A Study on Service Differentiation in Bufferless Optical Packet/Burst Switched Networks

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Abstract
Service differentiation should be present in the next generation optical core networks in order to provide the sufficient QoS to real time applications and to utilize network resources optimally. By avoiding the use of contention buffers, we obtain low cost switches with simple management. In this paper we present analytical models for two service differentiation algorithms for bufferless optical packet/burst switched networks, namely the Wavelength Allocation algorithm (WA) and the Preemptive Drop Policy (PDP). Simulation results verify our analytical model. Regarding the PDP, we briefly address end-to-end QoS issues. Finally, regarding the performance of these service differentiation algorithms, we show that the PDP is more efficient compared to the WA.

Keywords: Service differentiation, optical packet/burst switching, teletraffic modeling, simulations.

1. Introduction

In recent years we have experienced an explosive growth of the Internet traffic in the core networks. Fuelled by both the increasing access network capacity and the increasing number of Internet users, this growth has put a demand on an increasing capacity in the core networks [10]. Optical networks utilizing Wavelength Division Multiplexing (WDM) has emerged as the most promising technology to increase available capacity in future core networks [11]. However, as pointed out in [9,12], since electronics cannot match the speeds of optical technology, the WDM networks must evolve into architectures like Wavelength Routed (WR) networks, Optical Packet Switched networks (OPS) and Optical Burst Switched networks (OBS). Of these, OBS and especially OPS are viewed as the most promising switching architectures, at least in the long run [9]. First, due to the benefit from statistical multiplexing, both OPS and OBS networks show better performance compared to WR networks [9]. Furthermore, OPS/OBS can better adapt to changes in the traffic pattern and changes in the network infrastructure. Both of these benefits become even more prominent as the networks move to become increasingly data-centric due to the self-similar pattern of the Internet traffic [8,9].

Today's Internet provides only the best-effort service, where each packet is getting the same treatment and there are no guarantees to the end-to-end delay or the packet loss rate (PLR) [14]. However, the increasing number of real-time applications and interactive Internet applications demand a stricter Quality of Service (QoS), both in terms of end-to-end delay and PLR, than the current best-effort service can offer [3]. Also, as the networks become increasingly data centric, we see that critical services such as emergency services and important business services become packet based. Although the best-effort service is not suited to carry real-time or interactive applications, it is well suited for web browsing, file transfers and other relaxed services. Hence, in order to give the different applications their needed level of QoS and to utilize network resources optimally, service differentiation should be present in future core networks [3].

Many of the existing service differentiation schemes for traditional store-and-forward networks mandate the use of buffers to isolate the different traffic classes. However, as pointed out in [16,17], such schemes are not suitable for the WDM layer. First, electronic buffering necessitates the use of O/E and E/O converters, which results inn a significant increase in the cost of the switch and loss of data transparency. Second, although optical buffering can be realized by utilizing Fiber Delay Lines (FDLs), it can only give limited buffering capabilities compared to electronic buffering. As pointed out in [16,17], a viable solution is to completely avoid the use of contention buffers. Hence, service differentiation must be provided using techniques not found on buffers to isolate the different service classes, i.e. bufferless service differentiation techniques.

This paper presents an analytical model of Wavelength Allocation algorithm (WA), which has previously been presented in [2]. We also present and provide an analytical model of a novel service differentiation architecture, namely the Preemptive Drop Policy (PDP). Both the WA and the PDP provide service differentiation in bufferless OPS/OBS networks. In the WA we reserve a set of wavelengths exclusively for high priority traffic, which results inn a lower PLR for high priority traffic compared to low priority traffic. In the PDP, in the case of output contention, we allow a limited number of high priority packets/bursts to preempt low priority traffic currently in transmission. We obtain service differentiation with respect to the PLR since successful preemptions result inn lower PLR for high priority traffic compared to low priority traffic.

Related research includes an analysis of the segment and drop policy (SDP) for OBS with burst segmentation (BS) [13]. Here, in the case of output contention, the contending bursts are first segmented and then dropped or transmitted according to the priority of the bursts. Typically, higher priority bursts are transmitted, while lower priority bursts are dropped. Unlike the work in [13] we do not utilize BS, i.e. the whole packet/burst is dropped in the case of output contention. This makes the WA and the PDP suitable for OPS networks (since packets should not be segmented) as well as for OBS networks without BS. In [15], a preemptive service differentiation policy is presented for a network with FDL buffering and deflection routing. Unlike their work, we do not use buffering or deflection routing. The authors of [17] present a service differentiation architecture for OBS networks by utilizing a QoS offset scheme. Since this architecture assumes that wavelength reservation is performed using an offset time (OT) based scheme [6,17], the WA/PDP is not directly applicable to this OBS architecture. However, it is likely that the WA/PDP will operate properly in the Fibre Delay Line (FDL) based OBS architecture presented in [6,12].

The rest of the paper is organized as follows: Section 2 presents the system model. Section 3 presents the WA followed by an analytical model. Section 4 presents the PDP followed by an analytical model. Section 5 presents simulation results and a comparison study between the WA and the PDP. Finally, section 6 concludes the paper.

2. System model

2.1. Switch Architecture

We consider an asynchronous optical packet switch with full wavelength conversion and no internal blocking (the architecture presented here is also valid for the FDL based OBS scheme [6,12]). The switch consists of M input fibres and M output fibres, as shown in figure 1. By utilizing WDM, each fibre provides N wavelengths to transport data, each with a specified capacity C bps. When a packet arrives at the switch, the packet header is extracted and processed electronically by the control module. While the

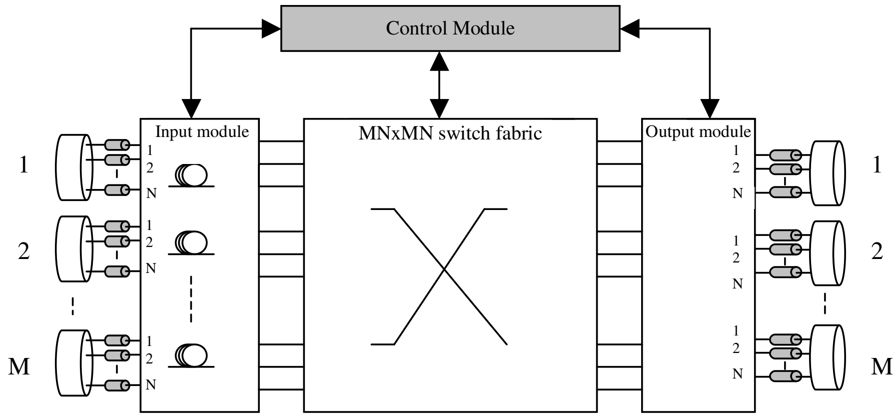

Figure 1: Overview of an optical packet switch.

header is processed, the packet payload is buffered using FDLs located at the input module. Based on the destination information extracted from the packet header, the control module decides which output fibre the packet is switched to and configures the switch fabric accordingly. The switch has no buffers for contention resolution, i.e. the switch behaves much like a loss system, which makes the packet loss rate (PLR) an important QoS parameter. We also assume a uniform traffic pattern, which means that we have an equal load on every output fibre and can restrict our study to consider the PLR on a single output fibre.

2.2. Traffic Model

In the following proposed traffic model, the total number of wavelengths at an output fibre is N, as shown in figure 2. We consider a network with two service classes, i.e. a high priority (HP) class and a low priority (LP) class (the use of two service classes only in the core networks is argued by the authors of [1]). The output fibre in our focus receives HP and LP packets from all input fibres. In order to simplify our analysis in the following sections, we model packet arrivals to the output fibre according to two mutually independent Poisson processes with constant arrival intensity, as shown in figure 2. HP packets arrive with intensity α_H and LP packets arrive with intensity α_L. Hence, the share of HP and LP traffic is $A_H = \alpha_H / (\alpha_H + \alpha_L)$ and $A_L = 1 - A_H$ respectively. We also assume that the packet lengths (L) for HP and LP traffic are exponential i.i.d. with mean service time $\mu^{-1} = E(L)/C$.

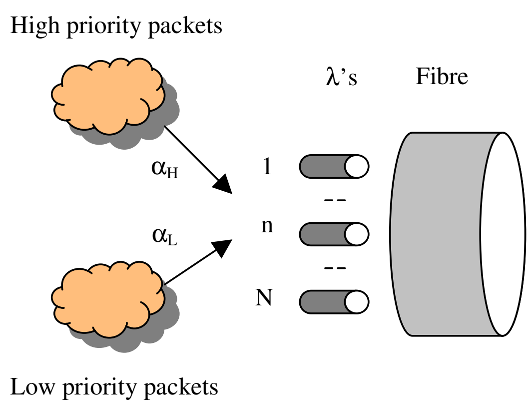

Figure 2: Traffic model of an output fibre

3. The Wavelength Allocation algorithm

In order to provide service differentiation in OPS/OBS networks, the Wavelength Allocation algorithm (WA) can be deployed [2,5]. A part of this analysis has already been presented in [19]. To start the analysis, a total of N available wavelengths at an output fibre are divided into three pools according to priority, i.e. a high priority (HP) pool with W_H wavelengths, a medium priority (MP) pool with W_M wavelengths and a low priority (LP) pool with W_L wavelengths. Incoming packets can access these wavelengths only if they have the necessary priority level. This means that LP packets can only access wavelengths from the LP pool, MP packets can access wavelengths from the LP pool as well as from the MP pool (total $N_M = W_L + W_M$ wavelengths), while HP packets can access wavelengths from all pools (total $N_H = N = W_L + W_M + W_H$ wavelengths) [2].

3.1. Analytical model

In the following proposed analytical model, only the high- and low priority levels (HP and LP) are utilized, as shown in figure 2. The total number of wavelengths at an output fibre is N, while the number of wavelengths available to both priority levels is $n = N_L$. Hence, the number of wavelengths reserved for HP traffic is $W_H = N - n$. In order to obtain analytical expressions for the PLRs, we model the WA as a state diagram as shown in figure 3. The state gives the number of wavelengths busy transmitting packets. With full wavelength conversion, we only have to bother with the number of wavelengths taken and not which wavelengths that are taken (i.e. we view all wavelengths as indistinctive resources). In figure 3 we see that both HP packets and LP packets (total intensity $\alpha_H + \alpha_L$) are accepted from state 0 to state n - 1 (i.e. as long as there is fewer than n wavelengths busy transmitting packets, both HP and LP packets are accepted and transmitted). However, from state n to state N - 1, only HP packets are accepted and transmitted, while LP packets are discarded. In state N, both HP and LP packets are discarded.

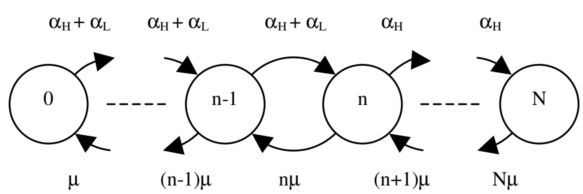

Figure 3: State diagram of the WA

We denote the state probabilities as $Q(i)$ and derive the following steady state equations from cut operations:

$$i\mu \cdot Q(i) = (\alpha_H + \alpha_L) \cdot Q(i-1) \qquad 1 \le i \le n \tag{1}$$

$$(i+1)\mu \cdot Q(i+1) = \alpha_H \cdot Q(i) \qquad n+1 \le i \le N \tag{2}$$

Also, since the system always must be in some state, we have that:

$$\sum_{i=0}^{N} Q(i) = 1 \tag{3}$$

From the equations (1)-(3) we can easily derive the state probabilities:

$$Q(i)=\begin{cases}\left(\dfrac{\alpha_H+\alpha_L}{\mu}\right)^i\cdot\dfrac{1}{i!}\cdot Q(0) & 1\le i\le n\\[2ex] \left(\dfrac{\alpha_H+\alpha_L}{\mu}\right)^n\cdot\left(\dfrac{\alpha_H}{\mu}\right)^{i-n}\cdot\dfrac{1}{i!}\cdot Q(0) & n+1\le i\le N\end{cases} \tag{4}$$

$$Q(0)=\left[\sum_{i=0}^{n}\left(\frac{\alpha_H+\alpha_L}{\mu}\right)^i\cdot\frac{1}{i!}+\left(\frac{\alpha_H+\alpha_L}{\mu}\right)^n\cdot\sum_{i=n+1}^{N}\left(\frac{\alpha_H}{\mu}\right)^{i-n}\cdot\frac{1}{i!}\right]^{-1} \tag{5}$$

From the state probabilities in equations (4) and (5), and from the state diagram in figure 3, we can derive the expressions for the time congestion for HP traffic (E_H) and LP traffic (E_L). The time congestion measures how much of the time the system finds itself in a state where new arrivals are discarded. According to previous discussion we have that:

$$E_H=Q(N) \tag{6}$$

$$E_L=\sum_{i=n}^{N}Q(i)=Q(N)+\sum_{i=n}^{N-1}Q(i)=E_H+\sum_{i=n}^{N-1}Q(i) \tag{7}$$

We can clearly see from equations (6) and (7) that $E_L > E_H$, which is in accordance with what we pursued. Furthermore, since we have Poisson arrival processes, according to the PASTA (Poisson Arrivals See Time Averages) property [7], the call congestion or packet loss rate (PLR) equals the time congestion, i.e.:

$$P_{loss}^{HP}=E_H\,,\,P_{loss}^{LP}=E_L \tag{8}$$

This model can easily be generalized into J service classes and analytical results for the PLRs can be derived based on the appropriate state diagram.

In the case with no service differentiation (i.e. the best-effort service), the loss probability P_{loss}^{O} can be calculated using the Erlang B formula for the loss probability in a *M/M/n/n* system [7]:

$$B(A,n)=\frac{A^n}{n!}\Big/\sum_{i=0}^{n}\frac{A^i}{i!} \tag{9}$$

With available resources $n = N$ and an aggregated arrival intensity $\alpha_O = \alpha_H + \alpha_L$, the PLR in the best-effort case is given as:

$$P_{loss}^{O}=B(A,N)=B(\alpha_O/\mu,N) \tag{10}$$

3.2. The case with general service times

The analytical values for the PLRs found in equations (1)-(10) assumed that the packet lengths (and thus the service times) are exponential i.i.d. However, it can be shown that the equations for the state probabilities (and thus the PLR) are also valid for a general service time, i.e. the PLR is only dependent on the first moment of the service time only. That is, the PLRs are not only valid for a *M/M/n/n* system, but also for a *M/G/n/n* system. The proof for equation (9) has been showed in [4], and similar procedure as used there should be adapted to prove equations (4) and (5). Although not reported here, simulations performed verify this claim.

4. The Preemptive Drop Policy

In the Preemptive Drop Policy (PDP), all available wavelengths at an output fibre are shared amongst both HP and LP traffic. As long as there is at least one free wavelength, new arrivals are transmitted independent of the service class of the arriving packet. When all wavelengths are busy, new LP arrivals will be discarded. However, new HP arrivals are allowed to interrupt a LP packet currently in transmission and take over (preempt) the respective wavelength for its own use. As part of the PDP we define and use a parameter p denoting the probability for successful preemption, i.e. with $p = 0$ we do not allow any HP packets to preempt (which refers to the best-effort scenario). On the opposite, with $p = 1$, HP packets will succeed in every attempt to preempt LP traffic (as long as there are LP packets currently in transmission). By adjusting the value of p we achieve any desired level of the PLR for HP traffic. Such control is essential in order to provide absolute QoS guarantees in the core networks [3,18]. At last, if all wavelengths are busy transmitting HP packets only, new HP as well as LP arrivals are discarded.

Figure 4 shows the different possible preemption scenarios. In figure 3a), a HP packet preempts a LP packet currently in transmission. The HP packet arrives at time h_a. The LP packet currently in transmission is interrupted and the packet is lost (i.e. dropped at the current switch). However, the receiving node will receive a fraction of the LP packet already sent. Figure 3b) shows a LP packet arrival when a HP is currently in transmission. Since the LP packet is not allowed to preempt the HP packet, the LP packet is lost. Figure 3c) shows a HP packet arrival when a HP packet is currently in transmission. The arriving HP packet is lost since HP packets are not allowed to preempt other HP packets currently in transmission. This situation is also valid when there is a LP arrival to a wavelength currently transmitting a LP packet.

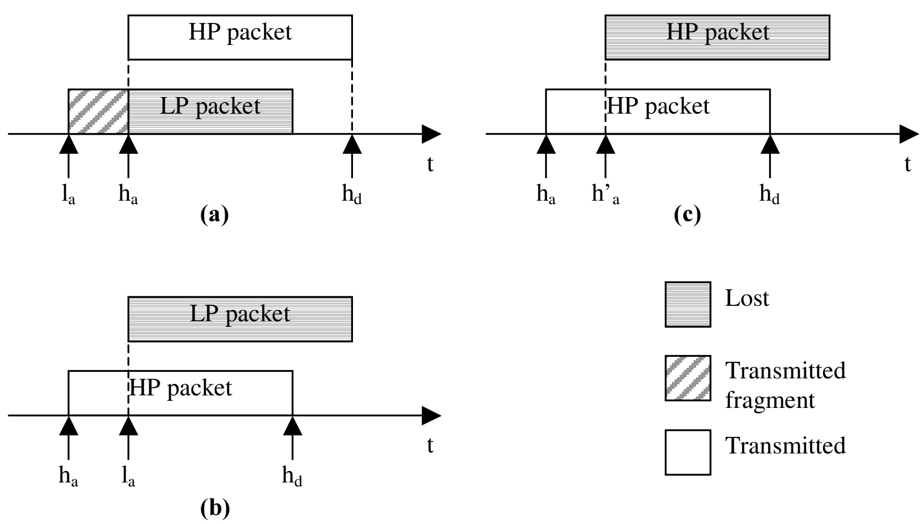

Figure 4: The different preemption scenarios in the PDP

When preemption occurs, the receiving node will receive the part of the LP packet already transmitted, as demonstrated in figure 3a). In order to avoid such segments to be further transmitted in the network, the receiving node must be able to detect whether arriving packets are intact or not. This can be performed by utilizing a checksum in the header, i.e. upon arrival to the receiving node, the checksum is calculated and compared to the checksum in the header. Hence, incomplete packets are then detected and deleted upon arrival to the receiving node [13].

Simulations performed show that there is approximately 3 % increase in the number of lost packets as we move from a scenario without service differentiation to a scenario with two service classes. However, in order to simplify our analysis, we assume a work conservative system, i.e. there is no increase in the total number of lost packets after service differentiation is introduced in the network (see [17] for a more detailed definition of the term 'work conservative' in this context). We also ignore the effects of the switching time in the analytical model.

4.1. Analytical model

We model the PDP as a two-dimensional state diagram as shown in figure 5. The states give the number of HP and LP packets currently in transmission respectively, i.e. in state *(2,3)*, 2 HP packets and 3 LP packets are currently in transmission. The arrival process is Poisson and the service time is exponential i.i.d., according to the traffic model in section 3.

When the system is congested (i.e. in the states *(i,j)* where $i + j = N$), new LP arrivals are lost. However, new HP arrivals may preempt LP packets currently in transmission with a probability p. We also see that preemption is not possible when the system is fully occupied with HP packets. In order to obtain numerical values for the state probabilities, we solve the state diagram using node equations [7]. We first define the unit step function according to equation (11):

$$u(k) = \begin{cases} 1 & k < N \\ 0 & k = N \end{cases} \tag{11}$$

Then we set up the node equations for the state diagram in equations (12) and (13):

$$\begin{aligned} &Q(i,j)\cdot\left((i+j)\mu + \alpha_H + \alpha_L\right) = Q(i-1,j)\cdot\alpha_H\cdot u(N-i) \\ &+Q(i+1,j)(i+1)\mu + Q(i,j-1)\cdot\alpha_L\cdot u(N-j) + Q(i.j+1)(j+1)\mu \end{aligned} \qquad 0 \le i+j < N \tag{12}$$

$$Q(i,j)\cdot\left(p\cdot\alpha_H\cdot u(i) + N\mu\right) = Q(i-1,j)\cdot\alpha_H\cdot u(j) + Q(i.j-1)\cdot\alpha_L\cdot u(i) \qquad i+j = N \tag{13}$$

Finally, since the system must be one of the states, we have that:

$$\sum\nolimits_{i=0}^{N}\sum\nolimits_{j=0}^{N-i} Q(i,j) = 1 \tag{14}$$

From figure 5 we see that HP traffic is lost when there is a HP arrival and preemption is not possible, i.e. in state *(N,0)*, or when there is a HP arrival and preemption fails. Preemption fails with a probability *1-p* when the system is in a congested state except for state *(N,0)*. This leads us to the PLR for HP traffic in equation (15). Furthermore, LP

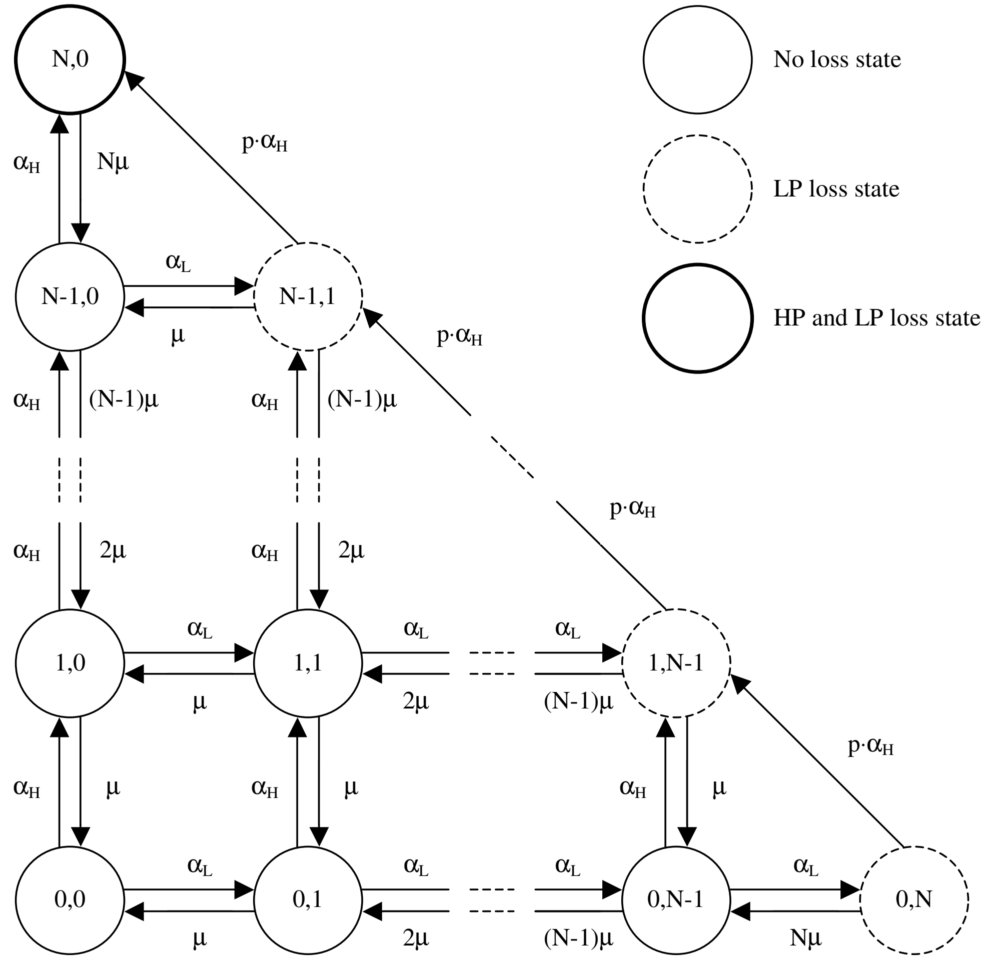

Figure 5: State diagram of the PDP with wavelength conversion

traffic is lost when there is a LP arrival and the system is congested or when HP arrivals successfully perform preemption. This leads us to the PLR for LP traffic in equation (16).

$$P_{loss,wc}^{HP} = \frac{\alpha_H \cdot Q(N,0) + \sum_{i=0}^{N-1} (1-p) \cdot \alpha_H \cdot Q(i, N-i)}{\alpha_H \sum_{i=0}^{N} \sum_{j=0}^{N-i} Q(i,j)} = Q(N,0) + \sum_{i=0}^{N-1} (1-p) \cdot Q(i, N-i) \qquad (15)$$

$$\begin{aligned} P_{loss,wc}^{LP} &= \frac{\alpha_L \cdot Q(N,0) + \sum_{i=0}^{N-1} (\alpha_L + p \cdot \alpha_H) \cdot Q(i, N-i)}{\alpha_L \sum_{i=0}^{N} \sum_{j=0}^{N-i} Q(i,j)} \\ &= Q(N,0) + \sum_{i=0}^{N-1} \left(1 + p \cdot \frac{\alpha_H}{\alpha_L}\right) \cdot Q(i, N-i) \end{aligned} \qquad (16)$$

We see that when preemption is not available (i.e. when $p = 0$), the PLR's for HP and LP traffic are equal, which is in accordance with our expectations. Due to state explosion, the equations are hard to compute for large values of N. Furthermore, in the case of n priority classes, we must solve an n-dimensional Markov chain.

4.2. End-to-end issues in the PDP

The analytical results derived in section 4.1 and 4.2 give the PLR for HP and LP traffic in a single optical output port (link). However, since a packet traverses several such links from its source node to its destination node in the core network, the end-to-end PLR is dependent on the PLR in every link the packet traverses. We now consider a network consisting of J links labelled by $1,2,\ldots i,\ldots, J$. We denote $\boldsymbol{l} = l(n_1, n_2, \ldots, n_D)$ as a path in the core network with length D, which starts at link n_1 and traverses the links $n_2,..,n_{D-1}$ before it ends in link n_D. From equations (15) and (16), we see that the PLR is a function of the arrival intensity of HP (α_H) and LP (α_L) traffic, the mean service time (μ^{-1}), the number of available wavelengths (N) and the probability for successful preemption (p), which are unique for each link. We denote the PLR for HP and LP traffic at link n_i as $P_{loss}^{HP,i}(\alpha_H^i, \alpha_L^i, \mu^i, N^i, p^i)$ and $P_{loss}^{LP,i}(\alpha_H^i, \alpha_L^i, \mu^i, N^i, p^i)$, respectively. Also let $\Re$ be the set of all possible routes $\boldsymbol{l}$ in the network and let λ_l^{HP} and λ_l^{LP} be the arrival intensity for HP and LP traffic to path $\boldsymbol{l}$. We also assume that the PLR in a certain link is independent on the PLRs in the other links. It can then be shown that the end-to-end PLR for HP and LP traffic traversing path $l(n_1, n_2, \ldots, n_D)$ with length D is:

$$P_{loss}^{HP,end} = 1 - \prod_{i=1}^{D} (1 - P_{loss}^{HP,i}(\alpha_H^i, \alpha_L^i, N^i, \mu^i, p^i)) \tag{17}$$

$$P_{loss}^{LP,end} = 1 - \prod_{i=1}^{D} (1 - P_{loss}^{LP,i}(\alpha_H^i, \alpha_L^i, N^i, \mu^i, p^i)) \tag{18}$$

According to [20], the reduced arrival intensity offered to link n_j can be approximated by:

$$\alpha_H^j = \sum_{l \in \Re : j \in l} \lambda_l^{HP} \prod_{i=1}^{J} (1 - I(i,j,l) \cdot P_{loss}^{HP,i}) \tag{19}$$

$$\alpha_L^j = \sum_{l \in \Re : j \in l} \lambda_l^{LP} \prod_{i=1}^{J} (1 - I(i,j,l) \cdot P_{loss}^{LP,i}) \tag{20}$$

where $I(i,j,l)$ equals one or zero depending whether or not $n_i, n_j \in \boldsymbol{l}$ and link n_i strictly precedes link n_j along route $\boldsymbol{l}$, respectively.

5. Simulations and results

This section presents both simulation and analytical results regarding the performance of the WA and the PDP. Several independent simulations were performed and the average PLR was calculated. For all simulation results we have plotted the error-bars showing the limits within a 95 % confidence interval. Simulations have been obtained using the DEMOS (Discrete Event Modelling On Simula) software. The analytical results are obtained using equations (1)-(16). All simulations have been performed with Poisson arrival process and exponential i.i.d. packets.

Regarding the WA, we have simulated an output fibre according to the models in figure 2 and 3. The mean packet lengths equal $E(L) = 400$ *bytes*. The total number of wavelengths is set to $N = 32$, each with a capacity of 2,5 Gbps. In the case with service differentiation, the number of wavelengths available to LP packets is set to $n = 29$. The generated traffic is comprised of 10 % HP traffic ($A_H = 0.10$) and 90 % LP traffic ($A_L = 0.90$), i.e. $\alpha_L = 9\alpha_H$. In the case with no service differentiation, no wavelengths are reserved for HP traffic, i.e. $N = n = 32$. Total packet arrival rate is then $\alpha_O = \alpha_H + \alpha_L$. In figure 6, the packet loss rate as a function of the system load is presented.

First, we see that the analytical results obtained match well with the results obtained from the simulations. Second, compared to traffic without priority, we see from figure 6 that a lower PLR for HP packets comes at the cost of a higher PLR for LP packets. According to the conservation law, this is expected [7]. Third, we also see that only a small number of wavelengths ($W_H = 3$) need to be reserved for HP packets in order to reduce packet loss rate with a factor of 10^3 compared to traffic without priority.

Regarding the PDP, figure 7 shows the PLR for HP and LP traffic as a function of the system load. The number of wavelengths is $N = 4$, the variable $p = 1$ and the relative share of HP traffic is $A_H = 0,2$. First, we see that the simulation results match the analytical results for all system loads, which verifies our analytical model.

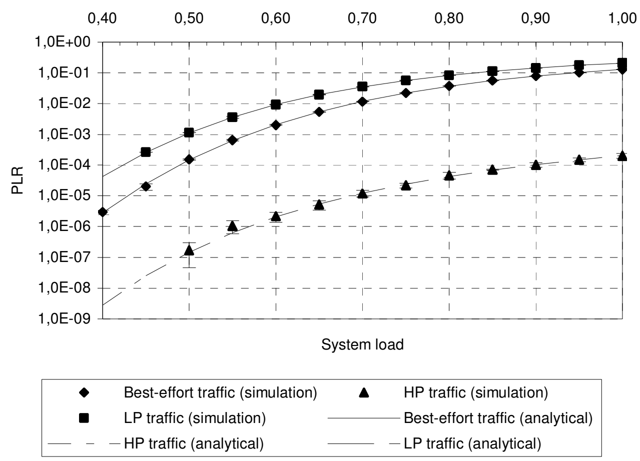

Figure 6: The PLR as a function of the system load for the WA

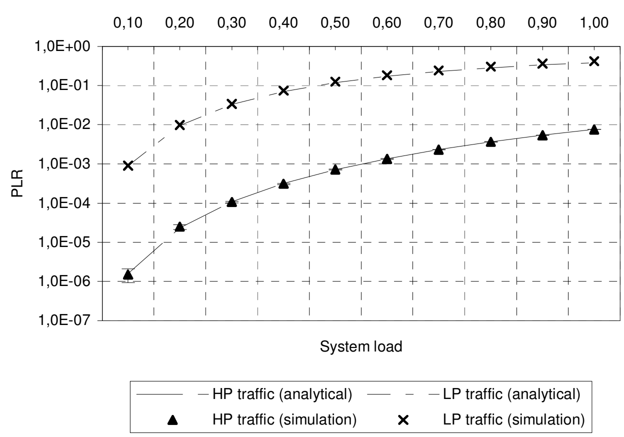

Figure 7: The PLR as a function of the system load for the PDP.

5.3. A concise comparison study between the WA and the PDP

Intuitively we should expect the PDP to have better performance than the WA, since all available wavelengths are used to transport both HP and LP traffic. Both the PDP and the WA can achieve any desired PLR for HP traffic if the number of wavelengths is large enough. However, in order to compare these algorithms, we adjust the different parameters so that the PLR for HP traffic is less than 10^{-5} and then compare the resulting PLR for LP traffic. The system load is set to $A = 0,8$, the share of HP traffic is $A_H = 0,1$ and the total number of wavelengths is $N = 32$. Table 1 shows the PLR for HP and LP traffic for both algorithms. For the PDP we have utilized empirical distributed packet lengths and the variable $p = 1$. For the WA algorithm we have utilized $n = 28$.

	HP traffic	**LP traffic**
PDP	$PDP_{HP} = 2{,}42 \cdot 10^{-6}$	$PDP_{LP} = 4{,}43 \cdot 10^{-2}$
WA	$WA_{HP} = 4{,}59 \cdot 10^{-6}$	$WA_{LP} = 1{,}01 \cdot 10^{-1}$

Table 1: Comparing the PWA and the WA algorithm

From table 1 we see that $PDP_{HP} < WA_{HP}$ and $PDP_{LP} < WA_{LP}$, which means that using the PDP results inn lower PLRs for both HP and LP traffic compared to the WA. Hence, we can conclude that the PDP has better network performance than the WA in the circumstances assumed here. How the system load and the relative share of HP traffic influence the outcome of this comparison has not been considered. Also, the packet length distribution influences the outcome of this comparison too. This is because the WA is independent on the packet length distribution, as showed in section 3.2, while the PDP can be shown to be dependent on the packet length distribution.

Furthermore, regarding the management plane, the PDP involves slightly more processing than the WA. For the WA, the switch needs only to keep track of how many wavelengths that are busy transmitting packets at each output fibre. For PDP the switch must in addition keep track of the window and how many packets that are preemptied within the window for every output port. Whether the increased performance in the PDP can compensate for this increased processing or not is still an open question.

6. Conclusion

Several approaches may be taken in order to provide service differentiation in future optical core networks. If we avoid using contention buffering, we achieve both simple management and low cost switches. Both the WA and the PDP examined in this paper provide service differentiation in bufferless OPS/OBS networks. By using (multi-dimensional) Markov chains, we have derived analytical expressions for the packet loss rates in an asynchronous optical packet switch with full wavelength conversion. Simulations verify the analytical model. We have also performed a comparison study between the WA and the PDP. Analytical results show that the PDP is more efficient than the WA.

Future work will consider an analytical model of improved QoS policies, which includes the use of deflection routing and possibly contention buffering. Also, an extended simulation model, which considers a complete network with more realistic traffic sources will be studied. At last we plan to examine methods on how to provide absolute end-to-end QoS guarantees in OPS/OBS networks [3].

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