Hybrid Optical Network with Traffic Classification and Switching Selection Scheme Based on Fuzzy Logic

Ana Carolina de Oliveira da Silva
Post Graduate Program in Electrical Engineering (PPGEE)
University of Brasília
Brasília, Brazil
anacarol.os88@hotmail.com

William Giozza
Communication Networks Group
University of Brasília
Brasília, Brazil
giozza@unb.br

Abstract—**This paper presents a performance evaluation study of an OCS/OBS hybrid optical network using a traffic classification and optical switching selector scheme based on fuzzy logic. The fuzzy logic scheme verifies the statistical parameters of the input traffic and selects the appropriate optical switching paradigm. The hybrid optical network performance is evaluated in terms of block probability and efficiency in the use of the network resources. Our results show that the hybrid optical networking approach, when submitted to non-uniform traffic, uses network resources in a more efficient way compared to an optical network implementing one unique optical switching paradigm.**

Keywords - Hybrid Optical Network; Optical Circuit Switching;Optical Burst Switching; Fuzzy Logic.

I. INTRODUCTION

With the maturity of Wavelength Division Multiplexing (WDM) technology, and the increasing bandwidth demand in telecommunications networking, researchers and engineers have been looking for optical networks solutions that use the maximum capacity offered by fiber optics [1-5].

Moreover, it has been observed that the type of traffic carried by modern telecommunications infrastructures, supporting the integration of services provided by the Internet, differs greatly from old Poisson traffic models. Traffic properties such as long-range dependence and self-similarity are present from local networks to large backbones, preventing the modeling of present traffic behavior by a Poisson process [6-11]. Therefore it seems important to consider traffic self-similarity characteristics - measured by the Hurst parameter - for planning and management of the network [7][12][13].

Optical networks can be classified according to three optical switching paradigms, with different implications in terms of complexity and performance: Optical Circuit Switching (OCS), Optical Burst Switching (OBS) and Optical Packet Switching (OPS) [1]. OCS has a simpler management method and works by establishing light paths ("optical circuits") between source and destination nodes; however, as well known, this switching paradigm is inefficient when subjected to high granularity traffic. OPS is an attractive option since it can transport Internet Protocol (IP) packets directly in the optical network. However, the absence of an equivalent to the Random Access Memory (RAM) in the optical domain and other technological barriers restrain the use of this optical switching paradigm in the implementation of optical networks in the near future. OBS scheme gathers input packets at the source node and sends them to the destination node as an optical burst. Therefore, OBS constitutes a compromise between OPS and OCS paradigms, facilitating the network management and improving the use of the available bandwidth [1][3].

In order to better adapt the characteristics of different types of optical switching to the diversity of the traffic presently carried by major telecommunications infrastructures (network cores or backbones), the concept of hybrid optical network emerged, characterized by a single optical network implementing more than one of the optical switching paradigms. For instance, Gauger et al. [14] proposed a hybrid optical network OCS/OBS, aiming to take advantage of the high-granularity-traffic transport characteristic of OBS networks and the large bandwidth traffic supported by OCS networks.

This work presents a performance study of a hybrid optical network OCS/OBS, where the decision of the appropriate optical switching paradigm to incoming traffic is done on the basis of their statistical parameters using fuzzy logic.

This paper is organized as follows: Section II presents the hybrid optical network topology used, Section III describes the fuzzy classifier used to select the more appropriate optical switching paradigm to an incoming traffic pattern, Section IV presents the performance evaluation study and Section V presents the conclusions.

II. HYBRID NETWORK OBS/OCS

The OCS model adopted in this work uses First Fit as Routing and Wavelength Assignment (RWA) algorithm [2]. The wavelength assignment strategy assumes that network nodes do not perform wavelength conversion.

The OBS model was implemented according to the Just Enough Time (JET) protocol [1], assuming the existence of a parallel network of infinite capacity to the transport of control packets associated to the optical bursts. Therefore, resources are busy end-to-end, simulating the resource reservation, and unoccupied as the optical bursts pass through each link. The validation of the OBS implementation was made by comparison with results presented in Teng and Rouskas [16].

The OCS/OBS hybrid optical network includes a traffic classifier and switching selector module based on fuzzy logic in each edge node. Figure 1 illustrates the OCS/OBS hybrid optical network model used in this work.

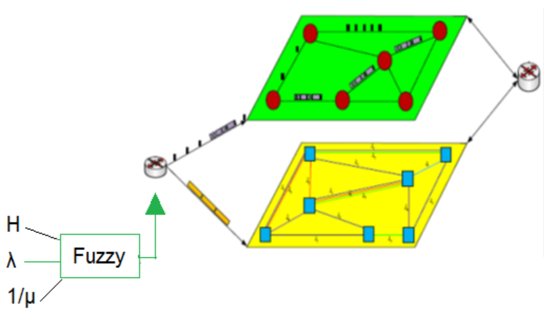

Figure 1. Parallel hybrid optical network with traffic classifier.

The traffic classifier and optical switching selector module works based on statistical parameters of the incoming traffic - packet arrival rate (λ), inter-arrival time (Δt) and Hurst parameter (H) and selects the more appropriate optical switching paradigm (OCS or OBS) to apply to the incoming traffic at each time slot, at each edge node of the parallel hybrid optical network (Figure 1).

III. TRAFFIC CLASSIFIER

Fuzzy logic was chosen to implement the traffic classifier and switching selector (in short, the traffic classifier) because of its robustness in handling imprecise input values and its flexibility to work with traffic characteristics evolution. In general, problems solved by fuzzy logic can be solved by other tools; however, in the case of nonlinear problems, fuzzy logic presents advantages, avoiding the creation of complex mathematical models and requiring only the knowledge of an expert. Once the traffic classifier handles different statistics that cannot be added, it can be considered as a non-linear system.

Fuzzy analysis divides the problem into three steps [17]:

- Fuzzyfication – The input variables are transformed into linguistic values associated with an inference function;
- Inference – The linguistic values are analyzed by an array of rules;
- Defuzzification – Linguistic output of the rules matrix is transformed into a numeric value.

In this work, the membership functions of the inputs and outputs of the traffic classifier were constructed considering the expected network behavior and by analyzing traffic traces available in the literature [6][10][11][18][21]. The fuzzyfication step was performed from the numerical values corresponding to the statistical characteristics of the traffic. The traffic classifier was developed based on the MATLAB fuzzy toolbox.

The input λ corresponding to the arrival rate of packets in the network, illustrated in Figure 2, considers Low arrival rates lower than $4x10^5$ packets/s; Medium rates between $3x10^5$ packets/s and $5x10^5$ packets/s; and High rates superior to $4x10^5$ packets/s.

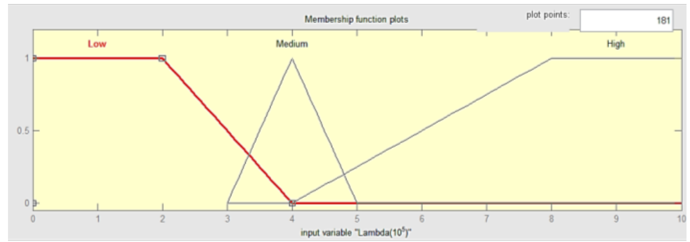

Figure 2. Traffic classifier – input λ.

The input Δt corresponding to the inter-arrival time (Figure 3) considers Low, intervals shorter than 3μs; Medium intervals between 2μs and 4μs; and High intervals longer than 3.5 μs.

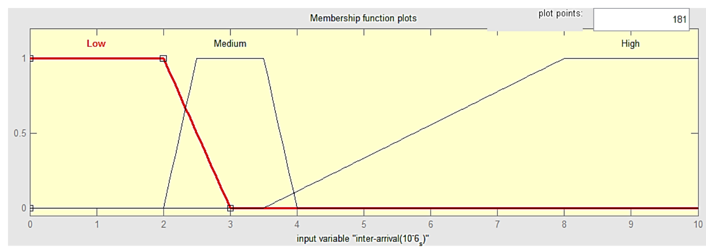

Figure 3. Traffic classifier – input Δt.

The input H corresponding to the Hurst parameter (Figure 4) considers Poisson traffic values lower than 0.55; Hybrid, a trapezoidal function from 0.4 to 0.6; and Self-similar for higher values than 0.55.

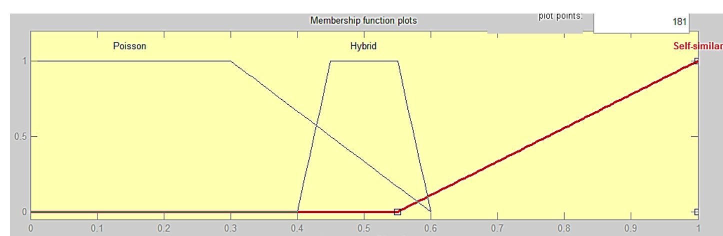

Figure 4. Traffic classifier – input H.

The output of the traffic classifier is adimensional and is on a scale 0-1 as shown in Figure 5. For output values between 0 and 0.7, the incoming traffic is considered appropriate to OBS transport and for values greater than 0.5, the incoming traffic is considered appropriate to OCS transport. These values were selected in a way that the centroid of the resulting area after the defuzzification tends to the right side, implying higher priority to Quality of Service (QoS) than to the economy of resources.

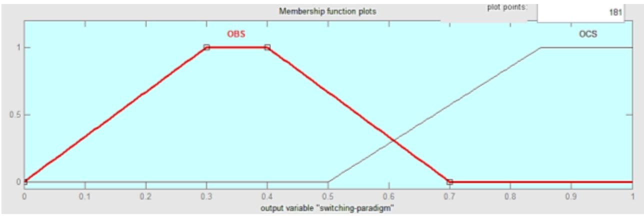

Figure 5. Traffic classifier –output.

The matrix rules (fuzzy inference step) for the traffic classifier is described in Tables 1 to 3.

TABLE I. MATRIX RULES FOR THE CLASSIFIER – ΔT LOW.

Hurst Parameter (H)	Packet Arrival Rate (λ)		
	Low	***Medium***	***High***
Poisson	OBS	OCS	OCS
Hybrid	OCS	OCS	OCS
Self-similar	OBS	OCS	OCS

TABLE II. MATRIX RULES FOR THE CLASSIFIER – ΔT MEDIUM.

Hurst Parameter (H)	Packet Arrival Rate (λ)		
	Low	***Medium***	***High***
Poisson	OBS	OCS	OCS
Hybrid	OBS	OCS	OCS
Self-similar	OBS	OBS	OCS

TABLE III. MATRIX RULES FOR THE CLASSIFIER – ΔT HIGH.

Hurst Parameter (H)	Packet Arrival Rate (λ)		
	Low	***Medium***	***High***
Poisson	OPS	OBS	OCS
Hybrid	OPS	OBS	OBS
Self-similar	OBS	OBS	OCS

The defuzzification process is done using the centroid method [17], which provides as output the center of gravity of the fuzzy set. Figure 6 illustrates a temporal series of Voice over IP (VoIP) traffic used to validate the traffic classifier.

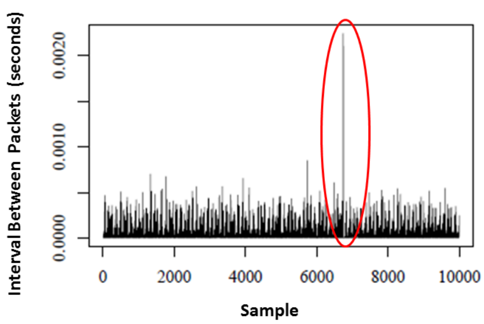

Figure 6. Temporal Serie of a VoIP traffic [11].

The highlighted moment in Figure 6 correspond to an instant which could cause a wrong classification, since it is a high inter-arrival time. However, the use of fuzzy logic to the classification allows considering the statistical parameters together, avoiding a wrong decision, especially in the presence of spurious in the incoming traffic, making the traffic classifier more robust. The traffic classifier output obtained for the input illustrated in Figure 6 was OCS which is consistent, since VoIP is a service which requires high QoS.

IV. PERFORMANCE EVALUATION

The simulation tool used in this work is an extension of the Transparent Optical Network Simulator (TONetS) presented in Soares et al. [15] allowing performance comparison between a parallel hybrid optical network as in Gauger et al. [14] and an optical network OCS under the same traffic conditions. TONetS is an educational simulation tool, developed in JAVA and conceived in blocks to allow its evolution. TONetS, initially developed to work with OCS switching, has been adapted in this work to support OBS switching in a parallel hybrid optical network.

The main gain when using hybrid optical networks is the economy and the optimization of resources while transporting sparse traffic. In order to assess these gains, we define the metric Relative Resource Economy:

$$E_U(\%) = \frac{U_{OCS} - U_{OBS}}{U_{OCS}} \times 100 \quad (1)$$

where U_{OCS} and U_{OBS} are the utilization of the network using OCS and OBS, respectively.

In order to evaluate the performance difference between the OCS and OBS switching paradigms and the hybrid optical network approach proposed, a simple topology with 3 nodes was tested, using the three forms of switching (OBS, OCS and Hybrid). Each simulation considered: 1000 requests, two replications and a confidence level of 0.95. Forty wavelengths by optical fiber link were assigned using the First Fit algorithm and all simulations were performed considering the optical network nodes without wavelength conversion capability.

Using the simple 3-node topology illustrated in Figure 7, the OBS and OCS schemes were evaluated separately and together submitted to an incoming non-uniform traffic handled by the traffic classifier in order to select which one is more appropriate. In the case of the hybrid optical network approach, the Hurst parameter was varied uniformly between 0.3 and 1.0 to ensure the dynamism in the network. In all scenarios analyzed, 40 optical channels were used (i.e., wavelengths) by link subjected to an initial load of 10 Erlangs and 140 Erlangs, with increments of 10 Erlangs, in order to compare performances based on metrics such as Blocking Probability and Utilization.

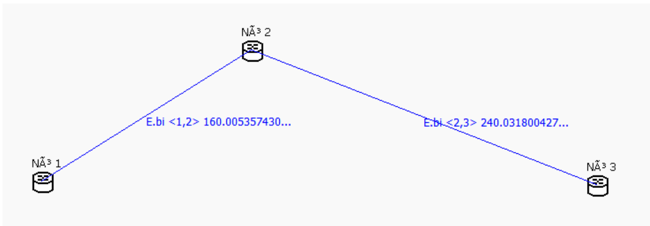

Figure 7. Analysed topology.

As a first scenario studied, an OCS network with the topology illustrated in Figure 7 was submitted to an initial load of 10 Erlangs with five increments of 10 Erlangs. Figure 8 illustrates the overall OCS utilization in this case.

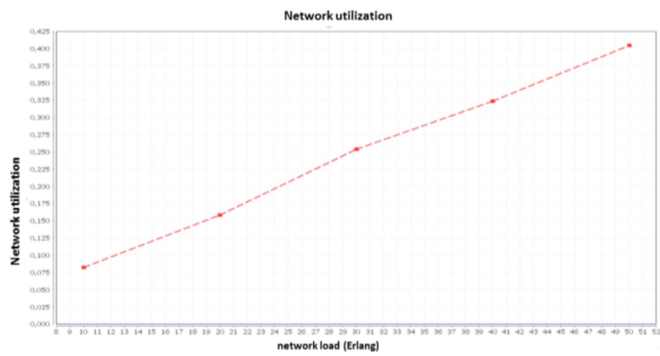

Figure 8. Network utilization with OCS and initial load of 10 Erlangs.

Due to the low load level, a blocking probability almost negligible was observed and a low utilization of the network resources of the OCS network. Similar results were observed with an OBS network and a hybrid OCS/OBS network. However, OBS switching achieved a slightly lower performance, for instance, 0.15% of blocking probability at 50 Erlangs.

As a second scenario studied, the same OCS network previously presented (Figure 7) was subjected to an initial load of 140 Erlangs with five increments of 10 Erlangs. Figures 9 to 11 illustrate the general network utilization, the blocking probability, and wavelength utilization, respectively.

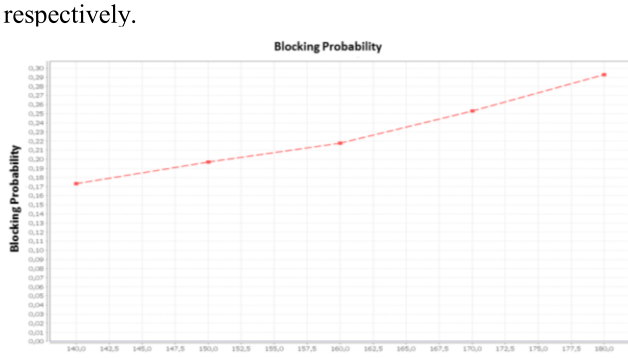

Figure 9. Blocking Probability with OCS and initial load of 140 Erlangs.

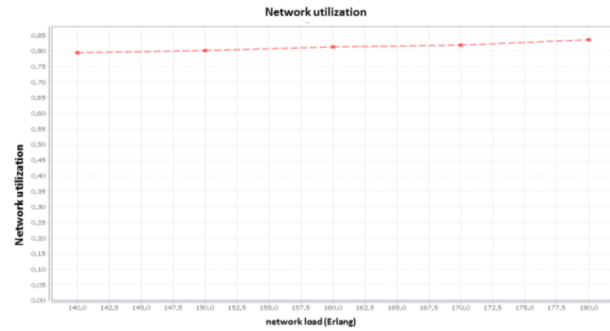

Figure 10. General network utilization with OCS and initial load of 140 Erlangs.

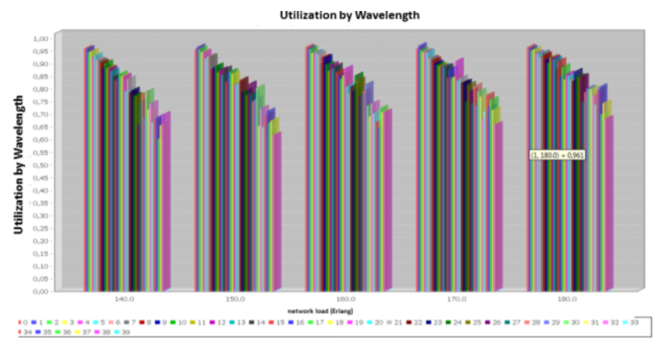

Figure 11. Utilization by Wavelength with OCS and initial load of 140 Erlangs.

In this second scenario, the blocking probability observed was high - 29.2% at 180 Erlangs - as well as the network utilization - 83.6% capacity at 180 Erlangs. The same traffic load condition was applied to OBS switching, resulting in the utilization by wavelength performance shown in Figure 12.

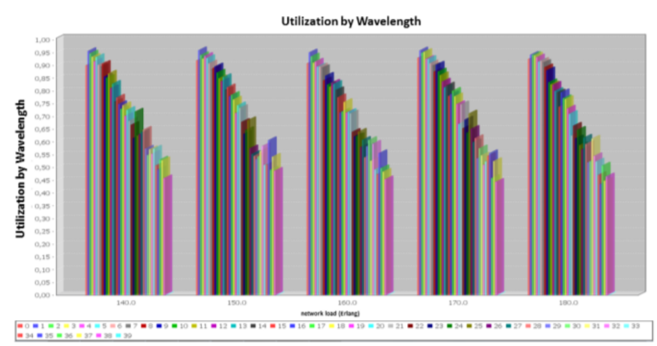

Figure 12. Utilization by Wavelength with OBS and initial load of 140 Erlangs.

From Figures 11 and 12, it can be observed that OBS switching allows improving the network performance. This result is consistent and can be associated with the fact that with OBS, intermediate links are released after the passage of the optical bursts. Therefore, these resources are available to new requests. Moreover, when the network load is high, intermediate links becomes relevant to performance. Table 4 illustrates the Relative Resource Economy, as in (1), obtained using the OBS paradigm.

TABLE IV. RELATIVE RESOURCE ECONOMY

LOAD (E)	OCS	OBS	$E_U(\%)$
140	0.802	0.694	13.47
150	0.801	0.715	10.74
160	0.822	0.714	13.14
170	0.822	0.709	13.75
180	0.83	0.726	12.53

As expected, OBS showed better performance in terms of resource economy. For all load conditions, we obtained savings higher than 10% compared to OCS; this is an important factor especially when considering large networks which increase the availability of resources requiring large investments.

The same load condition of the previous scenario was applied to the hybrid OCS/OBS network, with the value of the Hurst parameter ranging uniformly between 0.3 and 1.0. The performance obtained in terms of utilization by wavelength is shown in Figure 13.

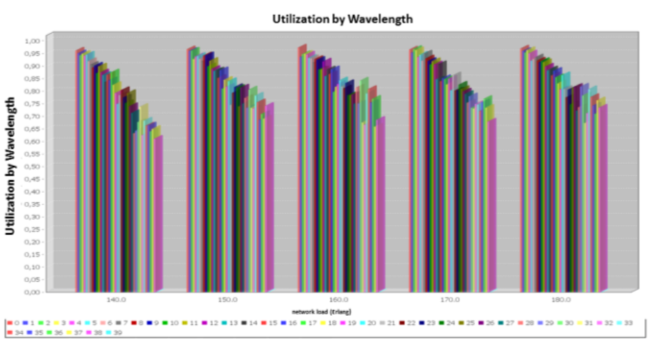

Figure 13. Utilization by Wavelength with Hybrid OCS/OBS switching and initial load of 140 Erlangs.

The hybrid OCS/OBS switching, as expected, showed intermediate results between those obtained with the OCS and OBS separately. While hybrid OCS/OBS network presented smaller network utilization in the presence of low granularity traffic, OCS network appeared to be transparent to the granularity of traffic, wasting the available resources. The OCS/OBS blocking probability was about 5% lower than OCS at 180 Erlangs. These performance differences are more apparent according to the incoming traffic. In the case of sparse traffic, a larger portion of the traffic is switched by bursts, making the overall performance of the OCS/OBS network closer to that obtained with the OBS paradigm. For more continuous traffic, the opposite occurs. Recent studies [18-21] indicates that backbones traffic is mainly composed of data packets, which implies that a significant portion of the traffic can be switched by bursts, optimizing the existing infrastructure and avoiding the waste of resources.

V. CONCLUSIONS AND FUTURE WORK

This work presents a performance study comparing an OBS/OCS hybrid optical network approach to the OCS and OBS paradigms isolated.

The OCS/OBS hybrid optical network studied uses a traffic classification and optical switching selector scheme based on fuzzy logic.

Our results show that, when the traffic is non-uniform, a hybrid optical network approach uses the available resources in a more efficient way than an optical network implementing one unique optical switching paradigm.

The use of Fuzzy Logic at each edge hybrid node makes traffic classification scheme robust to errors in the estimation of the input parameters, traffic growth and the emergence of new applications. The use of statistical traffic parameters to select the optical switching paradigm makes this scheme transparent to protocols. In the work presented by Lee [23], the author proposes a hybrid network and suggests a classification of traffic according to the duration of the flow. The decision threshold, however, remains an open issue. The classifier presented here fills this gap, consisting of a generic and robust solution, which can be seen as an offshoot of the work of Lee.

This work brings some challenges to be investigated, such as the evaluation of reducing latency in high QoS services using hybrid optical networks and the consequent reduction in dispute over resources with lower QoS services and the use of fuzzy logic in other ways to manage traffic.

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