Control Plane Architecture for QoS in OBS Networks Using Dynamic Wavelength Assignment

Sungchang Kim, JinSeek Choi, and Minho Kang

Optical Internetworking Lab, Information and Communications University,
58-4, Hwaam-Dong, Yuseong-gu, Daejeon, Korea
`{pluto,jin,mhkang}@icu.ac.kr`

Abstract. We address the control plane architecture of how to provide advance quality of service (QoS) in optical burst switching networks based on dynamic wavelength assignment. Unlike existing QoS guaranteeing scheme, such as buffer-based and offset-time based scheme, our proposed dynamic virtual lambda partitioning (DVLP) scheme does not mandate any buffer or extra offset time, but can achieve better QoS performance. This new DVLP scheme shares wavelength resources based on several different priority of classes in an efficient and QoS guaranteed manner. Also, hysteresis characteristic of DVLP is placed on robustness, meaning that each traffic classes with blocking probability conforming to the target value continue to receive the required QoS, despite the presence of misbehaving packets such as bursty arrival traffics. The performance results show that the proposed scheme effectively guarantees a target blocking probability of each traffic classes both in Poisson and Self-similar traffic environment.

1 Introduction

Increasing demands for transmission bandwidth driven by the growth of IP (Internet Protocol) based data traffic, especially real time multimedia services, give rise to dense wavelength division multiplexing (DWDM) technology which make possible to exploit the huge potential bandwidth of optical fibers. In addition to this advanced technology, it is natural to find ways to build the next-generation optical Internet architecture, which can transport IP packets directly over the optical layer without any opto-electro-optic (O/E/O) conversions.

Though optical packet switching technology can be attractive for all optical backbone networks, this technology has some technological limitations such as optical RAM and all optical processing. Presently, optical burst switching technology is under study as a promising solution for optical Internet backbone in the near future since OBS eliminate the electronic bottleneck at switching node with the help of no O/E/O conversion and guarantee the Quality of service (QoS) without any buffering [1][2][3].

In order to support today's mission-critical Internet traffic, optical Internet also has to support different traffic types based on their needs. However, until now there is

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little consideration of QoS in OBS networks. Existing QoS schemes for network layer are not readily achievable for WDM layer since the optical technology is not mature to support the optical buffering. Thus, in order to guarantee the QoS effectively in optical level, it is necessary to develop a new QoS scheme in optical layer, which should take into account the following considerations.

- Data information should be processed in all optical manner without E/O and O/E conversion at intermediate nodes.
- The upper levels of blocking probability and end to end delay should be supported.
- The hardware complexity such as processing time and implementation cost should be minimized.
- The QoS scheme should be efficiently scalable, reliable and available for WDM networks.

The focus of this paper is on the design of the control plane of OBS network and QoS guaranteeing algorithm based on dynamic wavelength assignment. The basic concept and general architecture of OBS core router is presented in Section 2 with data burst and control packet format and detailed description on the switch control unit. Subsequently, we proposed dynamic wavelength assignment algorithm for QoS performance using dynamic virtual lambda partitioning scheme in Section 3. Using this algorithm into the OBS network, Section 4 covers simulation and results, and some concluding remarks are made in Section 5.

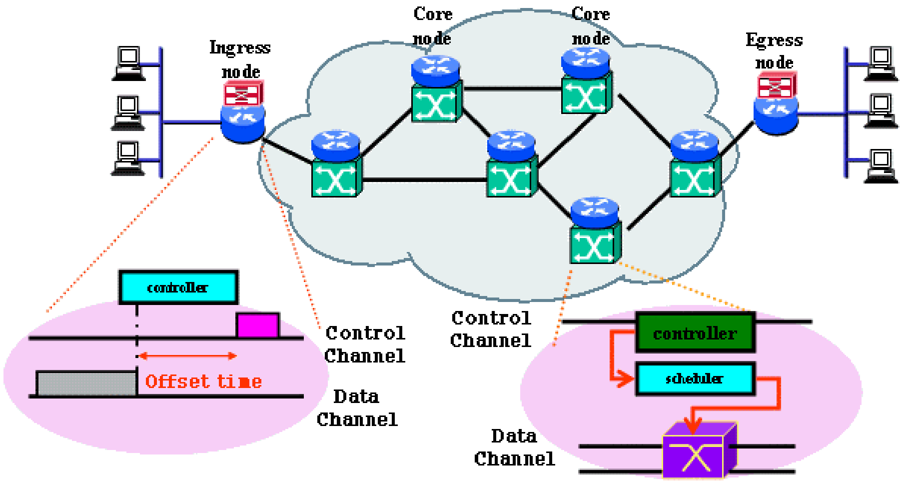

Fig. 1. An optical burst-switched network

2 Optical Burst Switching Network

OBS network consists of optical core routers and electronic edge routers connected by WDM links. Each burst in the OBS consists of a control header packet and a data burst. The information of the data burst length and offset time is carried in the control header packet. Different from the conventional store-and-forward packet switching, the OBS uses separate wavelength channels for the data burst and its control header. The overview of OBS network is shown in Fig. 1, which consists of optical core routers and electronic edge routers connected by WDM links.

In an OBS network, packets are assembled into bursts at the network ingress and disassembled back into packets at the network egress. Therefore, the bandwidth is reserved at the burst level using a one-way process and a burst can cut through intermediate routers. The OBS network can be envisioned as two coupled overlay networks: a pure optical network transferring data bursts and a hybrid control network transferring control header packets. The control network is just a packet switched network, which controls the routing and scheduling of data bursts in the all optical network based on the information carried in their control header packets. This coupled overlay networks take advantage of both mature electronic control technologies and promising optical transport technologies.

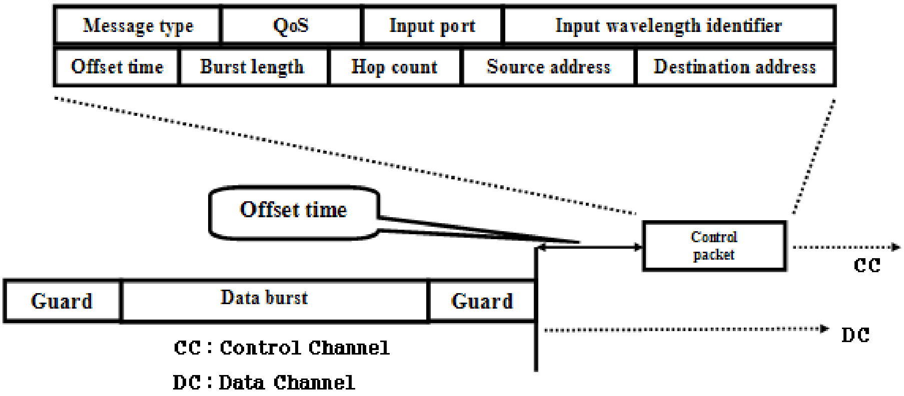

Fig. 2. Burst control packet format

Fig. 2 shows one example of control header packet format. The ***Message type*** indicates the header packet type. The message type field in each message uniquely determines the exact layout of the message. For the dynamic routing, there must be control messages such as link condition, header processing time and node condition to exchange information between each node so that it can discriminate the control header for the data burst and the control message packet for the maintenance of the network. The ***QoS*** indicates the following data burst's priority. With this and the offset time, core routers can select the shortest or the alternative light paths. It can be developed further to flow-based QoS. The ***Input port*** and the ***Input wavelength identifier*** are for the indication of the incoming data burst's port and wavelength. This provides switching information to the core router. The ***Offset time*** indicates the separation time between control header and data burst, which consists of the basic offset time and routing offset time. The ***Burst length*** indicates the length of data burst. The ***Offset time*** and the ***Burst length*** fields provide information for the core routers to reserve the proper bandwidth and duration, and the ***Hop count*** is used to prevent bursts not to lose their destination router or the looping environment. ***The Source address*** and ***Destination address*** are addresses of the source and the destination.

2.1 Control Plain Architecture of OBS Network

The architecture of OBS core router using MEMS switch fabric is shown in Fig. 3, which mainly consists of switching control unit (SCU) and MEMS switch parts. Control channels are separated from data channels and terminated at the SCU. Control channels can be implemented either in-band or out-of-band signaling, which can be determined whether control channels and data channels are established within the same fiber. Typically in the case of in-band signaling, each input fiber has (K-*k*) channels for data burst, and *k* channels for control packets. On the other hand, in the case of out-of-band signaling, the control channel interface is independent from that of data channel, which means that the control networks can be implement by either electrical wire such as coaxial cable or fiber. The switch matrix which presented in Fig. 3 is MEMS technology based switching fabric, since MEMS switching fabric is considered as a promising technology can adopt next generation all optical switching matrix. The SCU electronically processes each incoming burst control packet (BCP) to reserve a bandwidth its corresponding data burst (DB) in advance while the data bursts are still remain in the form of optical signal in the MEMS fabric.

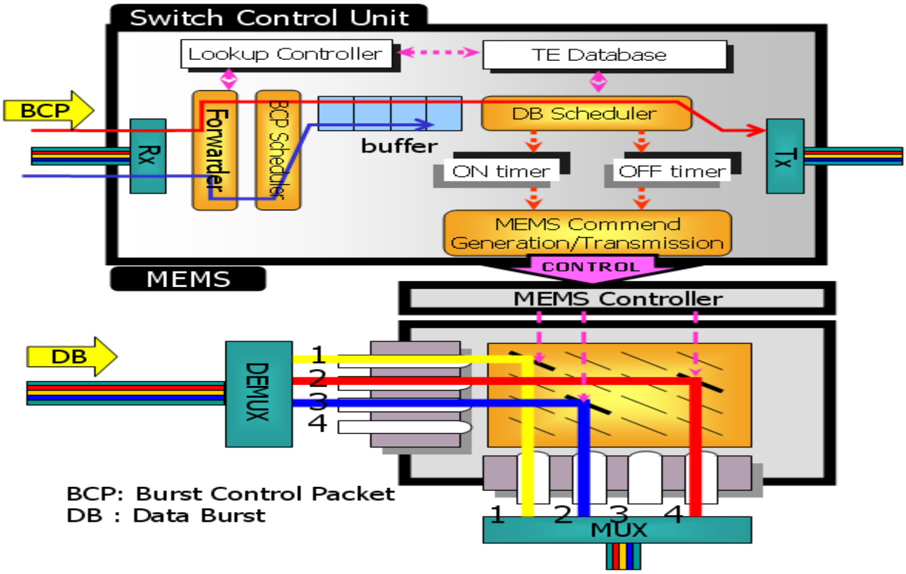

Fig. 3. OBS core node architecture

The detailed functional descriptions of SCU are described as follow. The Rx/Tx is 155Mbps ~ 622Mbps burst mode optical transceiver which is placed at input and output interfaces. These perform optical to electrical or electrical to optical conversion, receiving and transmitting of asynchronous control packets which are usually fixed size, and L1 and L2 decapsulation functions. The forwarder performs the forwarding of BCP into the appropriate queue, which can be designed according to the destination and priority class, using lookup controller and TE database to decide on which outgoing control channel and priority class to satisfy the BCP.

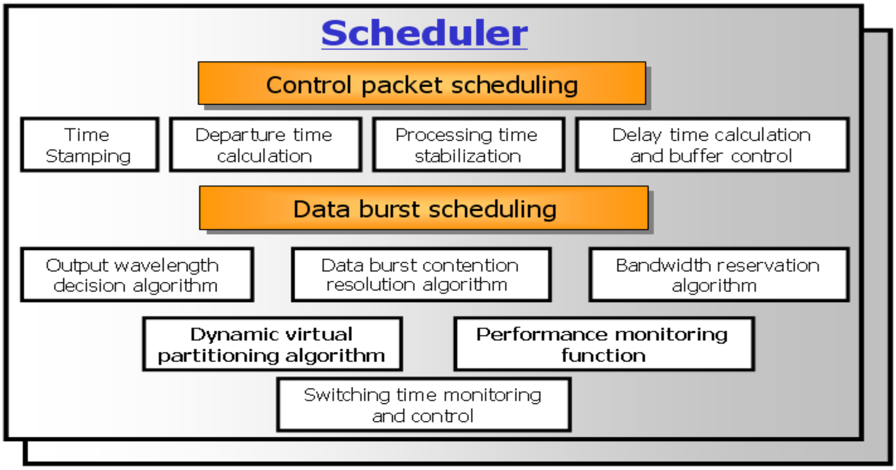

Fig. 4. Functional block diagram of scheduler

The scheduler in Fig. 4 is divided by two aspects. The one is control packet scheduling function and the other one is data burst scheduling function. The detailed functional block diagram of scheduler is presented in Fig 3. responsible for both the scheduling the MEMS switch of the data burst and the scheduling the transmission of its BCP.

The control packet scheduling function works as follows. Time stamping function first attaches a time-stamp to each arrival BCP, which records the arrival time of the associated data burst to the MEMS switching fabric. The departure time calculation function calculates the estimated departing time of control packet. If the expected departing time is exceed the upper bound of tolerable time, data burst will arrive earlier than control packet at the next hop. This phenomenon is called early arrival of data burst. In this situation, the scheduler may simply drop a control packet or assign a FDL to the data burst to make up additional delay time. Processing time stabilization function prevents large processing time variance which causes a serious increasing of end-to-end delay. Delay time calculation and buffer control function concerned about FDL control for data burst and buffer control for BCP. As we already know that OBS systems are not necessary for FDL, but limited number of FDL can significantly improve the network performance. The multiple buffer system for BCP can be implemented to support differentiated services operating with weighted fair queuing or preemption policies.

The first data burst scheduling function is output wavelength decision algorithm, which mainly searches for an idle outgoing data channel time slot to carry the data burst, making potential use of the FDLs to delay the data burst. Until now, various schemes are proposed as a direction of maximizing channel utilization. Data burst contention resolution algorithm also required to reduce the blocking probabilities, since the OBS network has inherently high blocking probabilities (bufferless concept). Subsequently, configuration monitoring and control function is carried out with the configuration information sent by the scheduler, the switch controller sends back an acknowledgement to the scheduler. The scheduler sends ON command to the switch controller based on arrival time of data burst and OFF command based on passing time of data burst. The scheduler then updates the state information of the data channel and control channel, modifies the BCP (e.g, the offset time and the data channel identifier). Our proposed dynamic virtual lambda partitioning (DVLP) algorithm is shown one of the main function in OBS control plane to support QoS performance. In order to guarantee a QoS performance, performance monitoring functions (e,g. blocking probability, channel utilization, and delay) are essential.

In order to implement practical OBS network, there are a lot of challenging issues to be solved. In respect of edge router, burst offset time management, burstification and burst assembly mechanism [4] are a critical issues. On the other hand, core routers need data burst and control header packet scheduling [5], protection and restoration mechanism and contention resolution scheme[6].

3 Dynamic Virtual Lambda Partitioning in OBS Network

In the view of OBS core routers, a burst control packet (BCP) arrives asynchronously from control channels of multiple input fibers. Processing of the BCP includes optical-electric conversion, address lookup to determine the output port, time and wavelength assignment, and switch control for possible reconfiguration of the switch. At the same instance, the scheduler feedbacks the information of the scheduling status to routing function block which increases the efficiency of the routing function. In the view of dynamic virtual partitioning, we focus on the scheduler, which is clearly an important function of resource sharing. In fact, OBS networks inherently have high blocking probability, which is mainly responsible for scheduler since it doesn’t consider any buffering scheme in the intermediate nodes.

The dynamic virtual lambda partitioning (DVLP) is a scheme for sharing wavelength resources divided into several priority classes. All of the wavelengths within the fiber are dynamically partitioned depending upon QoS requirements. Furthermore, wavelength reservation policy of the each priority class is different. For example, high priority traffic can access the wavelength resources within own priority class as well as the resources in lower priority classes. The proposed algorithm guarantees a target blocking probability of each traffic classes and does not increase end-to-end delay without any extra offset time.

3.1 Description of DVLP Algorithm

We consider data and control channels of transmission rate R, a number of wavelengths in a fiber W, which is offered traffics from K classes. Class k traffics arrive as a Poisson process of rate λ_k, and independent exponentially distributed service times with mean $1/\mu_k$, that means data burst size is variable length. Define $W(i) = \{ [w_1, \cdots, w_k] \mid 1 \le w_1, \cdots, w_k \le W - K + 1, \sum_{n=1}^{K} w_n = W \}$ where $i = 1, 2, \cdots$, as the set of occupied wavelengths of each priority class when the ith BCP arrives at the scheduler and each class has to possess at least one wavelength. $B(i) = \{ [b_1, \cdots, b_k] \mid 0 \le b_1, \cdots, b_{N-1} \le 1\}$ and $G = \{[g_1, \cdots, g_k] \mid 0 \le g_1, \cdots, g_k \le 1\}$, which represent the set of monitored blocking probability and the set of target blocking probability respectively.

DVLP has the following key ideas. First, at the time of design, each class is allocated a proper number of wavelengths, say, w_{k0} to class k, where $\sum_{n=1}^{K} w_{n0} = W$ to guarantee the QoS requirements, which the w_{k0} may be derived from traffic forecasts in conjunction with target blocking probabilities. These initial values are dynamically changed depending upon whether target blocking probabilities are satisfied or not along with time. This mechanism is implemented by a differentiation of monitored blocking probabilities which is easily calculated by comparing previous value. In order to reconfigure the number of wavelengths in each class, we adopt the threshold mechanism which has hysteresis characteristic. Using this mechanism, when the traffics are excessively fluctuated with time, the frequency of reconfiguration will be alleviated with less variance of time. Finally, the wavelength reservation rule of the each class is different depending upon its priority. Specifically, the high priority class traffics can reserve the bandwidth not only within its own wavelengths, but also the wavelengths in lower priority classes. For example, the class k traffics can access the wavelengths from the own class k to the lowest class 1.

The block diagram of our proposed DVLP algorithm is presented in Fig. 5. In this figure, we can define that T^u and T^o indicate occurrence number of the under-blocking and over-blocking probabilities respectively. Also, the th_u and th_o are the threshold values for under-blocking and over-blocking probabilities which can be determined to achieve hysteresis characteristic. In order to have a hysteresis charateristic, the th_o value sets up grater than th_u to alleviate the effects cased by bursty traffics. If the T^o is greater than th_o , this case is only occurred when the monitored blocking probability is over the target blocking probability, the higher class choose a wavelength which is randomly selected from the best effort class and vice versa.

When the BCP arrives at the scheduler, various reservation schemes can be applied such as first fit, round robin, and random. In our DVLP algorithm, we apply the LAUC-VP(Latest Available Unused Channel-Void Filling) [5] scheme. This scheme uses the void/gap, which is the unused channel capacity between the two data bursts in data channel. Using this scheme, we can achieve higher channel utilization and lower blocking probabilities than first fit or random scheme.

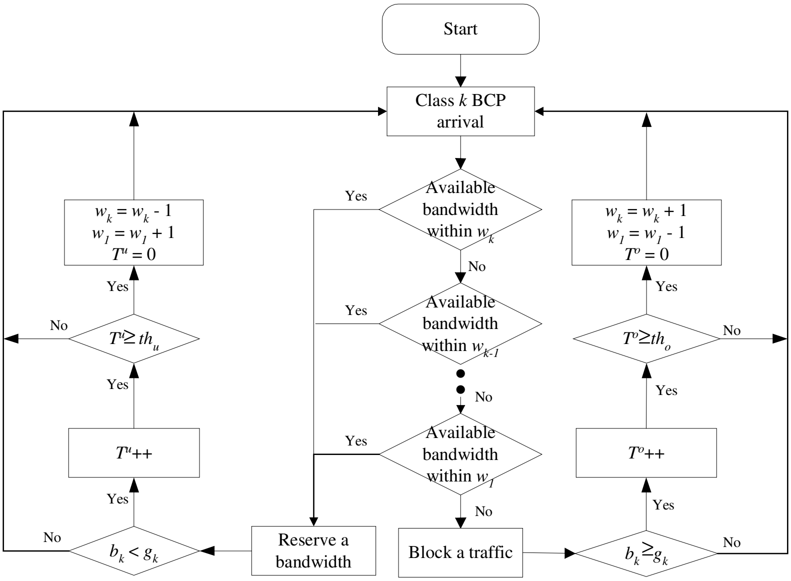

Fig. 5. Block diagram of DVLP algorithm

DVLP scheme is similar to the dynamic trunk reservation mechanism in TDM networks [7]. However, the performance of trunk reservation in TDM systems is different from that of the WDM system because of granularity of bandwidth reservation. Moreover, due to the delayed reservation, the statistical multiplexing gain of OBS will be another story compared with classical TDM networks.

4 Simulation and Results

We simulate the DVLP algorithm extensively using OBS simulator which made by java language. The simulation model is assumed that each node has 8×8 ports and that the priority of QoS defines three classes such as class 1, class 2 and class 3. Class 3 is the highest priority class and the class 1 is the lowest one. The scheduling mechanism for the data burst adopts the LAUC-VP scheme where 10 voids information can be stored in the scheduler because the memory space of scheduler is limited. After the simulation, we recognize that the 10 voids information for each channel is enough. We simulated that the distribution ratio of class 1, class 2 and class 3 are 70%, 20% and 10%, respectively. Additionally, we assume that the transmission rate of data and control channel is 10Gbps.

Basically, if the ingress edge router reduces the degree of self-similarity by certain traffic shaping function then exponential traffic affects the network performance. Unless the ingress edge router has any traffic shaping function, self-similar traffic affects the network performance. For this reason we chose the two different input traffics which one is Poisson and the other is self-similar traffic. We choose the Pareto distribution which is simplest self-similar characteristic distribution with Hurst parameter H=0.9.

In order to decide the data burst length, we have to consider the several constraints. Usually, the link utilization of the OBS network will largely depend on the number of control channel, guard band period and traffic load. Let L_b be the average data burst length (in time unit), θ be the guard period of data burst, ρ be the offered load, and R and r be the data and control transmission rate. Then, the link utilization of the OBS network can be represented by

$$\eta = \frac{KR}{KR + kr} \times \frac{L_b - \theta}{L_b} \times \rho \tag{1}$$

Among the above factors, the guard band period θ can be significantly affected the channel utilization because of the technological limitations. For example, the switching time of the promising MEMS switch is in several *ms* order. Therefore the guard period θ of data bursts can be *ms* order. Let $\theta = 0.4ms$, in order to obtain 0.7 channel utilization, we can get the minimum burst length $L_b = 4.14ms$. Based on this constraint, we assume the data burst durations to be 4ms and offset time is $40\mu s$. Since, we do not use any buffer (or FDL), we analyze the blocking probability of classless OBS, say, completely sharing of wavelength resources, that can be modeled M/M/m/m systems [8] which is commonly called as the Erlang's B formula.

$$B(k, \rho) = \frac{m^k / k!}{\sum_{n=0}^{k} m^n / n!} \tag{2}$$

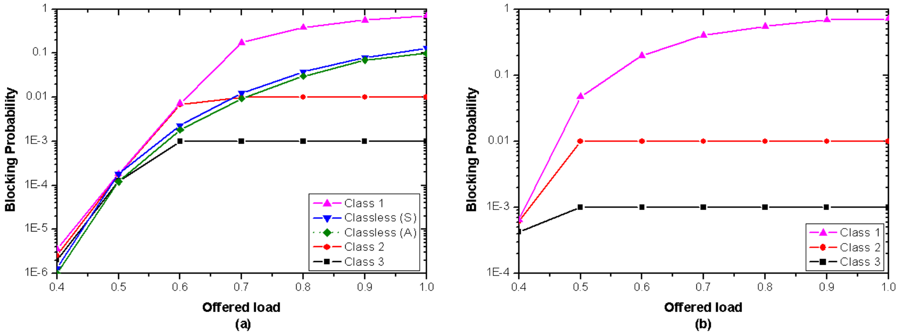

Fig. 6. (a) Average blocking probability of each class via offered load when Poisson traffic is applied. (b) Pareto traffic is applied

4.1 Performance Results

Fig 6(a) shows the blocking probabilities of individual priority classes as a function of the offered load when 32 wavelengths per port are used. The results of blocking probabilities for classless OBS obtained from Erlang's B formula (represented A) are in good agreement with those from the simulation (represented S). We set the desired blocking probabilities of priority 3 class as 10^{-3}, priority 2 class as 10^{-2}, and priority 1 is the best effort service. As can be observed by comparing the blocking probabilities between priority 3 class and priority 1 class, service differentiation can be obtained by taking advantage of the DVLP algorithm. Fig. 6(b) indicates that the overall blocking probability when self-similar traffic is applied is higher than previous Poisson traffic case. However, we can see that service differentiation is also achieved between class 3 and class 1 very well.

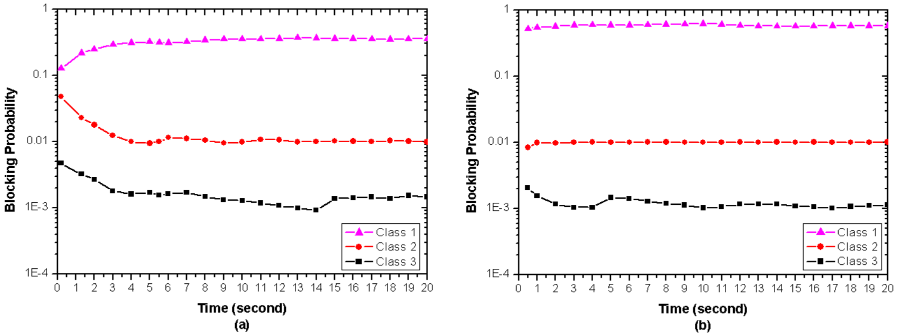

Fig. 7. (a) Average blocking probability of each class via time when the offered load is 0.8 and Poisson traffic applied. (b) Pareto traffic is applied

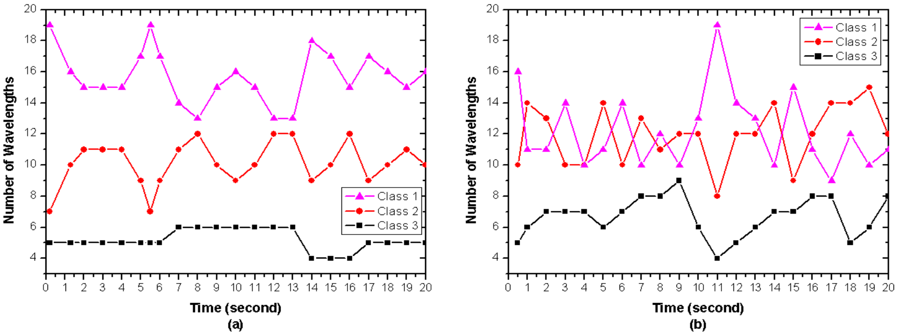

Fig. 8. (a) The number of wavelengths per class for 32 wavelengths per port when the offered load is 0.8 and Poisson traffic is applied. (b) Pareto traffic is applied

In addition to the service differentiation, Fig. 7(a) and (b) indicate that priority 3 and 2 classes show the desired blocking probabilities during the operating time when the offered load is 0.8 both Poisson and Pareto traffic cases respectively. However, price paid for the low blocking probability of priority 3 class is that the priority 1 class has higher blocking probabilities than the classless case in the high offered load. This implies that the conservation law holds well. Thus we can regard the classless blocking probability is same as the average blocking probability of whole priority classes. Specifically, priority 3 guarantees the desired blocking probability after some settling time. This transient period can be existed to searching for the number of optimum wavelengths per group because the initial value w_{ko} is decided just after forecasting the future arrival rate and QoS requirements.

Fig. 8(a) and (b) show that the number of wavelengths dynamically varies by different priority classes when offered load is 0.8. The priority 3 and 2 classes minimally use the number of wavelengths while guaranteeing the desired blocking probability. As it can be seen in the case of Poisson traffic, the occupancy of wavelengths in priority 3 class is only from 4 to 6 wavelengths to guarantee the performance. On the other hand, in the case of Pareto traffic in Fig. 8 (b), the occupancy of wavelengths in priority class 3 is from 3 to 9 wavelengths. This implies that priority class 3 holds more wavelengths to reduce the blocking probability comparing to the Poisson traffic. Furthermore, you can identify that the fluctuation of the number of holding wavelengths in each classes is increased comparing to that of the Poisson traffic case. In this simulation, we found that the variation of the wavelength number is increased as the desired blocking probability is getting smaller. To compensate this variation, we need reconfiguration in such a way that the threshold values, th_u and th_o, have to set smaller than before because these can be react sensitively for guaranteeing lower blocking probability.

5 Conclusion

This paper considers a scheme for sharing a wavelength resources based on several different priority of classes in an efficient and QoS guaranteed. Hysteresis characteristic of dynamic partitioning is placed on robustness, meaning that each traffic classes with blocking probability conforming to the target value continue to receive the required QoS, despite the presence of misbehaving classes such as bursty arrival traffics. The algorithm we proposed is simple to implement for QoS performance in OBS networks.

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