Multiclass Multiserver Service Differentiation in Optical Flow Switched Networks

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Key Words: Multiclass, Multiserver, $M/G/W_u$, Non-Preemptive, Optical Flow Switching (OFS).

Abstract: In this paper we wish to analyze the scheduling policy of Optical Flow Switching (OFS) network w.r.t the multiclass priority queue. OFS is an exciting new switching technique which can transfer Terabytes of data in a fraction of seconds, The exquisiteness of OFS is that no buffering and processing is involved at any intermediate routes. Using priority queuing, the flow w.r.t multiclass for multiserver QoS is implemented. We develop the Multiclass priority model with non-pre-emptive model (with no forced termination) to evaluate the performance of the Multiclass Multiserver supported OFS network using the multiclass priority queue. This work presents an entirely new dimension to the Queuing at Access Nodes. Extensive results obtained show the significant change in total and average waiting time as the number of servers is increased. On the other hand, as the priority of the class decreases, the average waiting time also increases.

1 INTRODUCTION

Nowadays processing cost at network nodes plays a major role in determining the Network cost. Optical networking technology has the potential for exponential rise in data rates (~3 times the current magnitude) in the coming decade. This calls for network architecture to harness its current potential. The OFS concept was conceived in 1989 at the inception of the All-Optical-Network [(AON) Consortium] (Chan,2012). These networks must not only be capable of supporting different kinds of operations for different kinds of user requirements, but also be able to do it economically. This paper evaluates the effects of the multiclass operations.

Current networks using DWDM systems have bit rates up to 10 Gb/s for a single channel to network primary switching centers, and the industry is on the verge of deploying 40-Gb/s systems, with a potential to increase up to 160 Gb/s (Mahony,2006).The above premise is supported by the factors such as the cost, need to support advanced functions for future networks, reduction in the port count for increased bit rates for all optical networks (Mahony,2006).

Table 1: Residential Bandwidth Requirements (Mahony,2006).

Application	Downstream Requirement	Upstream Requirement
HDTV	60 Mbit/s	<1Mbit/s
Online Gaming	2-20 Mbit/s	2-20 Mbit/s
VoIP Telephone	0.3Mbit/s	0.3 Mbit/s
Data/E-Mail	10 Mbit/s	10 Mbit/s
DVD Download	14 Mbit/s	<1 Mbit/s
Total	~100 Mbit/s	~30 Mbit/s

The above table presents the bit rates required for the future optical networks. Flow Switching Architecture is a perfect candidate for high data rate, bursty transactions. Optimum configuration has to be established between the three network parameters (blocking probability, delay and wavelength utilization) for enhanced performance. Statistical Multiplexing of different flows in a scheduled fashion from different users has to be achieved for efficient utilization of the network. Thus, high network utilization can be achieved if the users are willing to wait for service according to a schedule. Schedule (incurring delay) or accept high blocking probability upon request for service (Chan, 2010). Variety of scheduling algorithms have been analyzed for application in the OFS networks, FCFS (Weichenberg, 2009). Priority applications using two classes (Khayata, 2012) and Entropy based Scheduling (Zhang, 2010).

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2 ARCHITECTURAL OVERVIEW OF OPTICAL FLOW SWITCHING

OFS is an end to end transport service from source to destination, in which user connects through an all optical path via the access networks available to him, unlike the OPS and the OBS, the buffering of data takes place at the source and the destination OXC's, the user is allotted bandwidth via a scheduling algorithm which may be FCFS or Priority. OFS is envisioned as an all optical data plane which is supplemented by an electrical control plane (responsible for routing).The transaction between the source and the destination may take place in Terabits and the connection is established and held for hundreds of milliseconds.

OFS is proposed as a large transaction operation in which the routing takes place via an all-electronic plane and data transmission takes place via the all optical plane. This form of switching can be easily implemented on the existing fiber architectures Optical Packet Switching and Optical Burst Switching and also serves to lower the access cost to all the users for the large transaction operations. The lower traffic transactions can be served by Generalized Multiprotocol Label Switching (GMPLS) or the Electronic Packet Switching (EPS) switching technique because using the OFS operation for such small bandwidth transactions is not economically viable. The access to the resources (bandwidth) is subjected to an end to end scheduling algorithm. The buffering of the data takes place at the source and the destination OXC's, thus rendering unnecessary the need for any buffering at the network core, and also allowing for the data to be routed as an indivisible entity in a single flow, hence the name.

2.1 OFS Topology

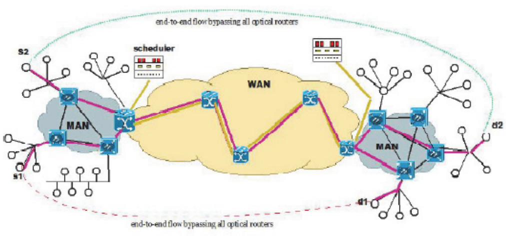

Figure 1: OFS topology (Khayata , 2012).

The network consists of N_1 Metropolitan Area Networks (MAN) connected by a single Wide Area Network (WAN). An OFS MAN node comprises an Optical Cross Connect (OXC) with direct connections to adjacent MAN nodes as well as one or more access networks based on Distributed Node (DN) architectures. We let "N_d" denote the total number of such DNs per MAN. The bidirectional links forming these connections are actually implemented with two fiber links, carrying a signal in opposite directions.

It may be the case that the mesh topologies underlying such MANs may be random, we can assume that they are based on Moore Graphs (Weichenberg, 2009) (such Graphs are chosen because of their cost effectiveness) inter-MAN OFS traffic could coexist on the same fiber in the embedded tree. Assuming that there exist a total of W_a wavelengths available for a fiber Q_1 to transmit data and W_u represent the wavelengths available between Q_1 and any fiber Q_2 of the other N_1-1 MANs (Weichenberg, 2009), W_u is a subset of W_a.

2.2 OFS Communication

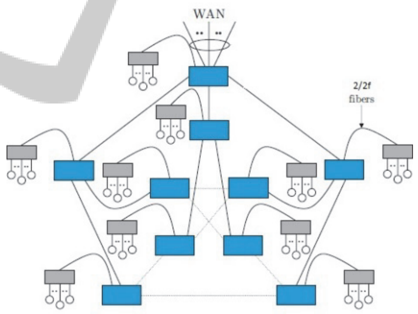

Figure 2: OFS MAN (Weichenberg,2009).

The end to end sequential reservation takes place in two steps, (i) Reservation of resources between source WAN and destination WAN. (ii) Reservation between the Distribution node and the scheduling node at the source and destination, respectively. Consider a source S present in MAN M_1 which tries to perform an end to end transaction with the destination D in MAN M_2.A Flow is generated at the source DN D_1 in MAN M_1 to the destination DN in MAN M_2(This is explained in detail in the next section).We will consider the case of two fibers in the numerical analysis because of the simpler calculations; however, these calculations can be easily scaled to consider 2f fibers as well.

At a MAN's scheduling node, there exist N_l-1 first-work resources (Weichenberg, 2009).

$$W_u=\frac{f*W_a}{N_1-1} \qquad (1)$$

3 SCHEDULING ALGORITHM

Consider a flow that is generated at an end user (S) residing in DN D_1 within MAN M_1 and that is destined for an end user (D) residing in DN D_2 within MAN M_2. As soon as this flow is ready for transmission, the source end user sends a primary request r_1 to the scheduling node associated with M_1, requesting an end-to-end all- optical path for its flow transmission.

At a MAN's scheduling node, there exist N_l-1 FIFO queues, one queue corresponding to every possible MAN destination. Each queue can be thought of as the queue for an M/G/W_u queuing system, in that the W_u wavelength channels dedicated to transmission from M_l to M_2 eventually serve the primary requests waiting in it. After the primary request arrives at the head of the queue, the secondary request is sent for the reservation of wavelength between the DN DN_1 and the S as well as the DN_2 and D, by their respective Scheduling Nodes. When the request is served, wavelength is allotted to the user and transmission can take place.

3.1 The Model

We have considered a multi-class, multi-server problem with more than two classes, to provide the service differentiation. This model is a non pre-emptive model in which K customer classes and N parallel servers are considered (The numbers of servers represent the available wavelengths W_u). We will use the notation i to depict the customer classes and j to depict the number of servers where i=1,2,3,4,…K and j=1,2,3,4,….N. The customers of class i arrives at the server j with a rate λ_i ,where total rate of arrival $\lambda = \sum_{i=1}^{k} \lambda_i$,and the normalized traffic being $\lambda_r = \lambda/w_u$.

Each customer is routed to a server j independent of the others with a probability $[p_{i,j}]_{1<i<K,1<j<N}$. The rate of customer arrivals to server j is therefore given by $\lambda_{i,j} = \sum_{i=1}^{K} \lambda_{i*}\, p_{i,j}$. The service time of a class i customer when executed on server j has a general distribution $F_{(i,j)}(.)$.We assume the servers are identical in every respect and the speed of a server is denoted by 's'. We analyze only the base time server distribution's first and the second moment which are represented by '$\bar{X}$' and '$\overline{X^2}$'. Therefore first and second moments of service time distribution of class i on server j are $\overline{X_{\iota,J}}$ and $\overline{X_{\iota,J}^2}$. Let $\rho_i = \lambda_r * \bar{X}$ be the traffic intensity of class i (Sethuraman,1999).

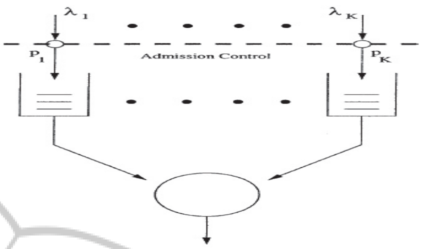

Figure 3: Multiclass Queueing with single server (Plambeck,2001).

3.2 Sequencing

If the cost associated with a particular server j is C_j and T_i denotes the effective response time of class i customers then in a K- class non pre-emptive M/G/1 queue priority is given to the class i customers over class j customers if $c_i/x_i > c_j/x_j$ minimizes $\sum_{i=1}^{k} c_i * \frac{\lambda_i}{\lambda} * T_i$.(Sethuraman,1999).

Assuming $\overline{L}$, $\overline{L^2}$ and $\overline{L^3}$ refer to the First, Second and Third moments of the flow transmission time L respectively, 'f' refers to the number of fibers and N_d refers to the number of DNs per MAN (Weichenberg, 2009).The first and second moment of the service time distribution are defined by:

$$\overline{X} \approx \overline{L} + \frac{f*\overline{L^2}*\lambda_r}{2(N_d - f*\lambda_r*\overline{L})} \qquad (2)$$

$$\overline{X^2} \approx \frac{N_d*\overline{L^2}}{(N_d - f*\lambda_c*\overline{L})} + 2\left[\frac{f*\overline{L^2}*\lambda_c}{2(N_d - f*\lambda_c*\overline{L})}\right]^2 + \frac{f*\lambda_c*\overline{L^3}}{3(N_d - f*\lambda_c*\overline{L})} \qquad (3)$$

3.2.1 Single Server Operation

In our model, the average waiting time for a class k is denoted by

$$W_k = \frac{\sum_{i=1}^{k} \lambda_i * \overline{X^2}}{2(1-\sum_{l<k}\rho_l)(1-\sum_{l\le k}\rho_l)} \qquad (4)$$

And the total waiting time is denoted by

$$T_k \;=\; W_k \;+\; \overline{X}_k \qquad (5)$$

Where $\overline{X}_k$ denotes the first moment of the service time distribution of class k.

3.2.2 Multiserver Operation

Average waiting time for class i on a server j ($W_{i,j}$)is given by:

$$W_{i,j} = \frac{\sum_{m=1}^{K} \lambda_m * p_{i,j} * \overline{X^2}}{2*(1-\sum_{k:k<i} \rho_{k,j})*(1-\sum_{k:k\leq i} \rho_{k,j})} \qquad (6)$$

Where $\rho_{k,j} = \lambda_{k,j} * p_{k,j} * \overline{X_{k,j}}$

And the average waiting time (W_i) for class i operation is,

$$W_i = \sum_{j=1}^{N} p_{i,j} * W_{(i,j)} \qquad (7)$$

And total time (T_i) for multi-server applications is given by

$$T_i = \sum_{j=1}^{N} \overline{X_{i,j}} * p_{i,j} + W_i \qquad (8)$$

The above results have been obtained directly from (Sethuraman,1999).

4 ANALYTICAL RESULTS

We have considered a 10-class operation with L=1 sec. Class-1 is the most delay constrained and the class-10 is the best effort class. The plots for average and total waiting time are as shown in the Figure 4 and Figure 5.We observe that for constant input parameters the peak waiting time for the Figure 5 drops by ~50% between 2-server to 3-server, where each point signifies an individual class for that particular server.

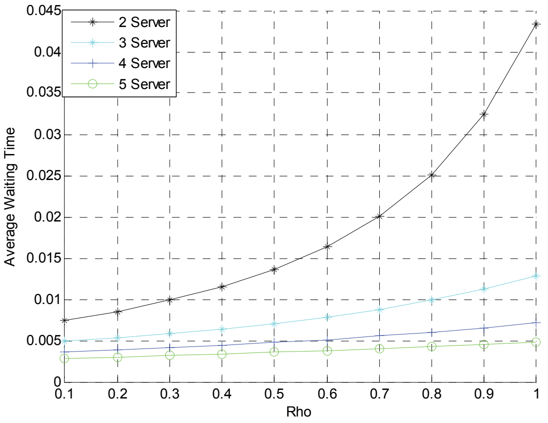

Figure 4: Average Waiting Time (sec) versus Traffic Intensity (rho) for 2, 3, 4, 5 servers with exponential flow.

We observe that for constant input parameters the peak waiting time for the Figure 5 drops by ~50% between 2-server to 3-server, where each point signifies an individual class for that particular server.

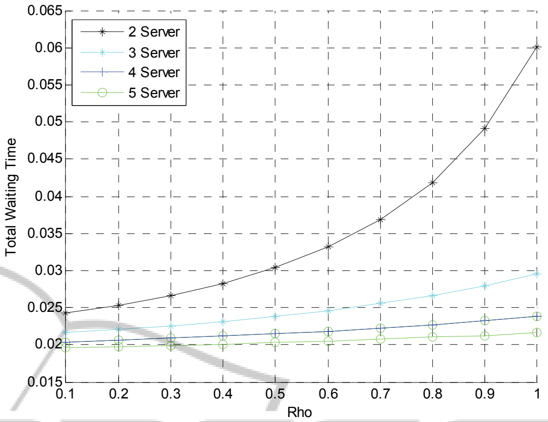

Figure 5: Total Waiting Time (sec) versus Traffic Intensity (rho) for 2, 3, 4, 5 servers with exponential flow.

It also shows a peak drop of ~63% between plots for 2- server and 5-server operations. For average waiting time, we observe that Peak drop is between 2-server and 5-server operation (~88%) and the least drop is between 4-server and 5-server operation (~27%) and the peak inter-server drop is between 2-server and 3-server operation (~69%). We observe that the difference between the peak waiting time for the least priority operation for subsequent classes decreases as the number of server increases. It can be concluded that the waiting times of all the classes of a particular server operation become constant, as the number of servers increases and approaches the number of classes under consideration.

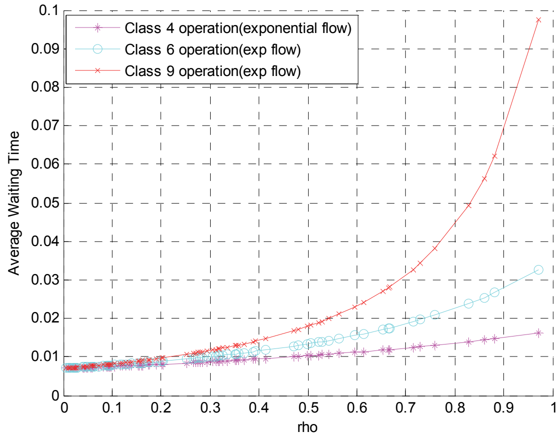

Figure 6: Average Waiting Time (sec) versus Traffic Intensity (rho) for 4, 6, 9 class operation with exponential flow.

In Figure 6., we have considered the operation for a fixed number of server and plotted the average waiting time for exponential flow, we observe that as the priority decreases, the waiting time increases and the peak waiting time also increases at a much faster rate. We have considered the 4-class,6-class,9-class operation. We observe that the peak waiting time drops ~70% between 9-class and 6-class and ~83% between 9-class and 4-class operation. Through this data, we can theorize that as the priority of the class increases, the waiting times becomes constant for lower and higher traffic input; hence the effect of increase of the traffic is highest on the lowest of priority inputs and lowest on highest of priority inputs. Thus, for the constant traffic input, the increase of the volume of traffic has a cascading effect on the lower priority classes, the waiting time increase is the severest in the lowest of priority classes, and thus the network has an upper limit on the number of operations that can be sustained economically. We also observe that when the utilization of the server is the highest and the traffic of the system approaches the peak value (~1 Erlang) the lowest of priority operations may have such high waiting time that it may become un-economical for the user. We must either reduce the number of operations that can be supported or increase the number of wavelengths that are allotted to the MAN network.

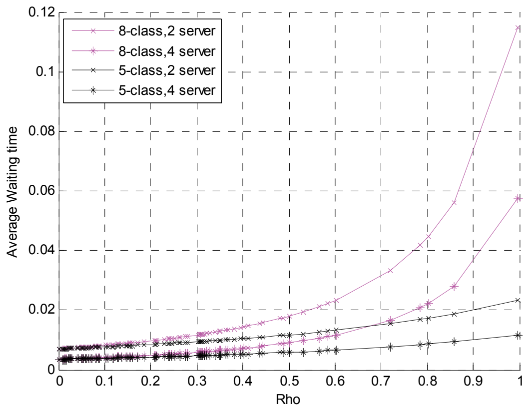

Figure 7: Average Waiting Time (sec) versus Traffic Intensity (rho) for 5 class for 2 and 4 server and 8 class for 2 and 4 server operation with exponential flow.

For Figure 7, we have considered the particular class of operation, viz class 8 and class 5, for 2-server and 4-server operation. We observe that the drop in the peak waiting time, observed across higher traffic is approximately 49% when the number of servers is increased, in class-8 case, whereas the effect over the lower class (class-5) is (~50-60%). We also observe that for lower amount of traffic (0-65%) of peak traffic, class-8, 4-server operation performs better than the class-5, 2-server operation. The above operation highlight the importance of increasing the number of servers, although their effect may vary as the priority of the operation is increased.

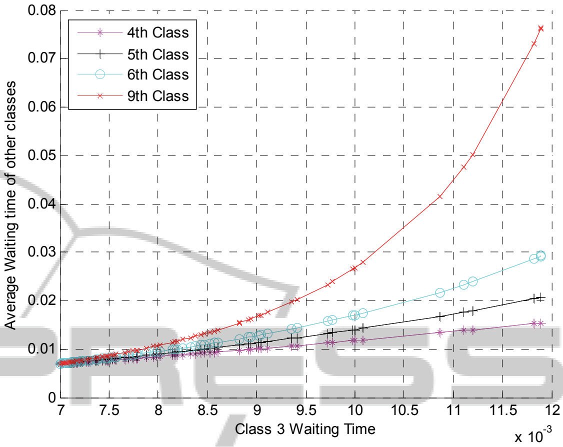

Figure 8: Average Waiting Time (sec) versus Class 3 Waiting Time for 4, 5, 6, 9 class operation with exponential flow.

The Figure 8 also proves that only a finite number of operations can be supported on the network, here the waiting times of class 4,5,6,9 are plotted against the class 3 waiting traffic for a fixed number of servers. The premise of such exercise is to find out the effects on increase of traffic on lower and higher traffic as well as their interdependence. We observe that with the increase of waiting time of a lower class traffic (class-3 in this case), there is a cascading effect on the higher classes (for lowest of priority operations) i.e. their waiting time increases exponentially on the increase of traffic and thus, for the least priority of classes, the waiting time may become so high that the cost becomes unsustainable. Thus, only a finite amount of classes can be supported by the OFS network, for a fixed number of servers.

We have observed in the above conclusion that the difference in the peak waiting time decreases as we increase the number of servers, so, we have to arrive at an optimum parameter which balances the economic consideration as well as the waiting time of the server.

5 CONCLUSION

This paper proposes QoS–based Service Differentiation in OFS Network using priority queuing. We have considered more than one class (multiclass) for many server (multiserver) problems to justify the paramount ability of OFS network usage to support different kind of operations. We develop an analytical model to evaluate the performance of the Multiclass Multiserver supported OFS network using the multiclass priority queue. Our proposed mechanism shows the efficacy of the proposed mechanism in OFS for various kind of operation. Results obtained clearly show the efficiency of the QoS based Multiclass Multiserver problem and its importance in increasing the number of server and its effect as the priority of the operation increases, which validates our results as in (Balter,2005). The result obtained also calls for an optimum balance to be found between the cost operation and the efficiency of the network, the number of operations it can support economically, we will analyze the optimum configuration in our future works.

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