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Performance Analysis of Fiber Delay Lines and Tunable Wavelength Converters for Contention Resolution in Optical Packet Switched Networks*

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Abstract In this paper, two contention resolution schemes have been studied, namely, feedback-based fiber delay lines (FDLs) Architecture (FFA) and feedback-based combined sharing of FDLs and tunable wavelength converters (TWCs) architecture (FFTA), for non-bursty traffic and bursty traffic on the basis of our optical packet switched test-bed. It is demonstrated that for non-bursty traffic, FDL is a preferable choice than TWC while TWC is a preferable one than FDL for non-bursty traffic to resolve contention in optical packet switching networks. Numeric results confirm that FFA is sufficient to obtain a reasonable packet loss probability (PLP) for non-bursty traffic, while for bursty traffic, FFTA, performs much better given that the total number of FDLs and TWCs used equals to those of FDLs used in FFA. With the increase of the average burst length, the number of TWCs in FFTA will gradually increase so as to obtain a reasonable PLP. However, even for the traffic with high degree of burstness, FFTA is still a cost effective and robust solution.

Keywords Tunable wavelength converters; Fiber delay lines; Contention resolution; Optical packet switch

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0 Introduction

Optical Packet Switching (OPS)[1] has been regarded as an efficient switching technique to exploit the capacity provided by density wavelength division multiplexing (DWDM) technology for the next generation optical Internet. Commonly, optical packet switched networks can be classified into two sorts, time-slotted network with fixed length payload and unslotted network with variable length payload. Contention resolution is an important topic in OPS networks. If no suitable resolution scheme adopted, one or more contending packets will be lost even if there is another free output or the contended output will be free at the next time slot. Conventional contention resolution includes: 1) In time domain[2], i.e., adopting FDLs to buffer the contending burst until the contended wavelength channel becomes free; 2) In wavelength domain[3], i.e., the bearing wavelength of contending packet will be converted to another free wavelength through wavelength conversion; 3) In space domain[4], i.e., deflection routing, which utilizes free link in the networks to bypass the contending node to destination. In this paper, we will emphasize on reporting our progress on contention resolution on the basis of our test-bed. Our test-bed consists of three ingress/egress nodes and one core node. The switch of core node consists of four main function blocks: 1) Input stage, where a demultiplexer selects the packet arriving on W wavelength channels, $\lambda_1, \cdots, \lambda_w$, on each of the N input fibers. In our test-bed, the parameters of W and N are chosen both as 2; 2) Switch stage, which consists of a 200 ns high speed optical switch matrix (8×8) and feedback-based FDLs to direct the arriving packets to the appropriate output fibers, or, to the appropriate free FDLs if contention occurs; 3) Output stage, where a passive coupler couples the packet arriving on W wavelength channels to the output fiber; 4) Control module, which includes the function such as the recognition and update of optical packet head, synchronous control, switching control. In the following sections, we'll focus on our contention resolution schemes.

1 The proposed architectures and operations

1.1 Feedback-based FDL architecture (FFA)

Fig. 1 (a) shows our first scheme, which is implemented by feedback-based FDLs to buffer the contending packets. We call this architecture FFA, in which FDLs are arranged in degenerate form from T to

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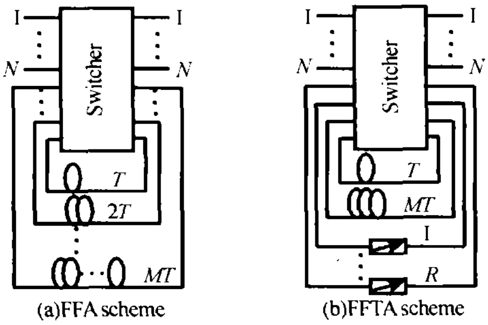
$M \times T$, i. e. , delays uniformly cover the entire range of buffer depth, from T to $M \times T$, with increments of one unit. One time unit, T, is the duration of one time-slot denotes the transmission time of one packet. The mechanism of this scheme is to schedule the contending packet in next time slot through buffering it in FDL. Because this architecture does not perform so good for bursty traffic as for non-bursty traffic (which will be analyzed in section 2), a developed feedback-based combined sharing of TWCs with FDLs is proposed.



(a)FFA scheme (b)FFTA scheme

Fig. 1 Structure of FFA and FFTA scheme

1.2 Feedback-based combined sharing FDLs and TWCs architecture (FFTA) and it's dimension

It has been demonstrated that TWC is good at resolving contention for bursty traffic[3]. In our developed architecture, we place TWCs in feedback form combined with FDLs as in Fig. 1 (b). All R TWCs are the same. The structure of FDLs is degenerate and delays uniformly covering from T to $M \times T$. We denote it as (M, R), which is the continuation of conventional FFA scheme. When R is zero, (M, R) architecture becomes an FFA. Once contention occurs, switching system can either schedule the contending packet into FDLs so that the packets can be transmitted in future time slot, or, by using TWCs, to tune the carried wavelength of the arriving packet to another free wavelength in the contending output fiber. If new contention occurs among the outputs of the FDLs, it will be resolved either by selecting free TWC or circulating the contending packets into the same FDL.

2 Traffic models

2.1 Non-bursty traffic model

We examine our contention resolution scheme through two kinds of traffic models, namely, non-bursty traffic model and bursty traffic model. Just as that McKeown et al used to evaluate Cisco 12000 series Routers to generate non-bursty traffic[5], we adopt the following assumptions:

1) The packet arriving independently with same distribution of Bernoulli process;

2) The destinations of the arrival packets is assigned uniformly among all outputs;

3) The traffic load of each fiber is 0.8 Erlang.

2.2 Bursty traffic model

As bursty data traffic will be preeminent in future applications, so we would like to pay more attention on bursty traffic case. At first we illustrate this model[6] briefly.

As in Fig. 2, time correlation of traffic on each input is modeled on the Markov chain. The chain is composed of three memoryless states: Idle, Burst I and Burst II, denoted as Burst i ($i \in \{1, 2, 3\}$) and defined as

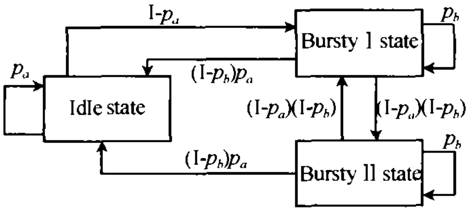


Fig. 2 The model used to generate bursty traffic

1) Burst 1: no packet;

2) Burst i ($i = 2, 3$): there is packet arriving in a current slot;

The transition of states is defined as

1) Burst i ($i = 2, 3$) to Burst 1: no packet arriving in a current slot, but there is one in previous slot;

2) Burst i to Burst j ($i, j = 2, 3$): if $i = j$, the destination output of the packet arriving in the current slot is different from that of the previous one. Otherwise, the output of both packets is same;

3) Burst 1 to Burst 2: there is a packet arriving in a current slot, but no one in previous slot.

We also define two kinds transition probability as: p_a the probability of no packet arriving in both current slot and the previous one, i. e. , the probability from Burst 1 to Burst 1; p_b the probability of there comes packet in both current slot and the previous one, i. e. the probability from Burst 2 to Burst 2 or from Burst 3 to Burst 3.

According to the characteristic of Markov chain, we get the transition probabilities as in Fig. 2. Then Eq. (1) corresponds to the steady-state solution of above Markov chain π_i is the steady-state probability of the system being in state i, where $i \in \{1,2,3\}$).

$$\begin{bmatrix} p_a & (1-p_b)p_a & (1-p_a)p_b \\ (1-p_a) & p_b & (1-p_a)(1-p_b) \\ 0 & (1-p_a)(1-p_b) & p_b \end{bmatrix} \cdot \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{bmatrix} \tag{1}$$

Solving (1) results in

$$\pi_1 = \frac{p_a(1-p_b)}{1-p_ap_b}; \pi_2 = \frac{(1-p_a)}{(1-p_ap_b)(2-p_a)};$$

$$\pi_3 = \frac{(1-p_a)^2}{(1-p_ap_b)(2-p_a)} \tag{2}$$

The average burst length, L, is calculated by observing that the probability of burst k is

$$p_r(k) = (1-p_b)p_b^{k-1} \quad (k \geq 1) \tag{3}$$

Thus the average burst length is

$$L = \sum_{k=1}^{\infty} kp_r(k) = \frac{1}{1-p_b} \tag{4}$$

The value of burst length also denotes the degree of traffic burstness. The larger the value, the higher the burstness of traffic will be.

3 Simulation results and numerical analysis

In this section, we will study the performance of FFA and FFTA for non-bursty and bursty traffic firstly. Then we will analyze and conclude that how to dimension efficiently the developed architecture according to the simulation results so that the performance will be achieved as well as possible for both non-bursty and bursty traffic. We employ eight degenerated FDLs for FFA, while the total number of FDL and TWC is also eight for FFTA. All the results are obtained when number of input/output ports is 16, and traffic load on each fiber is 0.8 Erlang. We assume that optical packets have fixed size and their arrivals on each wavelength are synchronized[5].

Fig. 3 shows the performance of FFA for non-bursty traffic. The more the FDL number, the less PLP will be, and the performance improved distinctly with the increase of FDL. While for bursty traffic, the results are widely divergent from the non-bursty traffic counterpart. As showed in Fig. 4, the heavier the burstness of traffic, the more slightly the PLP decreases with the increase of FDL. Therefore, FFA is not a favorable choice for traffic with high burstness although it can guarantee PLP requested through appending a large amount of FDLs.

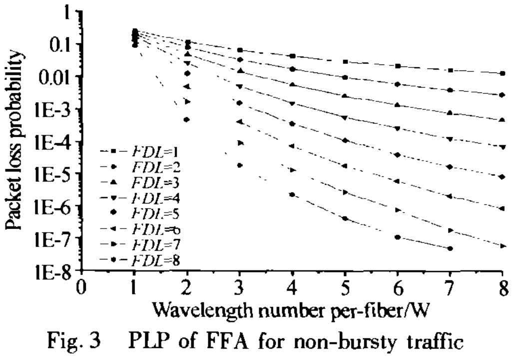


Fig. 3 PLP of FFA for non-bursty traffic

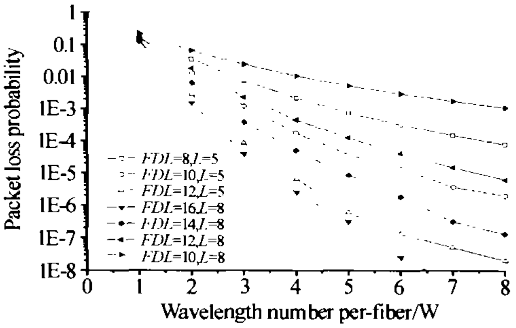


Fig. 4 PLP of FFA for bursty traffic

Fig. 5 plots the PLP of FFTA for non-bursty traffic, the more the FDL allocated in this architecture, the better the performance on PLP will be for contention resolution. Then we can conclude that the efficiency of FDL is much more than that of TWC for non-bursty traffic.

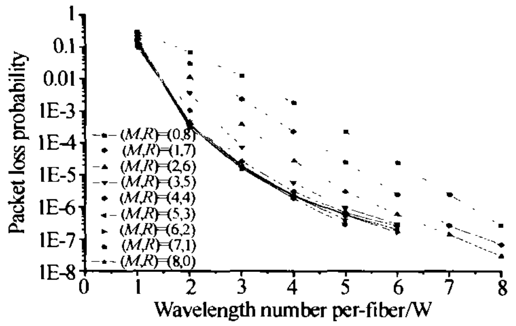


Fig. 5 PLP of FFTA for non-bursty traffic

From Fig. 6 ~ 8, we simulate the PLP versus the wavelength number on each fiber when the average burst length is 2, 5 and 12 respectively with different assignment of FDLs and TWCs in FFTA. We can find that the PLP for different configuration is very close to that of the non-burst traffic for a small average burst length, but with the increase of the burstness of traffic,

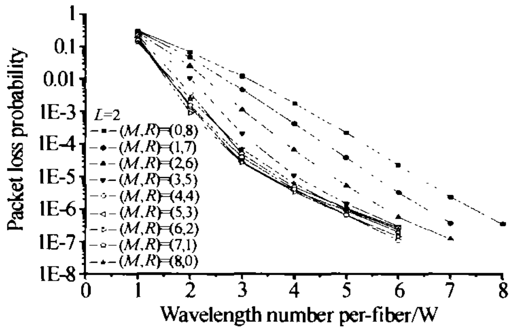


Fig. 6 PLP of FFTA for bursty traffic $L = 2$

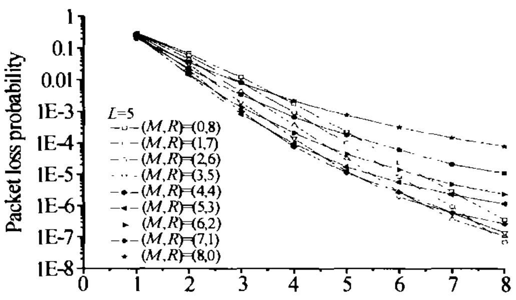


Fig. 7 PLP of FFTA for bursty traffic $L = 5$

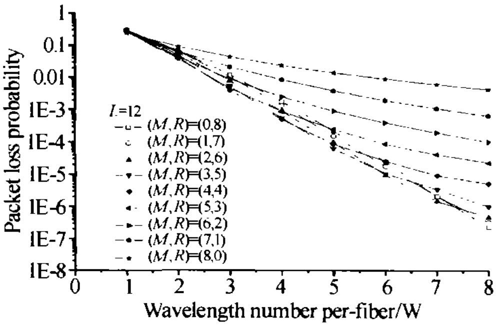


Fig. 8 PLP of FFTA for bursty traffic $L = 12$

it is more efficient to increase the number of TWC than FDL to decrease the PLP.

From above numeric results, we can reach the following conclusions:

1) For non-bursty traffic, FDL is a preferable choice than TWC to resolve contention. While for bursty traffic, TWC is more efficient than FDL for contention resolution.

2) For a prefixed PLP constraints, e.g., 10^{-6}, if the wavelengths per fiber is no less than 8, according to the simulation results described above, the most efficient way to decrease the PLP is with the combined use of FDLs and TWCs, e.g., for $L>2$ and $W \geqslant 8$, a configuration of $(M,R) = (5,3)$ is a good choice to obtain an reasonable PLP and a reasonable cost. This configuration is robust and adaptive for non-bursty traffic and bursty traffic.

It's easy to find what results in above conclusions if we analyses how FDL and TWC deal with contention. FDL is to schedule the contending packet in next time slot through buffering it in FDL temporarily. This will increase the contention probability of the next time slot. Of course it will be unfavorable for high burstness traffic. On the contrary, TWC can handle the contending packet immediately through another free wavelength without leaving any aftereffect to the subsequent time slots.

4 Conclusions

We have investigated the performance of two contention resolution schemes, Feedback-based FDL Architecture and Feedback-based combined sharing of FDLs and TWCs Architecture, for non-bursty traffic and bursty traffic on the basis of our optical packet switched test-bed. We demonstrate that if wavelength on each fiber is no less than 8, the former is sufficient to obtain a reasonable PLP for non-bursty traffic, while for bursty traffic, the developed architecture, FFTA, performs much better given that the total number of FDLs and TWCs used in it equals to those of FDLs used in FFA. With the increase of the average burst length, the number of TWCs needed for FFTA will gradually increase so as to obtain a reasonable PLP. However, even for the traffic with high degree of burstness, the developed architecture is still a cost effective and robust solution. We also derive the most robust dimension of FFTA basing on the numeric results.

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光纤延迟线和可调谐波长转换器在光分组交换网络竞争解决结构中的性能分析

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摘　要　研究了光分组交换网络中的两种竞争解决方案．结合课题研究的进展，基于突发和非突发业务，对这两种竞争处理结构进行了深入分析，得出了几点重要结论，首先，在竞争处理上，对于非突发业务，光纤延迟线比可调谐波长转换器有效；而对于突发业务而言，可调谐波长转换器比光纤延迟线有效．其次，在突发业务下反馈式光纤延迟线结构(FFA)是一种较为理想的竞争解决结构，但对非突发业务而言，反馈式光纤延迟线和可调谐波长转换器结构(FFTA)在成本上和结构尺寸上比 FFA 要有效的多．随着平均突发长度的增加，FFTA 中的可调谐波长转换器数目也要增加才能获得合理的分组丢失率。但无论是针对突发业务还是非突发业务，FFTA 都是一种成本有效的竞争解决结构．

关键词　可调谐波长转换器；光纤延迟线；竞争解决；光分组交换

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