OPTICAL PACKET AND BURST SWITCHED NETWORKS PERFORMANCE FOR TIME-DEPENDENT VIDEO TRAFFIC

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Abstract - In this paper we study the performance of optical packet and burst switched networks (OSN) to support video traffic with scaling characteristics. The optical buffering generally implemented by fiber delay lines (FDLs) is the main challenge to achieve a full-optical switching architecture. For the analysis the $M/G/\infty$ and fBm processes are considered to represent the time-dependent video traffic. These stochastic processes are examined in terms of its video traffic scaling (H), heavy-tail distribution (HTD) and autocorrelation (ACF) characterization. We show that with a small number of FDLs (25-50) of 33.92m each and no wavelength conversion an optical packet switch can achieve performance results similar to a burst architecture. Moreover, the jitter values introduced by these FDLs were lower compared to the jitter requirements of the more demanding video traffic. We also demonstrate that the video traffic scaling degree was not affect by the optical packet or burst buffering solutions. However, the video traffic tail distribution showed to be the critical aspect to the optical switches dimensioning and thus the future optical switched network performance.

Keywords: Optical packet and burst switching, video traffic modeling, Hurst or scaling estimation.

Resumo - Neste trabalho estudamos o desempenho de redes ópticas comutadas por pacotes e rajadas para suporte ao tráfego de vídeo com presença de dependência temporal. O principal desafio da comutação completamente óptica está no buffer óptico implementado por *fiber delay lines* (FDLs). Os processos $M/G/\infty$ e fBm foram considerados para representar o tráfego de vídeo com dependência temporal. Estes processos estocásticos foram examinados em termos da representação de grau de dependência temporal (H), distribuição de calda pesada (HTD) e função auto-correlação (ACF) do tráfego de vídeo. Os resultados mostram que com um pequeno número de FDLs (25-50) de 33.92m cada e, sem conversor de comprimento de onda, um comutador óptico de pacotes pode alcançar resultados de desempenho similares a uma arquitetura em rajadas. Além disso, os valores de *jitter* introduzidos por estas FDLs foram pequenos quando comparados aos requisitos da maioria das aplicações de vídeo. Também demonstramos que o grau de dependência temporal do tráfego de vídeo não foi afetado pelas arquiteturas ópticas de pacotes ou de rajadas. Entretanto, a distribuição do tráfego de vídeo mostrou ser o aspecto crítico no dimensionamento de comutadores ópticos e em conseqüência, no desempenho das futuras redes ópticas comutadas.

Palavras-chave: Comutação óptica de pacotes e em rajadas, modelos de tráfego de vídeo, estimação do parâmetro H.

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1. INTRODUCTION

The recent progress of full-optical networks gave a great impulse to the research of new optical switching technologies and devices. These achievements associated with video coding improvements also contributed to the development of bandwidth demanding video applications. Hence, video is a key traffic to be supported by the future optical switched networks. Moreover, the transport of multitraffic with quality-of-service (QoS) guarantee is a traffic engineering challenge since the deployment of ATM high-speed networks. The recent possibility of bringing the switching function to the optical domain led to new challenges to this research area.

In this paper we study the performance of optical switched networks to support video traffic with scaling or time-dependence characteristics and different QoS requirements. Video traffic has an inherent scaling invariance due to its encoding process. The scaling degree is here defined by the Hurst (H) parameter [1]. The analysis presented in this work concerns two major parts. In the first one, we examined the performance of the *restricted* $M/G/\infty$ [2] and the *non-restricted* fBm (fractional Browmian motion) [3] models to represent the video input processes. The $M/G/\infty$ and fBm performance were compared in terms of the models video traffic heavy-tail distribution (HTD) and autocorrelation function (ACF) characterization. The terms *restricted* or *non-restricted* are related to the models scaling degree range representation and duration. In the second part of the analysis the optical switched network (OSN) based on packet (OPS) (Fig. 1) and burst-edge-switch (OBS) (Fig. 2) architectures performance are evaluated. This means that the OPS and OBS switching/queueing behaviors are studied when fed by the $M/G/\infty$ and the fBm video input processes.

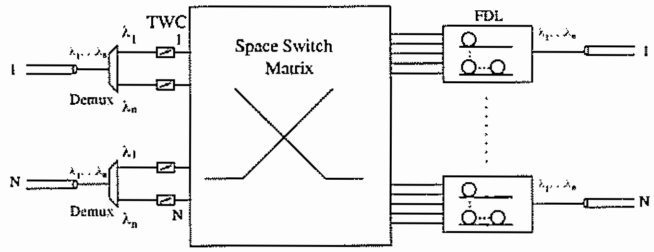


Figure 1. Optical packet switching architecture

Generally, in OPS networks the optical buffers are implemented by fiber delay lines (FDL) (Fig. 1). This OPS optical buffering [4, 5] solution is also complex to manage and control. The commercial optical switches are commonly based on semiconductor optical amplifiers (SOAs) enabling large switching fabrics. In [5] the authors present an interesting tutorial on optical switching architectures. For the OBS archi-

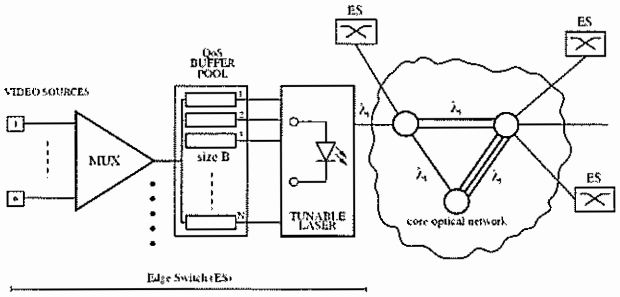


Figure 2. A generic Edge-Route OBS network architecture

tecture we consider the frame-to-burst (FTB) assembly function proposed in [6] to deal with video traffic. The performance results for the OBS and OPS architectures are presented in terms of packet loss ratio (PLR), jitter or packet delay variation, number of multiplexed sources and the impact of the scaling degree on optical switches. For the OBS we also discuss the edge delay introduced by the frame-to-burst assembly function.

The performance of OBS has been widely studied for Internet Protocol (IP) data burst traffic. These studies are basically centered on the packet-to-burst assembly function [7, 8, 9, 10] or wavelength reservation protocol [11]. We demonstrate that the video traffic distribution is a critical point to the optical switches performance and fabric design. We also show that the video scaling were not affected by the large buffer sizes and different edge delay. For the experiments we use several video sequences from different encoding processes. The results derived from this study lead to the optical buffer switch and link rate dimensioning considering different video QoS requirements and for OPS and OBS networks.

The reminder of the paper is organized as follows. In Section 2 we present the optical switched network architectures examined in this work. Section 3 describes the $M/G/\infty$ and fBm processes that are evaluated to model the video traffic sources. Section 4 presents the $M/G/\infty$ and fBm performance results. The burst and packet switches performance analysis and optical link dimensioning results are present and discussed in Sections 5 and 6. Finally, Section 7 is devoted to the conclusion of this work.

2. THE OPTICAL SWITCHED NETWORK ARCHITECTURES

Several circuit, packet [12, 13, 14, 15] and burst [16, 17, 11] switching techniques were studied to achieve the best optical switching architecture for WDM (wavelength division multiplexing) networks. In the optical domain a *circuit* corresponds to a lightpath that consists of dedicated wavelength channels providing a source-destination optical communication. This circuit switching also denoted as wavelength or lightpath switching provides guaranteed QoS in terms of information loss. However, optical circuit switching show the same drawbacks, e.g., bandwidth wasting, faced by the electronic networks. Besides, it is not suitable for the transmission of variable-bit-rate traffic.

Packet switching was expected to present the best optical switching architecture. A generic optical packet switching architecture (Fig. 1) is concerned of tunable or fixed wavelength converters (λC), optical buffering carried by fiber delay lines (FDL) and optical gates. The well known KEOPS (KEys of Optical Packet Switching) architecture [12, 5] shown on Fig. 3 was a promising solution to provide packet switching in a transparent full-optical network. In KEOPS the packets are converted to a fixed wavelength and broadcasted to k FDLs. The packets are then selected from one of these FDLs at the switch output in function of the optical link availability.

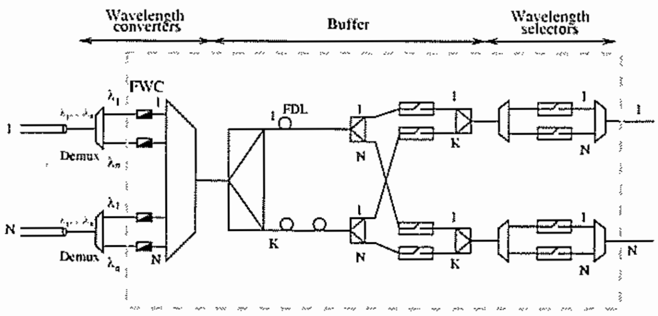


Figure 3. KEOPS switch architecture

The optical burst switching (OBS) [16, 17] was proposed as a solution to avoid the limitations and problems of the other switching possibilities. The electronic burst switching (EBS) also known as fast-circuit switching were widely investigated for ATM networks. Boyer [18] proposed a fast-reservation protocol[1] (FRP) with delayed (FRP-DT) and immediate (FRP-IT) transmission to provide burst data transport with bandwidth release after the burst deliverance. The readers should refer to [19] where the authors present a survey concerning these switching techniques and the application to the optical level.

In an optical switched network with OBS architecture the traffic processing is done at the network edging[2]. The objective is to avoid the same impairments of the optical packet switching fabrics. Thus, the control and data information are treated separately by edge-switch-routers. The edge processing is responsible for the burst-assembly and wavelength reservation functions. This solution remove the complexity from the optical core network. The information-to-burst assembly is indeed a traffic shaping (TS) function. This TS is applied even to original data-burst (ON-OFF) sources to achieve lower optical transmission cost. The wavelength reservation is done during the burst-assembly period in an one or two-way reservation procedure. Several wavelength reservation protocols similar to the FRP approach such as TAG (Tell-and-Go), RFD (Reserve-a-Fixed-Duration) and JET [10] (Just-Enough-Time) were investigated for OBS networks. In [11] the authors proposed a dynamic wavelength reservation for an OBS architecture. They also introduce a wavelength reuse factor (RUF) that enables the unused wavelength to be assigned to another edge-router. In what follows

[1]The ITU FRP is described in the ITU-T I.371 Recommendation *Traffic Control and Congestion Control in B-ISDN*, 1995.

[2]This idea is also based on the MPLS (multiprotocol label switching) optical networks solution [20].

we present a description of the $M/G/\infty$ and fBm models and their performance results to represent video input traffic with scaling characteristics.

The analysis presented in this work is a complete OPS and OBS performance evaluation study including different video input processes, buffer sizes, edge delay, optical link rate and packet loss requirements.

3. THE SCALING VIDEO TRAFFIC MODELING

The main drawback of the traffic engineering researches concerns the lack of accurate source and network traffic models. An accurate traffic model must represent the first and second-order statistics and also be tractable in terms of queueing theory. In our analysis we examined the performance of the $M/G/\infty$ point process and fBm models to represent different input first and second-order video statistics. The fBm and $M/G/\infty$ are considered monofractals since these processes generate sample paths with constant scaling degree. In [21] several measurements showed that the network traffic can present scaling variability after a period of time greater than four hours, i.e., the scaling is only considered as constant or monofractal during an interval less than four hours. In [22] a multifractal version of the fBm process is introduced where H is defined as function of the Hölder regularity ($H = h(t)$; $0 < h(t) < 1$). Multifractal processes can be interesting to model network traffic due to its scaling variability. However, it needs more investigation and accuracy to deal with queueing performance. The optical edge-switch performance is further investigated to support this two input processes.

A stochastic process $X(t)$ can be classified by its scaling degree as positive or long-range dependent (LRD) ($H > \frac{1}{2}$), short-range dependent (SRD) ($H = \frac{1}{2}$) or negative or anti-persistent ($H < \frac{1}{2}$). Some authors[3] denote all processes with $H \leq \frac{1}{2}$ as SRD. In the literature it is possible to find LRD processes defined as self-similar. However, a process can only be considered self-similar if its statistical characteristics, i.e., marginal distribution and scaling degree, holds for any time scale.

By definition $M/G/\infty$ represents positive scaling degree for a certain period of time. This restricted time shall be however enough to investigate the impact of the video traffic dependence on the optical switch queueing performance measures. The fBm is here defined as the non-restricted scaling model since it can represent the entire time-dependence range, i.e., $0 < H < 1$. The fBm and $M/G/\infty$ are defined as monofractals since they generate sample paths with constant scaling degree. For the analysis, we examined several video traces with different monofractal scaling degrees.

3.1 $M/G/\infty$

The $M/G/\infty$ [2] input or source process is represented by an infinite server with G distribution service time ($P[Z > t]$) fed by a Poisson process with λ mean arrival rate, i.e., the input process is defined by λ and the G distribution. Hence, we have that

$$P[Z > t] = \frac{\gamma(t) - \gamma(t+1)}{1 - \gamma(1)}, \qquad t = 0, 1, ...$$

where $\gamma(t)$ is the autocorrelation function of the $Z(t)$ process. The $M/G/\infty$ autocorrelation is defined by $\Gamma(t) = \delta^2\gamma_H(t), h = 0, 1, ...$ where $H = 1 - \beta/2$ and $\beta(0 < \beta < 1)$ and δ^2 are constants.

To achieve the positive scaling representation the $M/G/\infty$ input process ($Z_H(t)$) must have a decreasing and integer-convex ACF ($\gamma_H(t)$) with $\gamma_H(0) = 1$. Therefore,

$$\gamma_H(t) \sim H(2H-1)t^{2H-2}, \quad t \to \infty \tag{1}$$

To find the G service time distribution and considering the previous ACF definition we must have

$$P[Z_H > z] = \frac{|z+2|^{2H} - 3|z+1|^{2H} + 3|z|^{2H} - |z-1|^{2H}}{4(1-2^{2H-2})}, \tag{2}$$

for $z = 1, 2, ...$.

The $M/G/\infty$ also considers that the video traces ACF ($\rho(k)$) is

$$\rho(k) = e^{-\beta\sqrt{k}}, \quad k = 0, 1, 2, ... \ . \tag{3}$$

The β parameter is obtained from the real video traces. The G distribution is then related to video trace ACF by the expression

$$P[Z = k] = \frac{\rho(k-1) - 2\rho(k) + \rho(k+1)}{1 - \rho(1)} \tag{4}$$

Finally, the $M/G/\infty$ samples are generated by a Poisson to hybrid Gamma (F_G)/Pareto(F_P) distribution transformation (F_{PGP}) to keep the ACF (cf. Eq. 3) obtained from the video traces, i.e., for some $x^* > 0$ $F_{PGP} = \begin{cases} F_G(x) & x \leq x^* \\ F_P(x) & x > x^* \end{cases}$. As previously mentioned, the $M/G/\infty$ model has a restricted scaling representation in terms of its range and duration. Its main advantage concerns its markovian properties and thus leading to tractable queueing analysis.

3.2 FRACTIONAL BROWNIAN MOTION

The fractional Brownian motion (fBm) [3] is a gaussian stochastic process ($X_H(t)$) indexed in $\Re$ with zero mean and continuous sample path (null at origin). The fBm is known as the unique gaussian H-sssi, i.e., self-similar with self-similarity parameter and stationary increments. The variance of the independent increments is proportional to its time interval accordingly to the expression

$$Var[X(t_2) - X(t_1)] \propto |t_2 - t_1|^{2H},$$

for $0 \leq t_1 \leq t_2$. It can be proven [3] that the fBm is a stationary and self-similar process with parameter H, i.e., its

[3] See *J. Beran, Statistics for Long-Memory Processes, Chapman & Hall, 1994, pp. 53.*

statistical characteristics holds for any time scale. Thus, for any τ and $r > 0$, we have

$$[X_H(t+\tau) - X_H(t)]_{\tau\leq 0} \stackrel{d}{\approx} r^{-H}[X_H(t+r\tau) - X_H(t)]_{\tau\leq 0}$$

where r is the process scaling factor. Since $X_H(t)$ is gaussian, it is completely characterized by its mean (null) and its ACF which is given by

$$\rho(k) = \frac{1}{2}\sigma^2[(k+1)^{2H} - 2k^{2H} + (k-1)^{2H}]. \quad (5)$$

Norros [23] proposed a discretization procedure that enables a fBm model to generate an input process ($A(t)$) with scaling characteristics and non-zero mean and a variance. Denoting $A(t)$ as the number of received packets by a multiplexer up to time t, we have

$$A(t) = mt + \sqrt{am}X_H(t), \quad (6)$$

where m is the mean rate of the arrival process and $a = Var[A(t)]/(mt)^{2H}$ is a variance coefficient.

For the simulation experiments the fBm sample paths were generated by the simple and well known *Random Midpoint Displacement* [24] algorithm. The fBm samples generation depends only on m, σ and H parameters. However, the G distribution fitting procedure of the $M/G/\infty$ model presented in section 3.1 leads to a complex sample generation.

4. THE VIDEO TRAFFIC PERFORMANCE MODELING RESULTS

This section presents the $M/G/\infty$ and fBm performance to represent the scaling, heavy-tail distribution and autocorrelation of a video input process. The optical switched network performance are further evaluated under these stochastic processes. Four encoded video sequences [25] *StarWars* (JPEG), *Silence of the Lambs (Silence)* (H.263), *Mr. Bean* (MPEG-4) and *Race* (MPEG-1) were considered in the experiments. The video traces parameters such as sample-rate (sr), mean (m) and standard-deviation (σ) are shown on Table 1.

Sequence	m (kbits/s)	σ (kbits/s)
StarWars (JPEG)	5335.8	1200.8
Silence (H.263)	891.6	344.09
Bean (MPEG-4)	183.92	179.0
Race (MPEG-1)	1804.8	537.79

Table 1. Video sequences parameters ($sr = 25$ (frames/s)).

4.1 THE SCALING REPRESENTATION AND ACF RESULTS

For the scaling representation evaluation we use the Hurst Estimator Package (HEP)[4] that consists of different estimation methods. In this work, the scaling results were obtained from the AV-Wavelet [26] estimator since it presented low complexity due to its faster estimation algorithms. Several Hurst estimation results concerning video traffic scaling are presented in [27].

Table 2 illustrates the estimated Hurst ($\hat{H}$) parameters obtained from the real video traces. The video sequences scaling degree were also estimated after the edge-buffering and the results are shown in section 5.1. As we note all the video sequences have LRD characteristics. We chose these LRD sequences in order to examine the optical edge-switch under worst traffic conditions. Moreover, by definition the $M/G/\infty$ model can only represent positive scaling. Sources with $H \leq 1/2$, presenting the anti–persistence effect [28] [29], are strongly centered around its mean rate and thus we expect better queueing performance compared to LRD sources.

Sequence	$\hat{H}(AV)$
StarWars (JPEG)	0.889
Silence (H.263)	0.820
Bean (MPEG-4)	0.822
Race (MPEG-1)	0.878

Table 2. Video Sequences Scaling.

The *Race* and *Bean* MPEG sequences were smoothed within a Group-of-Pictures (GoP) level to fit the monotone decreasing and integer-convex ACF as defined in Eq. 3. This smoothing procedure is particularly important for the $M/G/\infty$ model since the G distribution is obtained from the video trace ACF defined as $\rho(k) = e^{-\beta\sqrt{k}}$. Tables 3 and 4 show the parameters now estimated from the samples generated by the $M/G/\infty$ and the fBm processes. Note that the models σ changings led to a slight difference on the $\hat{H}$ results.

Sequence	m (kbits/s)	σ (kbits/s)	$\hat{H}(AV)$
$Star\ Wars_{M/G/\infty}$	5508.4	1261.7	0.892
$Silence_{M/G/\infty}$	951.8	298.66	0.812
$Bean^{GoP}_{M/G/\infty}$	211.67	120.30	0.840
$Race^{GoP}_{M/G/\infty}$	1890.3	308.54	0.822

Table 3. $M/G/\infty$ estimated parameters.

Fig. 4 illustrates the ACF curves obtained from the original video traces and for the $M/G/\infty$ and fBm models.

The $M/G/\infty$ presented better ACF fitting results compared to the fBm for the video sequences with subexponential ACF (e.g. *StarWars*). However, this was not the case for the *Race* sequence. The best ACF fitting considering both models was achieved for the *Silence* (Fig 4.b) sequence.

Sequence	m (kbits/s)	σ (kbits/s)	$\hat{H}(AV)$
$Star\ Wars_{fBm}$	5426.6	1192.1	0.889
$Silence_{fBm}$	896.8	340.59	0.837
$Bean^{GoP}_{fBm}$	235.5	87.734	0.882
$Race^{GoP}_{fBm}$	1808.2	303.18	0.852

Table 4. fBm estimated parameters.

[4]The HEP contains the AV-Wavelet, R/S, Higuchi and Variance Hurst estimation methods. To obtain this package send an e-mail to coelho@ime.eb.br

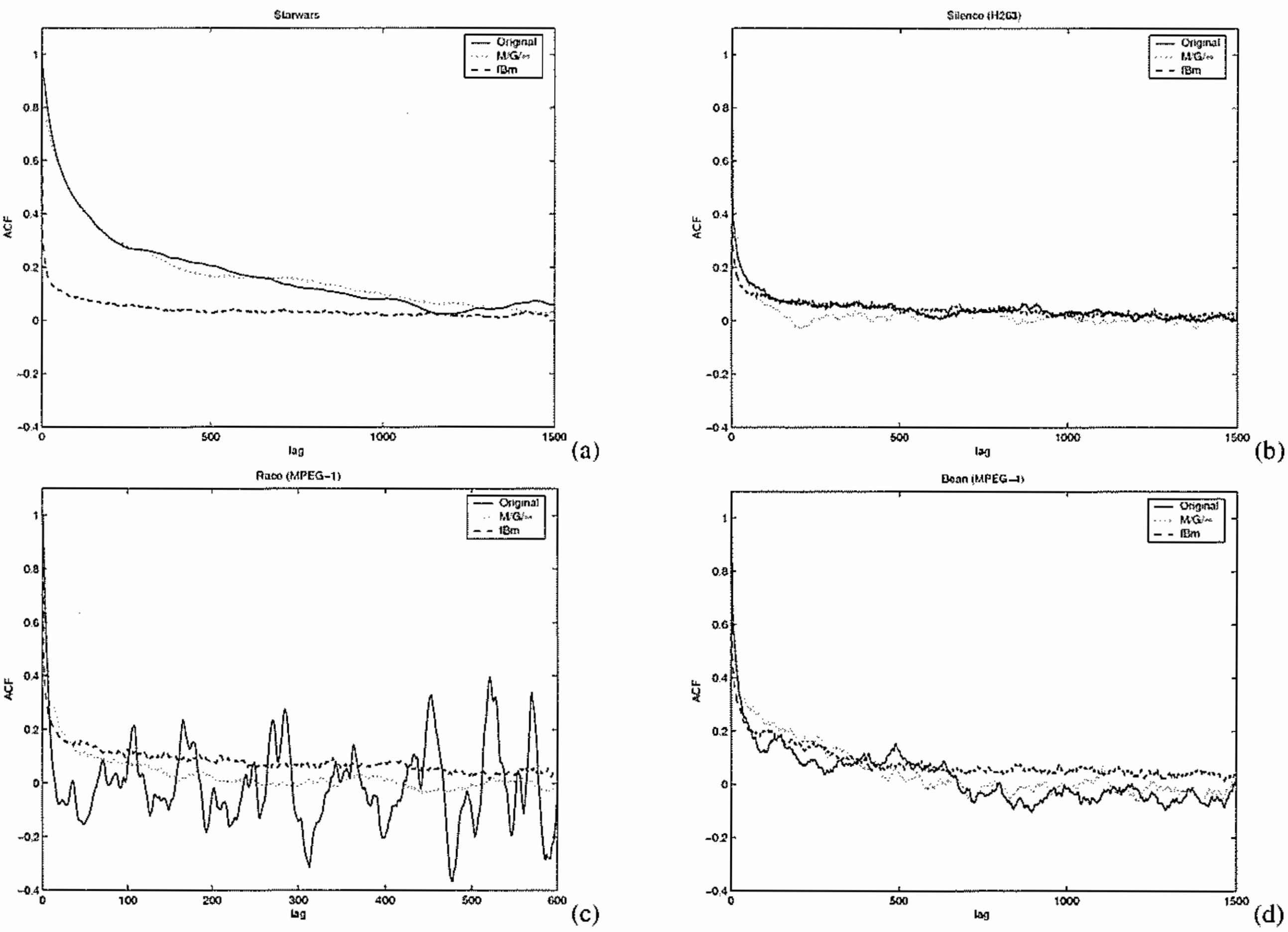


Figure 4. ACF for (a) *StarWars*, (b) *Silence*, (c) *Race* and (d) *Bean* Sequences.

4.2 HEAVY-TAIL DISTRIBUTION RESULTS

By definition we say that a random variable X has a heavy-tail distribution if

$$P(X > x) \cong cx^{-\alpha}, \qquad x \to \infty.$$

where $0 < \alpha < 2$ is the shape parameter and c is a positive constant [30]. The Pareto distribution is an important HTD since it well fits the heavy-tail distribution of the LRD processes. Note that the $M/G/\infty$ model uses the Poisson to Gamma/Pareto transformation (F_{PGP}) to fit the real video sequences ACF and HTD. The HTD results for the original video sequences and the models are depicted in Fig. 5.

The $M/G/\infty$ and fBm tail distributions were very close for the *Race* (cf. Fig. 5.c) sequence. For the *Bean* sequence however the fBm HTD were quite different from original video trace. In [31] we find a detailed analysis of the $M/G/\infty$ and fBm considering the complete scaling range representation. The OPS and OBS switching/queueing behavior is following evaluated when fed by the $M/G/\infty$ and the fBm video input processes. We also examined the impact of the scaling, ACF and HTD on optical switching.

5. THE OBS EDGE-SWITCH PERFORMANCE ANALYSIS AND OPTICAL LINK DIMENSIONING

For the OBS analysis we use the optical edge-switch frame-to-burst (FTB) assembly function [6] in which the encoded bits of a video frames are gathered to complete a burst. The assembly function also keeps the video delay QoS requirements. For the QoS buffer-pool queues dimensioning we considered different burst sizes (B), optical link rates (C) and edge-burst-processing delay (t_{ebp}).

Table 5 illustrates the t_{ebp} values as function of the different optical burst sizes and link rates. The switch queueing behavior fed by the $M/G/\infty$ and fBm video processes are then evaluated considering these parameters.

Burst size (B) in bits	C =10Gbits/s	C =2.5Gbits/s
2.12M	212 μs	848 μs
4.24M	424 μs	1.696 ms
42M	4.24 ms	16.8 ms
424M	42.4 ms	169.6 ms

Table 5. Edge-burst-processing delay.

The queueing behavior and the respective QoS are here represented by the maximum number of multiplexed video sources ($nmax_{OBS}$), the packet loss ratio (PLR) and the edge-processing delay. Simulations were run considering the $M/G/\infty$ and fBm processes and were compared to theoretical results.

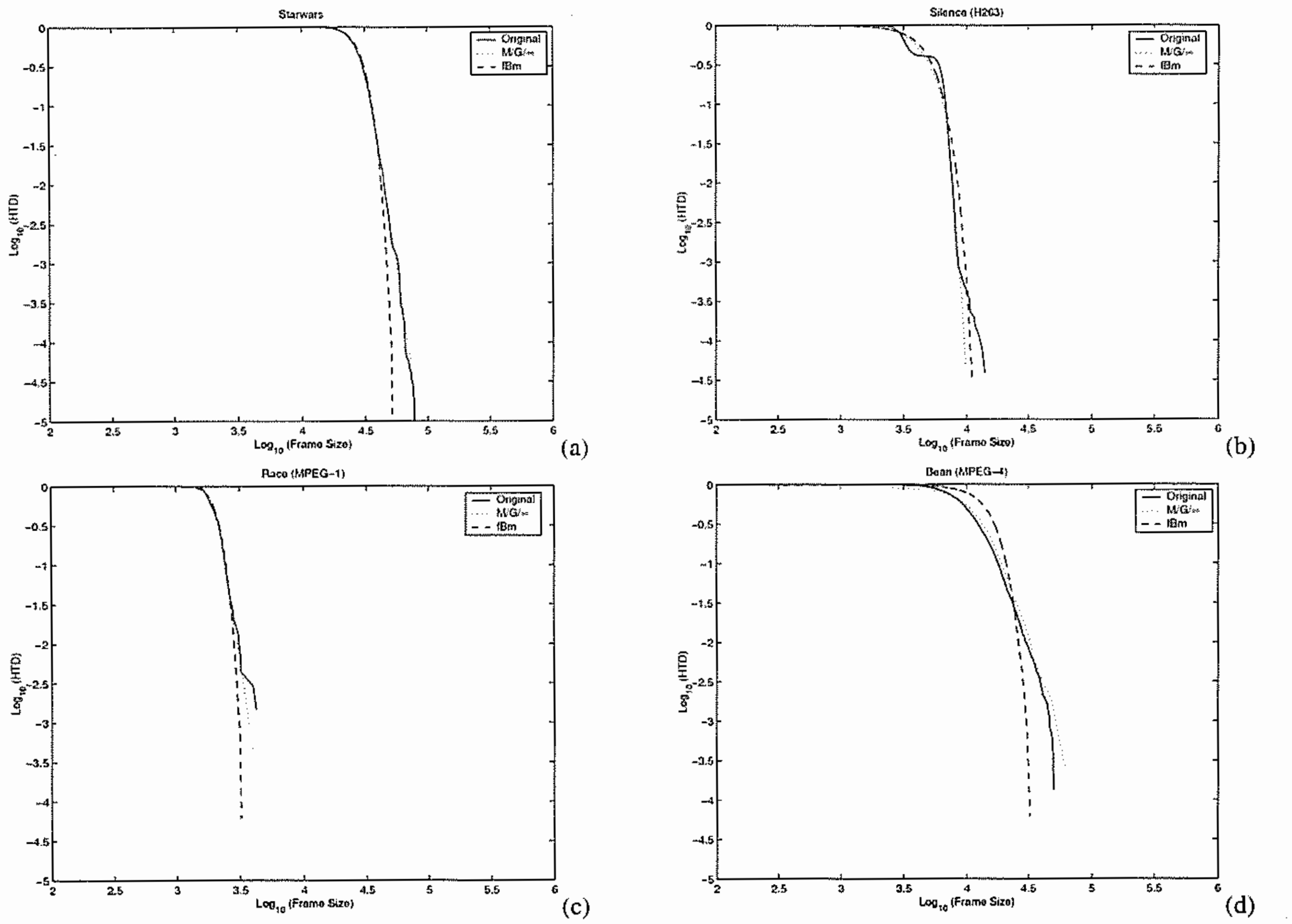


Figure 5. HTD for (a) *StarWars*, (b) *Silence*, (c) *Race* and (d) *Bean* sequences.

5.1 EDGE-SWITCH BUFFER AND LINK DIMENSIONING

Consider $A(t)$ as a fBm process, defined in Eq. 6 with parameters m, a and H; a queue system with deterministic service C (optical link rate) and an infinite buffer queue Q. The buffer queue behavior is thus a stochastic process $Q(t)$ defined as

$$Q(t) = \sup_{s \le t}(A(t) - A(s) - (t-s)C),\ t \in (-\infty, \infty). \quad (7)$$

If $\epsilon = P(Q > B)$ is the probability that a buffer of size Q becomes larger than a certain limit B, it follows that the required optical link bandwidth of an aggregate flow of n video flows $C_A(n)$ is

$$C_A(n) = nm + (\kappa(H)\sqrt{-2\ln\epsilon})^{\frac{1}{2H}} B^{\frac{H-1}{H}} (nma)^{\frac{1}{2H}}, \quad (8)$$

where $\kappa(H) = H^H(1-H)^{1-H}$. Thus, the maximum number of video connections ($nmax_{OBS}$) that can be multiplexed in an optical link with capacity C considering an edge-switch queueing buffer size (B) is determine by

$$n_{max}m + (\kappa(H)\sqrt{-2\ln\epsilon})^{\frac{1}{2H}} B^{\frac{H-1}{H}} (n_{max}ma)^{\frac{1}{2H}} \le C. \quad (9)$$

For a detailed description of these definitions and formulations the reader should refer to [32] and [23].

The scaling estimation results examined after the FTB assembly are shown on Table 6 considering fBm video sources. As expected, the H values did not present significant changings even for larger buffer sizes ($B = 424Mbits$), i.e., the scaling degree is not affected by the OBS assembly function. This similar behavior were found in ATM networks performance studies [33]. Other H degrees values ($H \le \frac{1}{2}$) may present different burst size distributions [34] and so needs further investigation.

Sequence	2.12Mbits	4.24Mbits	42Mbits	424Mbits
$StarWars_{fBm}$	0.896	0.898	0.892	0.892
$Silence_{fBm}$	0.822	0.813	0.822	0.812
$Bean_{fBm}$	0.844	0.853	0.845	0.848
$Race_{fBm}$	0.862	0.860	0.860	0.862

Table 6. Video Sequences Scaling ($\hat{H}(AV)$) for different Edge-buffer sizes (B).

The edge-switch simulation results for both models were compared to the theoretical values obtained from the equations presented in section 5.1. For these experiments we considered the parameters setting illustrated in Table 5. The video information loss is represented by $PLR = 10^{-x} \approx P(Q > B)$ where $x = 3, 2, 1$ only to reduce the simulation run-time. The results demonstrate that neither the scaling degree nor the buffer sizes impacted the PLR and tbe number of multiplexed video sources.

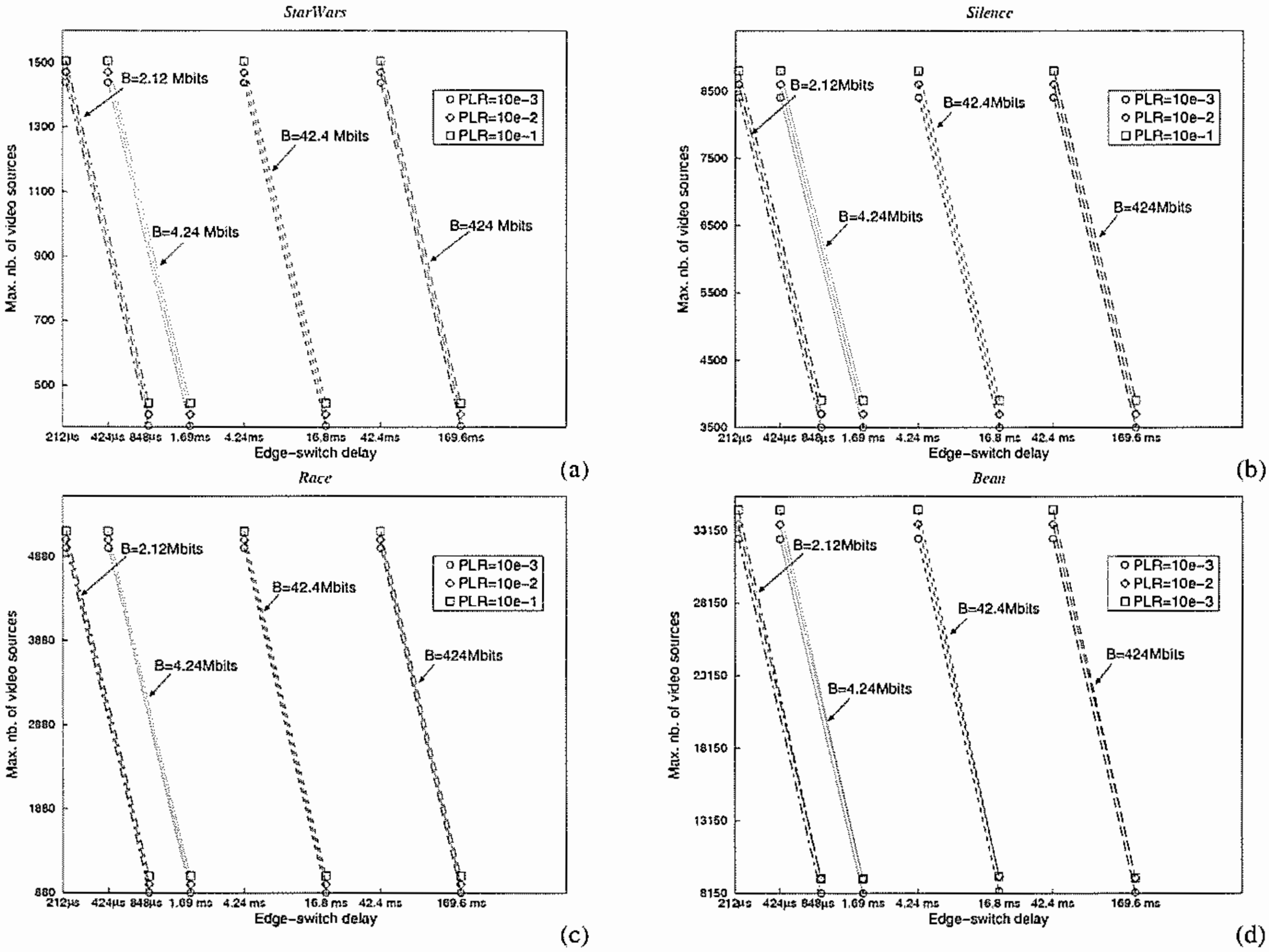


Figure 6. The Edge-Switch Performance Results-$M/G/\infty$ (a) *StarWars*, (b) *Silence*, (c) *Race* and (d) *Bean* sequences.

6. THE OPTICAL PACKET SWITCHING PERFORMANCE

In OBS networks these packet losses are due to the frame-to-burst assembly but the information is not necessarily lost since the data can be sent to one of the N queues present in the QoS buffer-pool. The edge-switch performance curves for the $M/G/\infty$ and fBm input processes are reported on Figs. 6 and 7 respectively. As expected the simulation results considering the fBm model were equal to the values obtained from the buffer-dimensioning equations described in section 5.1.

For the video streams differently from the IP traffic, the buffer-size choice must consider the video sampling rates. In our analysis we consider the frame sampling rate, i.e., we expect to receive a video frame each $42ms$. Thus, considering optical link rates of 10Gbits/s and 2.5Gbits/s the buffer-size must be $\geq 424Mbits$ (see Table 5). Video services delay requirements can range from $800\mu s$ (e.g., 20 Mbits/s HDTV) to 300 ms (e.g., 64 Kbits/s videoconference) [35, 36]. Therefore, to support video traffic with QoS requirements and the buffer pool queue size must be determined as a function of C and the service delay requirements.

Another very important result showed that different from the scaling behavior the video traffic tail distribution strongly affected the edge-switch performance results. Nevertheless, the video distribution is a crucial point to the optical buffer dimensioning in OBS networks.

The optical buffering based on FDLs associated with tunable (TOWC) or fixed wavelength converters (FWC) [13, 4, 12, 5] was the main solution adopted by optical packet switches (Figs 1, 3) to avoid contention. The best OPS fabric architecture is far from being achieved since FDLs and TOWC are very expensive and difficult to implement. Moreover, in the future OPS networks the contention procedures must consider multitraffic and different QoS requirements in terms of information losses, delay and jitter.

For the OPS performance analysis presented in this section we consider an optical network with KEOPS switches (see Fig. 3). The OPS performance results is then compared to OBS. For the OPS analysis we also examined the impact of the FDLs on the packet jitter, PLR and the number of multiplexed ($nmax_{OPS}$) video streams. We considered an OPS (N x N) simple queueing model operating in a synchronous or fixed packet size mode, k FDLs, optical link rate (C), n wavelengths and without wavelength conversion. The video packets of different connections are multiplexed within a wavelength.

Figures 8, 9 and 10 show the PLR versus the number of FDLs results for the $StarWars$, $Silence$ and $Race$ sequences respectively also represented by the $M/G/\infty$ and fBm stochastic models. Each FDLs has a 33.92m size that is

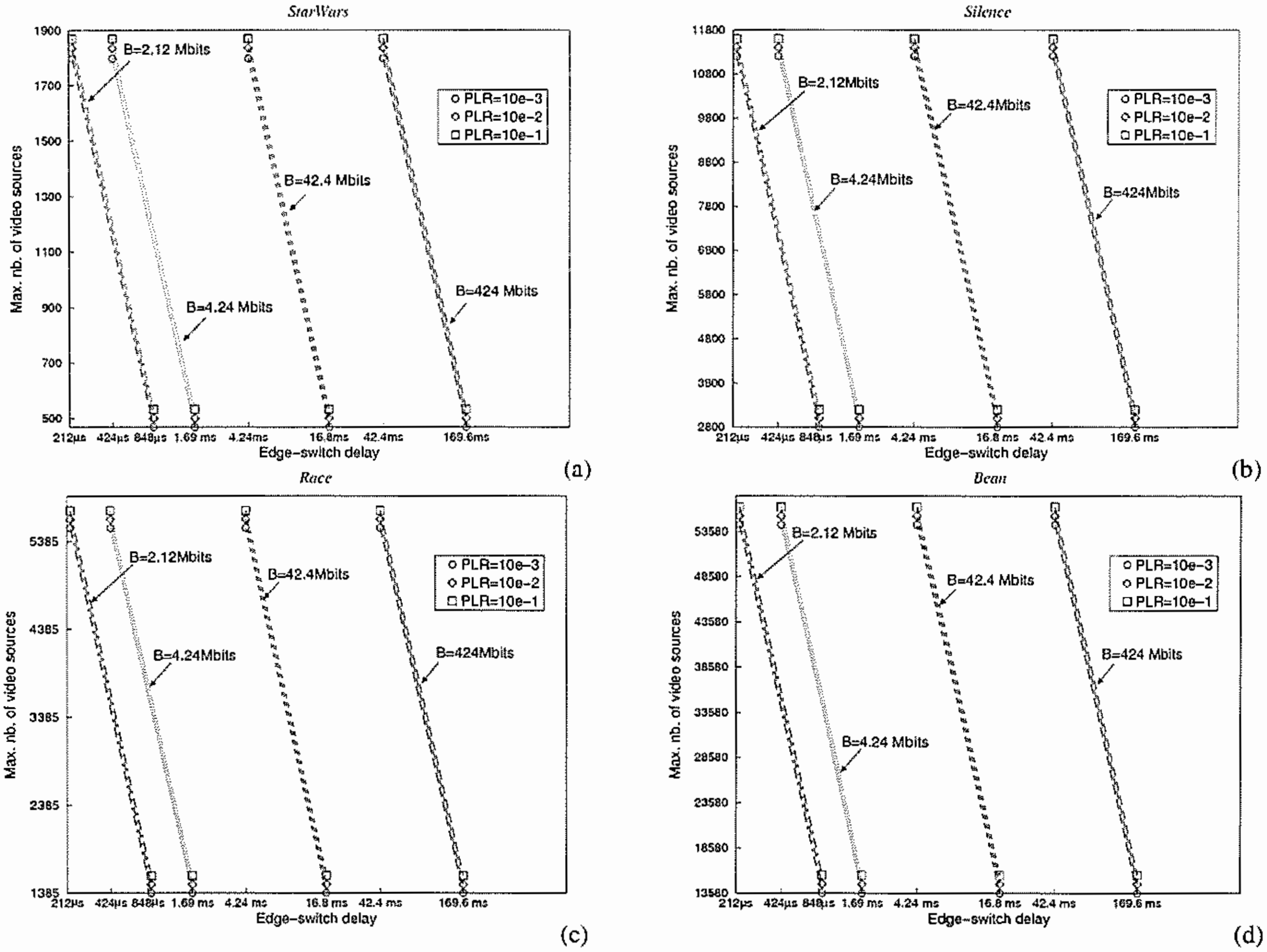


Figure 7. The Edge-Switch Performance Results-*fBm* (a) *StarWars*, (b) *Silence*, (c) *Race* and (d) *Bean* sequences.

equivalent to a 17 μs delay.[5]

The OPS achieved a lower number of multiplexed sources ($nmax_{OPS}$) when compared to the OBS values for all video sequences. For example, for the $StarWars_{Theo/fBm}$ (PLR 10^{-4}, $C = 2.5Gbps$) the OBS number of multiplexed sources was 447 while for the same PLR value the OPS achieved only of 280 sources using 25 FDLs. For $Silence_{Theo/fBm}$ we obtained $nmax_{OBS} = 2803$ while we have $nmax_{OPS} = 2010$ also for 25 FDLs. To achieve similar performance results, i.e., $nmax_{OPS} = nmax_{OBS}$, for a fixed PLR the OPS fabric should use 150, 200 and 130 FDLs for the $StarWars$, $Silence$ and $Race$ fBm sequences respectively. The KEOPS fixed wavelength converters were adopted to reduce the number of FDLs in the switch fabric. Besides, it shall reduce the jitter effects introduced by FDLs while keeping the video traffic QoS requirements. The number of wavelength converters is an important issue for a further study. In [37] the authors propose two techniques to share the wavelength converters in switch fabrics saving 40% of these converters.

Tables 7 and 8 present the minimum (m_{jitter}), average (A_{jitter}) and maximum (M_{jitter}) jitter[6] and scaling degree results fixing the numbers of FDLs as 25 and 50 respectively.

$Sequence$	$nmax_{ops}$	m_{jitter^s}	A_{jitter^s}	M_{jitter^s}	$\hat{H}(AV)$
$StarWars_{Theo/fBm}$	335	-3.7×10^{-6}	-3.2×10^{-10}	3.7×10^{-6}	0.881
$Silence_{Theo/fBm}$	2010	-3.7×10^{-6}	-3.4×10^{-9}	3.6×10^{-6}	0.833
$Race_{Theo/fBm}$	1005	-4.0×10^{-6}	-1.7×10^{-9}	4.0×10^{-6}	0.883
$StarWars_{M/G/\infty}$	280	-3.9×10^{-6}	-2.7×10^{-10}	3.7×10^{-6}	0.891
$Silence_{M/G/\infty}$	1500	-4.0×10^{-6}	-3.6×10^{-9}	3.9×10^{-6}	0.844
$Race_{M/G/\infty}$	740	-3.9×10^{-6}	5.7×10^{-10}	3.9×10^{-6}	0.875

Table 7. Results fBm and $M/G/\infty$ for 25 FDLs and PLR 10^{-4}.

$Sequence$	$nmax_{OPS}$	m_{jitter^s}	A_{jitter^s}	M_{jitter^s}	$\hat{H}(AV)$
$StarWars_{Theo/fBm}$	415	-7.6×10^{-6}	-6.5×10^{-10}	7.8×10^{-6}	0.820
$Silence_{Theo/fBm}$	2500	-7.4×10^{-6}	2.6×10^{-8}	7.9×10^{-6}	0.852
$Race_{Theo/fBm}$	1250	-7.4×10^{-6}	-3.1×10^{-9}	8.3×10^{-6}	0.851
$StarWars_{M/G/\infty}$	340	-8.3×10^{-6}	3.1×10^{-10}	8.3×10^{-6}	0.877
$Silence_{M/G/\infty}$	1800	-7.2×10^{-6}	1.0×10^{-10}	7.1×10^{-6}	0.828
$Race_{M/G/\infty}$	849	-8.1×10^{-6}	-1.5×10^{-9}	8.1×10^{-6}	0.869

Table 8. Results fBm and $M/G/\infty$ for 50 FDLs and PLR 10^{-4}.

Since, the jitter requirement of the more demanding video source is 1 ms (e.g., HDTV video services [35, 36]) these FDLs sizes can be considered interesting to guarantee the

[5]The propagation delay in an optical fiber cable is 5 $\mu s/km$.

[6]The negative jitter values mean that the switch output time between packets is less that the time arrival between packets. This is due to the high-speed of the optical links.

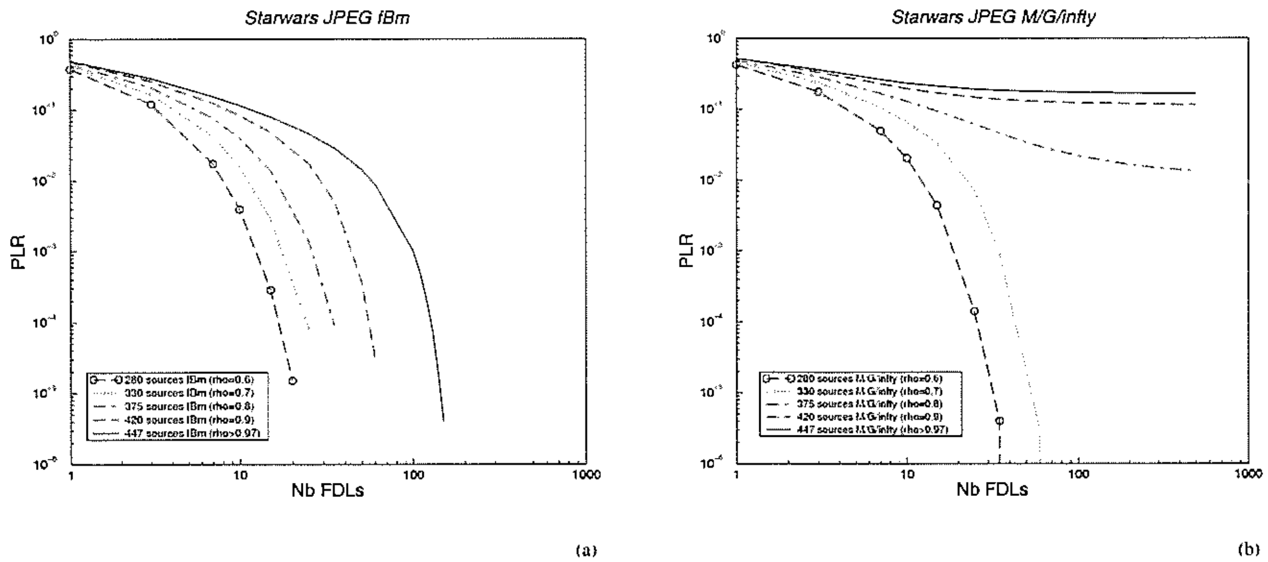


Figure 8. PLR X FDLs *StarWars* Sequence (a)fBm (b)$M/G/\infty$.

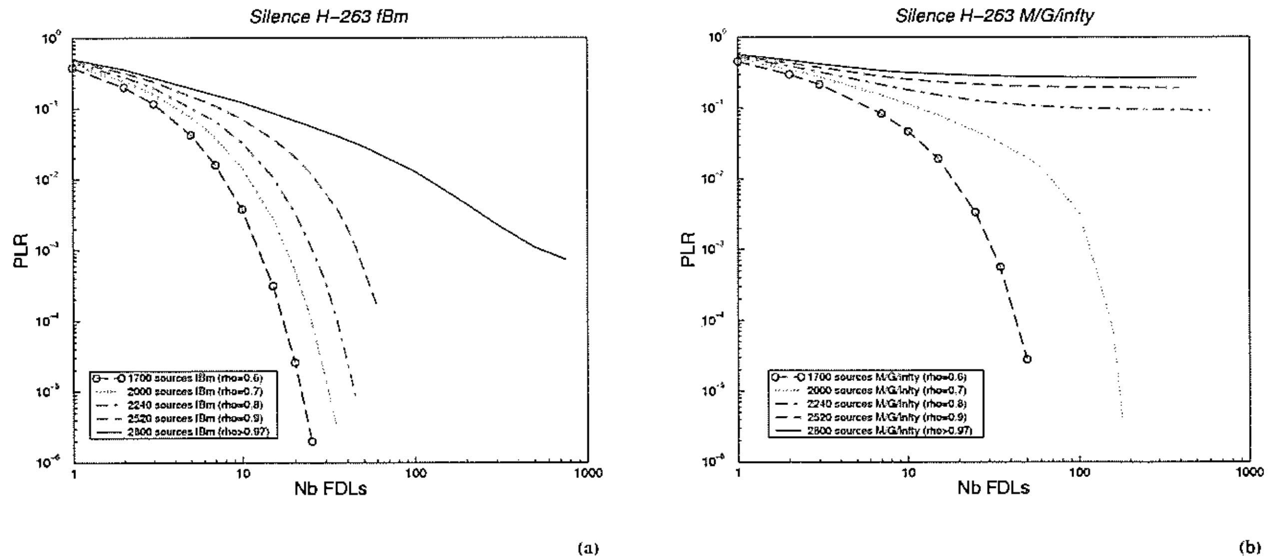


Figure 9. PLR X FDLs *Silence* Sequence (a)fBm (b)$M/G/\infty$.

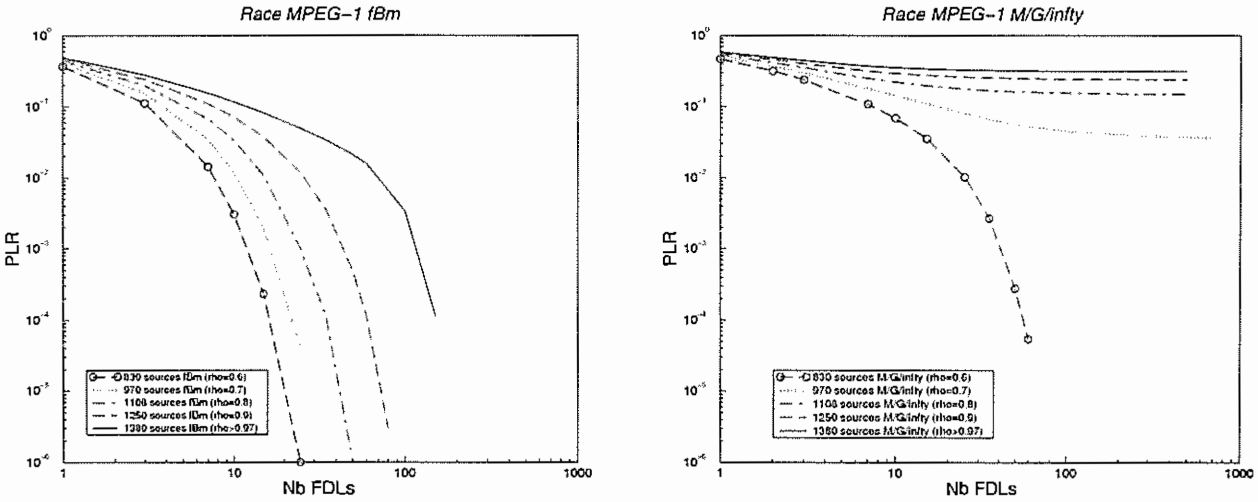
video services jitter needs in a OPS network. We also note from Tables 7 and 8 that as in OBS, the video scaling was not affected by the optical buffers even for different FDLs sizes. Moreover, we see that the major impact on OPS performance is due to the video streams distribution, e.g., for 50 FDLs, we have for the $Silence$ sequence $nmax_{OPS}$ = 2500 and 1800 for the fBm and $M/G/\infty$ respectively. This same aspect was also observed for the OBS architecture reinforcing that the traffic distribution will be responsible for the major impact on optical switches performance. Hence, traffic characterization must be take into account by the optical switches architectures design. This is also an important aspect to guarantee the services QoS requirements of the future optical networks.

7. CONCLUSION

In this paper we studied the performance of packet and burst optical switched networks to support video traffic with scaling characteristics and different QoS requirements. The $M/G/\infty$ and fBm stochastic processes were evaluated in terms of their performance to represent the video traffic scaling, heavy-tail distribution and autocorrelation.

We saw that the main drawback of optical switches is related to optical buffers. This is still a great challenge for the optical devices researches. The OBS is an alternative to the OPS optical buffering.

The results reported from the analysis demonstrate that the video traffic distribution can strongly influence the packet and burst switches buffers and link dimensioning and thus the optical network performance. We saw that the performance results were not affected by the scaling degree even for large burst edge-buffer and packet FDLs sizes. We believe that the detailed analysis presented and discussed in this paper will contribute to the design of the future optical switches to deal with video traffic and also guarantee its QoS requirements.



(a) (b)

Figure 10. PLR X FDLs *Race* Sequence (a)fBm (b)$M/G/\infty$.

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REFERENCES

[1] E. Hurst, "Long–term storage capacity of reservoirs," *American Society of Civil Engineers Trans.*, pp. 770–799, April 1951.

[2] M. Krunz and A. Makowski, "Modeling video traffic using m/g/∞ input processes: A compromise between markovian and lrd models," *IEEE J. Select. Areas Commun.*, vol. 16, pp. 733–748, June 1998.

[3] B. Mandelbrot and J. Van Ness, "Fractional brownian motions, fractional noises and applications," *SIAM Review*, vol. 10, pp. 422–437, October 1968.

[4] D. Hunter, M. Chia, and I. Andonovic, "Buffering in optical packet switches," *IEEE Journal of Lightwave Technology*, vol. 16, pp. 2081–2094, December 1998.

[5] G. Papadimitriou, C. Papazoglu, and A. Pomportsis, "Optical switching: Switch fabrics, techniques and architectures," *IEEE Journal of Lightwave Tecnology*, vol. 21, pp. 384–405, February 2003.

[6] E. Santos Jr. and R. F. Coelho, "Optical buffer and link dimensioning to support video traffic with scaling characteristics," *To appear in the Anais do XX Simpósio Brasileiro de Telecomunicações (SBT'03)*.

[7] K. Dolzer and C. Gauger, "On burst assembly in optical burst switching networks-a performance evaluation of just-enough-time," *Proceedings of the 17th International Teletraffic Congress*, pp. 149–160, December 2001.

[8] E. Sirén and E. Hyytiä, "Delay line configurations in optical burst switching with jet protocol," Tech. Rep. TD(02)24, COST279, May 2002.

[9] M. Yoo, C. Qiao, and S. Dixit, "Qos performance in ip over wdm networks," *IEEE J. Select. Areas Commun.*, vol. 18, pp. 2062–2071, October 2000.

[10] M. Yoo and C. Qiao, "Just-enough-time (jet): A high speed protocol for bursty traffic in optical networks," *Proceedings of the IEEE/LEOS Technologies for Global Information Infrastructure*, pp. 26–27, August 1997.

[11] M. Düser and P. Bayvel, "Analysis of a dynamically wavelength-routed optical burst switched network architecture," *Journal of Lightwave Technology*, vol. 20, pp. 574–585, April 2002.

[12] C. Guillemot et al, "Transparent optical packet switching: The european acts keops project approach," *Journal of Lightwave Technology*, vol. 16, pp. 2117–2132, December 1998.

[13] S. Danielsen et al, "Wavelength conversion in optical packet switching," *Journal of Lightwave Technology*, vol. 16, pp. 2095–2108, December 1998.

[14] M. Renaud, C. Guillemot, and B. Bostica, "Network and system concepts for optical packet switching," *IEEE Communications Magazine*, pp. 96–102, April 1997.

[15] D. Hunter and I. Andonovic, "Approaches to optical internet packet switching," *IEEE Communications Magazine*, vol. 38, pp. 116–122, September 2000.

[16] J. Turner, "Terabit burst switching," *Journal of High Speed Networks*, vol. 8, no. 1, pp. 3–16, 1999.

[17] C. Qiao et al, "Optical burst switching (obs)-a new paradigm for an optical internet," *Journal of High Speed Networks*, vol. 8, no. 1, pp. 69–84, 1999.

[18] P. Boyer and D. Tranchier, "A reservation principle with aplications to the atm traffic control," *Computer Network and ISDN Systems Journal*, vol. 24, pp. 321–334, 1992.

[19] M. Yoo and C. Qiao, "Choices, features and issues in optical burst switching," *Optical Networks Magazine*, vol. 1, no. 2, pp. 36–44, 2000.

[20] A. Viswanathan et al, "Evolution of multiprotocol label switching," *IEEE Comm. Magazine*, vol. 36, pp. 165–173, May 1998.

[21] M. Roughan and D. Veith, "A study of the daily variation in the self-similarity of real data traffic," *Proceedings of the 16th International Teletraffic Congress*, pp. 67–76, June 1999.

[22] P. Abry et al, "Multiscale nature of network traffic," *IEEE Signal Processing Magazine*, vol. 19, pp. 28–46, May 2002.

[23] I. Norros, "On the use of fractional brownian motion in theory of connectionless networks," *IEEE JSAC*, vol. 13, pp. 953–962, August 1995.

[24] M. Barnsley et al, *The Science of Fractal Images*. USA: Springer-Verlag New York Inc., 1988.

[25] V. S. Traces, "Available at: *StarWars* ftp://ftp.research.telcordia.com/pub/vbr.video.trace/, *silence* and *mr. bean* http://www-tkn.ee.tu-berlin.de/fitzek/trace/ltvt.html, *race* http://nero.informatik.uni-wuerzburg.de/mpeg/traces/,"

[26] M. Roughan, D. Veith, and P. Abry, "Real-time estimation of the parameters of long-range dependence," *IEEE/ACM Transactions on Networking*, vol. 8, pp. 467–478, August 2000.

[27] R. Pontes and R. Coelho, "The scaling characteristics of the video traffic and its impact on acceptance regions," *Proceedings of the 17th International Teletraffic Congress*, vol. 4, pp. 197–210, December 2001.

[28] R. Coelho and L. Decreusefond, "Statistical performance of tv/hdtv traffic over broadband digital networks," *Proceedings of the IEEE GLOBECOM*, November 1998.

[29] Q. Li and D. Mills, "Investigating the scaling behavior, crossover and anti–persistence of internet packet delay dynamics," *Proceedings of the IEEE GLOBECOM*, pp. 1843–1852, November 2000.

[30] A. Law and W. Kelton, *Simulation Modeling and Analysis*. USA: McGraw-Hill Book Company, 1982.

[31] A. Guimarães and R. Coelho, "Performance of video traffic models performance with restricted and non-restricted scaling representation," *Submitted to the Journal of High-Speed Networks*.

[32] F. Kelly, "Notes on effective bandwidths," *Stochastic Networks: Theory and Applications*, vol. 4, no. Oxford University Press, pp. 141–168, 1996.

[33] S. Molnár and A. Vidács, "On modeling and shaping self-similar atm traffic," *Proceedings of the 15th International Teletraffic Congress*, pp. 1409–1420, July 1991.

[34] M. Izal and J. Aracil, "On the influence of self-similarity on optical burst switching traffic," *Proceedings of the IEEE/GLOBECOM*, November 2002.

[35] J. Russell, "Multimedia networking performance requirements," *ATM Networks*, vol. Plenum Pubs. New York, pp. 187–198, 1993.

[36] R. Onvural, *Asynchronous Transfer Mode Networks: Performance Issues*. Artech House, 2nd Edition, 1995.

[37] V. Eramo, M. Listani, and . P. Pacifici, "A comparison study on the number of wavelength converters needed in synchronous and asynchronous all-optical switching architectures," *Journal of Lightwave Technology*, vol. 21, pp. 340–355, February 2003.

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