1. Feed-forward, 2. Feedback delay lines.

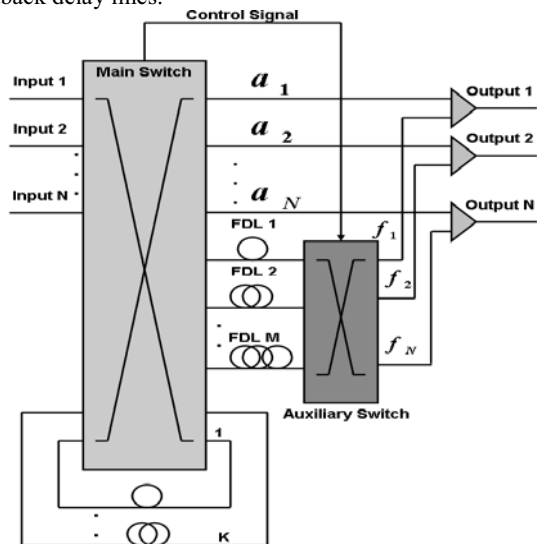


Figure 1. Hybrid buffering architecture combining feed-forward and feedback shared FDL [12]

The main switch of the hybrid buffering OPS consists of N input ports, K feedback FDLs, and $(N + M)$ output ports. Therefore, the required switching dimension of the main switch is $(N + K) \times (N + M + K)$. Among them, M output fibers are connected to auxiliary switch as input by feed-forward FDLs. The auxiliary switch requires $M \times N$ switching fabric. With feed-forward FDLs, the contended packets released from FDLs cannot re-buffer and, therefore, if it is not scheduled by the switching scheduler, they are lost. The contended packets buffered in K feedback FDLs can recirculate back to FDL input port until packets are sent to the desired output port. Each FDL can delay cells by a fixed number of time slots, and any two FDLs may have the same or different delay values. Each output fiber of the main switch is connected to its corresponding output fiber of the auxiliary switch to produce a single output fiber.

The scheduler of the switch is designed with the motivation of output port reservation [13]. Output port reservation could be stated as the guarantee of getting output port after coming out the buffered packets from FDL. In the first place, for an incoming packet, if the desired output port is free, hence, no output port contention is detected, then the packet is directly sent to its destination output port without any delay. However, if contention occurs, then the packet is forwarded to FDLs for buffering in order to resolve contention. Two set of FDLs are available to buffer contended packets: 1. Feed-forward shared FDL, 2. Feedback shared FDL. It is known that packet buffers in feedback FDL experiences larger delay and signal attenuation than feed-forward FDL due to recirculation. Therefore, initially, the contended packet is scheduled to send one of the free feed-forward shared FDLs in a way that, time slot overlapping can be avoided [13]. However, if such feed-forward FDL is not found then contended packet is scheduled to send one of the free feedback FDLs with the objective of output port reservation. Take note that with feedback FDLs, packets may recirculate many times. Therefore, in case, if output port reservation is not possible then packet is queued randomly to feedback FDL. However, in practice, it is required to reduce the number of circulations when scheduling FDL routes because optical signals get attenuated each time when they are switched. Therefore, in order to reduce number of circulations, the packets stored in the feedback FDLs that could not reserve the output port in the first place, it attempts to reserve the output port in the next circulation.

III. PARETO TRAFFIC MODEL

The term self-similar was first coined by Mandelbrot [14] and was implemented for the modeling of geological and hydraulic problems [15]. 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 more 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, the performance of optical switch is investigated under a heavy-tailed truncated Pareto distribution, which is considered as an effective model for bursty traffic in real networks [16, 17].

In this model, self-similar traffic is generated that contains fixed-length packets with packet duration equal to a time slot. ON-OFF Pareto model [18] is used to generate traffic where an input 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:

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

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.

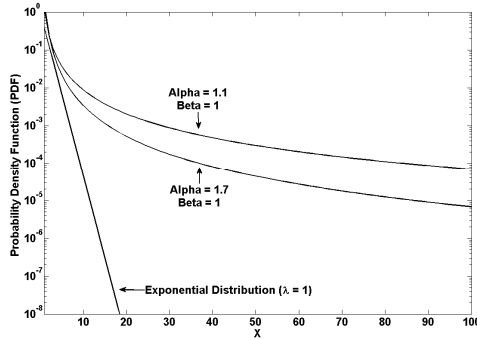


Figure 2. Comparison curve between Pareto distribution versus exponential distribution

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:

$$\rho = \frac{E_{on}}{E_{on} + E_{off}}, \text{ where } \alpha_{on}, \alpha_{off}, \text{ and } \beta_{on} \text{ are predefined}$$

and β_{off} is calculated in order to obtain specific traffic load, ρ .

IV. SIMULATION RESULTS

In this section, we represent the simulation results of a 32×32 hybrid buffering optical packet switch [12]. A series of simulations are carried out under various traffic load with fixed-length optical packets. Two traffic models are used to evaluate the performance of the switch: 1. Self-similar Pareto traffic, 2. Poisson traffic. The results obtained under different traffic model are compared together in order to show the impact of different traffic on the performance of WDM packet switches. 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. For self-similar Pareto process, we use the model as it is described in Section III. The performance metrics used in evaluation are packet loss rate (PLR) and average delay. Therefore, in the following sections, we will define PLR and average delay first, and then the performance of the switch will be evaluated.

A. Packet Loss Rate (PLR)

Packet loss rate or PLR could be defined as the ratio of total number of lost packets caused by contention to the total number of generated packets.

B. Average Delay

The average packet delay is defined as the number of time slots a cell has waited since its arrival into the input buffer till it is transmitted to its output port. In practice, the objective is to reduce PLR while reducing packet delay.

Fig. 3 shows PLR under different traffic load for different number of feed-forward FDLs. Take note that eight feedback

FDLs ($K = 8$) with maximum four circulations are considered for the feedback type FDL of the switch which is optimized in [12]. It is also considered that the length of the FDLs is distributed as described in [12]. In Fig. 3(a), the obtained PLR result is in Poisson traffic. It is found that PLR increases with the increment of traffic load. It is because as the traffic load increases, the chance of contention increases. Therefore, more packets need to buffer to resolve contention. From Fig. 3(a), it is found that if we increase the number of feed-forward FDL, the PLR decreases significantly, since, more packets can buffer as the availability of free FDL increases. Therefore, it is concluded that FDLs play a vital role to resolve contention, thus, in improvement of performance.

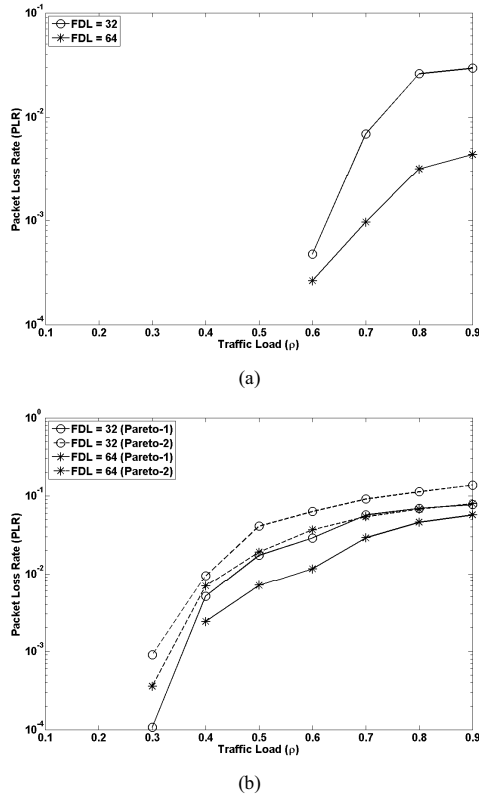


Figure 3. Packet loss rate versus traffic load; (a) Poisson traffic with rate λ_n , (b) Pareto traffic with $\alpha_{on} = 1.3$, $\alpha_{off} = 1.5$, $\beta_{on} = 1$ for Pareto-1 and $\beta_{on} = 2$ for Pareto-2

Fig. 3(b) illustrates PLR results for Pareto traffic under various traffic load for different number of feed-forward FDLs. In order to obtain self-similar process we consider that $\alpha_{on} = 1.3$, $\alpha_{off} = 1.5$. Two Pareto curves are illustrated in Fig. 3(b), which are marked as Pareto-1 and Pareto-2. It is considered that $\beta_{on} = 1$ for Pareto-1 and $\beta_{on} = 2$ for Pareto-2. In order to obtain a pre-defined traffic load the other parameter β_{off} is calculated. From Fig. 3(b) we found that Pareto-2 suffers from more PLR than Pareto-1. It is because as the value of β_{on} increases, the burstiness of Pareto traffic

increases. It is also observed that like Fig. 3(a), PLR decreases as the number of delay line increases. Comparing with Fig. 3(a), we observed that PLR is higher for Pareto traffic than for Poisson process under any traffic load. The effect of increasing the number of delay lines is lower for Pareto traffic than for Poisson traffic. Under heavy traffic load of 0.8 ($\rho = 0.8$), it is found that PLR for Poisson traffic for 64 FDLs ($M = 64$) is near to 10^{-3} , whereas for Pareto-2 traffic, PLR is about 10^{-1} , where the difference is about the factor of 10^2 .

Fig. 4 illustrates the average delay performance of the switch for Pareto and Poisson traffic under different traffic load. Like Fig. 3, two Pareto curves are generated in this simulation. Note that 32 ($M = 32$) feed-forward FDLs are used to carry out the simulation. From Fig. 4 it is observed that average delay increases as traffic load increases. It is because when packet arrival rate increases more packets stored in buffer to resolve contention, which is responsible to increase packet delay. However, it is observed that average delay for Pareto traffic decreases when offered load is moderate to heavy ($\rho = 0.5$ to 0.9). It is because, at this traffic load, contention is more likely to occur and more packets look for free FDLs. Therefore, due to the unavailability of free FDL packet drop rate increases. From Fig. 4, we observe that average delay is higher for Pareto-2 than for Pareto-1. We also observe that Poisson traffic produces lower average delay comparing to Pareto traffic under any traffic load.

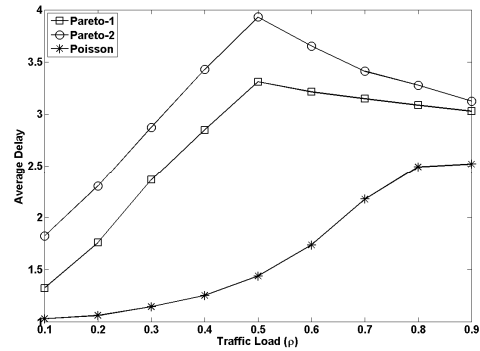


Figure 4. Average delay versus traffic load under Pareto traffic ($\alpha_{on} = 1.3$, $\alpha_{off} = 1.5$, $\beta_{on} = 1$ for Pareto-1 and $\beta_{on} = 2$ for Pareto-2) and Poisson traffic with rate λ_n

From the above simulation results, we found that the presence of bursty nature in data traffic results a significant performance decrement in WDM packet switch. Both PLR and average delay are higher for Pareto traffic under any offered load. Therefore, it is recommended to avoid generation of bursty traffic in WDM network.

V. OPTICAL COST ANALYSIS

In this section, we will investigate the optical cost of the switch. It is important to study the cost of an optical switch as it estimates the complexity of hardware, cost, scalability, etc. If the cost of a switch is too high then architecture loses its

scalability. In this paper, optical cost is determined by counting the number of fiber-to-chip coupling (FCC) [19]. FCC of an optical component is the number of interconnections to the outer world from that particular component. Although, obtaining optical cost based on FCC is completely based on heuristic, however, this approach is still applicable as it provides a rough estimation on hardware complexity. The cost of different optical components is given in Table 1 [19].

TABLE 1. COST OF DIFFERENT OPTICAL COMPONENTS IN TERMS OF FCC

Symbol	Description	Cost
$C_S(I, O)$	Cost of Switch with I inputs and O outputs	$I + O$
$C_{Coupler}(W)$	Cost of coupler of W channels into 1	$W + 1$
C_F	Cost of fiber	2

The optical cost of the architecture is given by:

$$Cost_{Total} = Cost_{Main} + Cost_{Aux.Switch}$$

The cost of the main switch can be expressed as,

$$Cost_{Main} = C_S[(N + K) \times (N + M + K)] + KC_F + NC_{Coupler}$$

$$Cost_{Main} = N + K + N + M + K + 2K + 4N = 6N + 4K + M$$

The cost of auxiliary switch can be written as,

$$Cost_{Aux.Switch-I} = C_S(M \times N) + MC_F$$

$$Cost_{Aux.Switch-I} = M + N + 2M = 3M + N$$

From the above two expressions, we can find the total cost of the architecture.

$$\begin{aligned} Cost_{Total} &= 6N + 4K + M + 3M + N \\ &= 7N + 4M + 4K \end{aligned}$$

Assume $N = 4$, $M = 4$, $K = 2$. Therefore, the total optical cost of the architecture is 52 units.

VI. CONCLUSIONS

In this paper, our motivation is to observe the impact of bursty traffic on the performance of hybrid buffering optical packet switch. Comparing with Poisson traffic, we found that the burstiness of optical data traffic has strong negative impact that degrades the performance of WDM packet switch. Therefore, we recommend that if possible it is advisable to avoid to generate burst of packets all destined for the same output port. From an economical point of view, the optical cost of the switch is studied in this paper. Although heuristic model is used to analyze the cost, however, it gives a rough estimation to determine hardware complexity, which might be effective to determine the size or the number of components used in the switch. Our analytical result shows that the cost of the proposed hybrid buffering switch is 52 units.

REFERENCES

- [1] G. I. Papadimitriou, C. Papazoglou, and A. S. Pomportsis, "Optical switching: switch fabrics, techniques, and architectures," *IEEE/OSA J. Lightwave Technol.*, vol. 21, no. 2, pp. 384-405, Feb. 2003.
- [2] M. Lackovic, C. Bungarzeanu, "Performance analysis of packet switched all-optical networks," In *Proceedings of 5th International Conference on Transparent Optical Networks*, pp. 174-179, June 29 - July 3, 2003, Warsaw, Poland.
- [3] T.S. El-Bawab, Jong-Dug Shin, "Optical packet switching in core networks: between vision and reality", *IEEE Communications Magazine*, vol. 40, 9, pp. 60-65, September 2002.
- [4] S. Yao, B. Mukherjee, and S. Dixit, "Advances in photonic packet switching: an overview," *IEEE Comm. Magazine*, pp.84-95, February 2000.
- [5] A. G. Fayaumi and A. P. Jayasumana, "Performance Model of an Optical Switch Using Fiber Delay Lines for Resolving Contentions," in *Proc. of the 28th Annual IEEE International Conference on Local Computer Network*, pp. 178-186, 2003.
- [6] H. Harai, N. Wada, F. Kubota, W. Chujo, "Contention Resolution Using Multi-stage Fiber Delay Line Buffer in a Photonic Packet Switch," in *Proc. of the IEEE International Conference on Communications (ICC 2002)*, vol. 5, pp. 2843-2847, 2002.
- [7] S. Danielsen, B. Mikkelsen, C. Joergensen, T. Durhuus, and K. Stubkjaer, "WDM packet switch architecture and analysis of the influence of tuneable wavelength converters on the performance," *J. Lightwave Technol.*, vol. 15, pp. 219-227, Feb. 1997.
- [8] S. Danielsen, C. Joergensen, B. Mikkelsen, and K. Stubkjaer, "Analysis of a WDM packet switch with improved performance under bursty traffic conditions due to tuneable wavelength converters," *J. Lightwave Technol.*, vol. 16, pp. 729-735, May 1998.
- [9] Eramo, V., Listanti, M., "Wavelength converter sharing in a WDM optical packet switch: dimensioning and performance issue," *Comput. Net.* 32(5), 633-651, 2000.
- [10] A. Pattavina, "Multi-wavelength switching in IP optical nodes adopting different buffering strategies," *Opt. Switching Netw.*, 1 (1) (2005) 65-75.
- [11] Huhnkuk Lim and Chang-Soo Park, "An Optical Packet Switch with Hybrid Buffer Structure for Contention Resolution of Asynchronous Variable Length Packets," *IEEE International Workshop HPSR 2004*, pp. 162-166, April 2004.
- [12] A. G. Reza, H. Lim, "Hybrid buffering architecture for packet contention resolution of an optical packet switch," *Optik - Int. J. Light Electron Opt.*(2010), doi:10.1016/j.ijleo.2010.04.017.
- [13] Z. Haas, "The 'staggering switch': An electronically controlled optical packet switch," *J. Lightwave Technol.*, vol. 11, pp. 925-936, pp. 499-503, May/June 1993.
- [14] B.B. Mandelbrot, J. W. Van Ness, "Fractional Brownian Motions, Fractional Noises and Applications," *SIAM Rev.*, Vol. 10, pp. 422-437, 1968.
- [15] B. B. Mandelbrot, J. R. Wallis, "Computer Experiments with Fractional Gaussian Noises," *Water Resources Research*, Vol. 5, pp. 228-267, 1969.
- [16] M. E. Crovella and A. Bestavros, "Self-similarity in World Wide Web traffic: evidence and possible causes," *IEEE/ACM Trans. Netw.*, vol. 5(6), 835-846, 1997.
- [17] M. Zukerman, T. D. Neame, and R. G. Addie, "Internet traffic modelling and future technology implications," in *Proceedings of IEEE International Conference on Computer Communication*, pp. 587-596, 2003.
- [18] M. Garrett and W. Willinger, "Analysis, modeling, and generation of self-similar VBR video traffic," in *Proc. SIGCOMM'94*, pp. 269-280.
- [19] R. Caenegem, J. Martinez, D. Colle, M. Pickavet, P. Demeester, F. Ramos, and J. Marti "From IP Over WDM to All-Optical Packet Switching: Economical View," *IEEE J. Lightwave Technol.*, vol. 24, no. 4, pp. 1638-1645, April 2006.