Improved optical packet switching structure with recirculation buffer and feedback tunable wavelength converter

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The performance of an optical switching network is mainly determined by its core node structure. An improved optical packet switching (OPS) node structure based on recirculation optical fiber delay line (FDL) and feedback tunable wavelength converter (TWC), and a specific scheduling algorithm for the node structure are presented. This switching structure supports both point-to-point and point-to-multi-points broadcasting transmission with superior capacity expansion performance. Its superiority in packet loss probability is proved by simulation.

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In an optical packet switching (OPS) network, contention resolution is necessary to handle the case where more than one packets are destined to go out of the same port at the same time. This is known as external bocking. Techniques designed to resolve the external blocking include optical buffering, exploiting the wavelength domain, and using deflection routing[1]. To avoid the contention, the packet using deflection routing may end up following a longer path to its destination, which is a method for network. The other two methods are used to an optical switching node. Optical buffer commonly consists of fiber delay lines (FDLs). According to the positions of the buffer, buffered packet switches are essentially classified as input buffering, output buffering, shared buffering, and recirculation buffering[2]. There are two configuration methods for tunable wavelength converter (TWC): not shared and shared[3]. The individual use of FDL or TWC cannot get the optimal effect. In recirculation buffering, a set of FDL is shared by all the outgoing fiber links, which improves the using ratio of FDL. When the traffic bursts, the outgoing ports fight for the use of shared FDL, which may cause the lack of FDL. For bursty traffics, there may be no free wavelength to be used in the shared TWC configuration method.

In this letter, we propose a node structure combining recirculation buffering and shared TWC to handle the contention, and at the same time, cut down the cost of the switch by reducing the quantity of expensive TWCs. This switching structure supports both point-to-point and point-to-multi-points broadcasting transmission with remarkable extendable capacity. Recirculation FDL and feedback TWC are chosen as two interior multicast modules, as shown in Fig. 1. $1\times N$ optical splitters, 1×2 optical splitters, multi-level FDLs, and TWC are used for the modules. The recirculation FDL module consists of N FDLs (N is the number of inputs/outputs). The FDL i delays an optical packet with a fixed delay equal to i slots. The feedback TWC module consists of N FDLs and a TWC, which can delay the packet for some slots and then convert the wavelength of optical packet to a wavelength that is free at the destination output port. For instance, consider an incoming signal arriving at the interior multicast module through multi-level optical demultiplexer and 1×2 optical splitter. If it is not blocked in the outgoing port, it will be transmitted to the outgoing port, otherwise it will be handled in the recirculation FDL or the feedback TWC and then sent back to the multi-level optical demultiplexer again.

The impproved OPS node structure is shown in Fig. 2. It consists of $1\times M$ optical demultiplexers, $1\times2N$ interior multicast modules, and $NM\times1$ optical combiners. For each incoming fiber link, there is an optical demultiplexer which divides the incoming optical signal to M different wavelengths. Then each wavelength is fed to a $1\times2N$ interior multicast module, recirculation FDL module, or feedback TWC module. The N output ports of each interior multicast module connect the input ports of the $NM\times1$ optical combiners, and the other N output ports connect the multi-level FDL in the interior multicast module.

The improved optical node structure makes use of the recirculation FDL module and feedback TWC module to

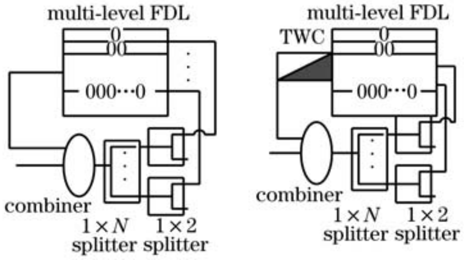

Fig. 1. Recirculation FDL module and feedback TWC module.

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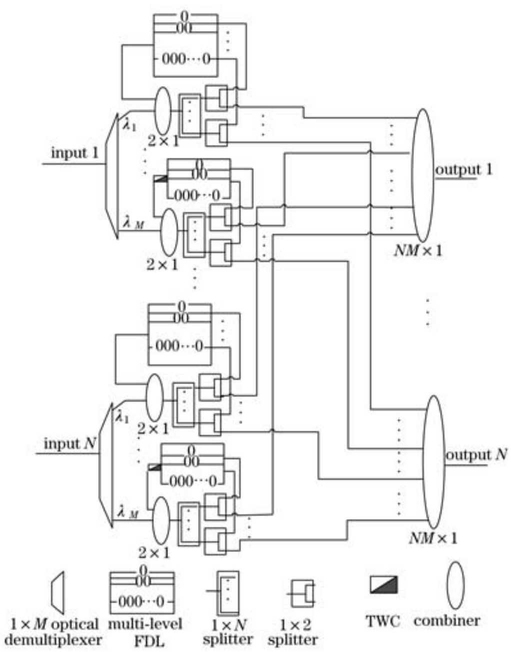

Fig. 2. Improved OPS structure.

overcome contention. The conservative mode and greedy mode scheduling algorithms for switching with buffer are presented and discussed. In the conservative mode, the current packet will be rejected when the specific FDL is occupied by another optical packet, even if there are other free FDLs with longer delay. While in the greedy mode, the current packet will not be rejected until there is no FDL with enough delay. Compared with optical buffer, there are mainly two configuration methods for TWC. One is to convert the wavelength of optical packet to a wavelength that is free at the destination output port. The other is to convert the wavelength to another given wavelength based on a mathematic formula. The second method is simple, needing no complex lookup algorithm.

An appropriate protocol has been demonstrated to optimize the OPS network[4,5], so a proper protocol for the improved OPS structure is necessary. Therefore we choose the second method to configure TWC and the greedy mode for optical buffer. We set up an event list which consists of the incoming packets and the packets in recirculation FDL module and feedback TWC module. Then we choose a packet, the trigger time of which is the minimal but not zero in the event list, as the current event. After the operation of the current event, the event list should be refreshed. Let t be the packet trigger time to the switch, which is the sum of the trigger time of the last packet from the same incoming port and the interval time. If t is bigger than the sum of the trigger time and the length of the last packet in the outgoing port, it will be successfully transmitted; otherwise it will be switched to the recirculation FDL or feedback TWC. If the FDL is available, the packet can be delayed for some time waiting for the free state of outgoing port, otherwise the arrival packet is lost. If the TWC is available, the wavelength of the packet can be changed to another one. One packet can go back to the recirculation FDL module or feedback TWC module for many times when the outgoing port is not free. The times that one packet goes back to the recirculation FDL module are not restrained, while in the feedback TWC module, it is at most K times (K=5). When it exceeds K times, the packet will be lost. The packet loss probability is the ratio of the number of the packets through the switch to the total number of the packets. We use C programming language to simulate the whole switching node and the packet flowing. We also define a variable to record the number of the packets passing the switching in order to calculate the packet loss probability. In the simulation, the total number of packets is fixed to 10^5.

The model of the self-similar traffic follows the conventional ON/OFF sources model[6] where the traffic is represented by alternating ON (packet presence) and OFF (inter-arrival time) periods. The length T of each period is modeled according to the Pareto heavy-tail distribution and presented as

$$T_{\mathrm{ON}} = \lfloor \mathrm{length}/(U)^{\frac{1}{\alpha}} \rfloor, \tag{1}$$

$$T_{\mathrm{OFF}} = \lfloor \mathrm{interval}/(U)^{\frac{1}{\alpha}} \rfloor, \tag{2}$$

where U is a random variable uniform on [0, 1], and $\lfloor * \rfloor$ indicates the floor function. We can set the numerical value of length and interval to control the traffic load α of the switch.

Figure 3 shows the packet loss probability as a function of the number of recirculation FDL modules connecting one input (p) and the number of feedback TWC modules connecting one input (q) for each structure (p_q_MODEL). The result presents that $p = 4$, $q = 4$ are

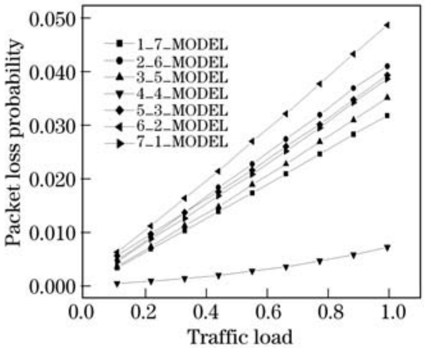

Fig. 3. Packet loss probability as a function of p and q for each structure. The number of inputs/outputs is 8, the number of channels per input/output is 8, the buffer depth of the FDL buffer is 8, and the delay granularity is 0.5

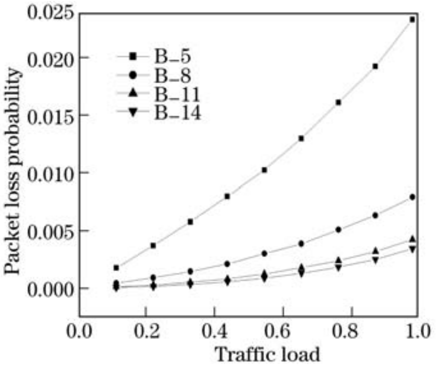

Fig. 4. Packet loss probability as a function of buffer depth for each structure.

enough to guarantee the minimum packet loss when the number of inputs/outputs, the number of channels per input/output, the buffer depth of the FDL buffer, and the delay granularity are 8, 8, 8, and 0.5, respectively.

Figure 4 shows the packet loss probability as a function of the buffer depth of FDL for each structure. As the buffer depth grows, the packet loss probability firstly decreases, and then becomes stable. The optimum buffer depth is 11 (B_11).

Figure 5 shows the packet loss probability as a function of the delay granularity of FDL for each structure. The result presents that the packet loss will increase if the delay granularity is either too small or too large. For this structure, the optimum delay granularity is 1.3 (G_1.3). When the delay granularity is 13, excess load[7] occurs.

Figure 6 shows the packet loss probability of a new-structure (NEW_4_4_MODEL) when p=4, q=4, and the buffer depth of the FDL buffer and delay granularity are 11 and 1.3, respectively. The packet loss capability of the NEW_4_4_MODEL is better than the 4_4_MODEL.

In the simulation, the transmission of the packets is asynchronous; also this structure can work in a synchronous way. In synchronous OPS systems, it is necessary to synchronize the packets before they are switched in the switching structure. So it needs more FDL stages for synchronization than the optical switching structure itself[8]. Recirculation buffer architecture in the improved OPS structure can greatly reduce this complexity. The switching structure supports two expansion capabilities, channel expansion and wavelength expansion, as shown in Figs. 7(a) and (b).

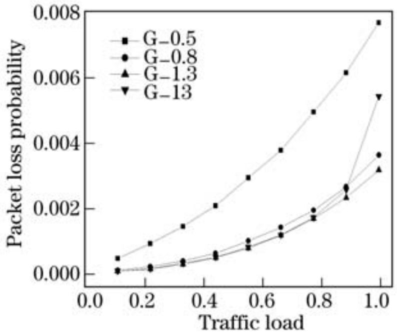

Fig. 5. Packet loss probability as a function of delay granularity for each structure.

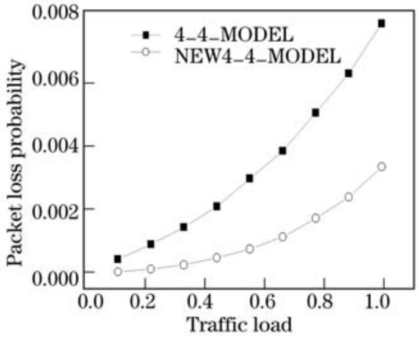

Fig. 6. Packet loss probability for NEW_4_4_MODEL and 4_4_MODEL.

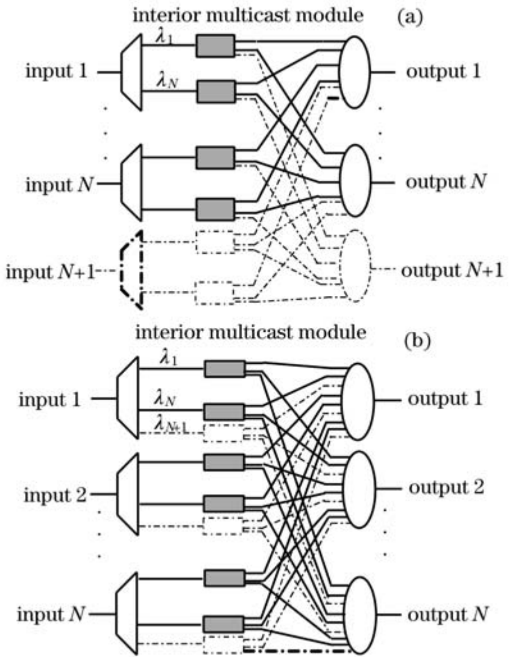

Fig. 7. Expansion capabilities of the improved OPS structure. (a) Channel expansion, (b) wavelength expansion.

In conclusion, we propose an improved OPS structure with the recirculation FDL module and feedback TWC module. The basic idea of specific scheduling algorithm is to fully utilize the feedback loop so that the packet loss probability can be reduced. Simulation results demonstrate that the structure with the number of recirculation FDL modules connecting one input, the number of feedback TWC modules connecting one input, the buffer depth of the FDL buffer, and the delay granularity being 4, 4, 11, and 1.3 works well in OPS network with the minimum packet loss.

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References

1. S. Yao, B. Mukherjee, and S. Dixit, IEEE Commun. Magazine **38,** (2) 84 (2000).
2. J. Wang, Y. Song, S. Wang, and Q. Zeng, Proc. SPIE **5625,** 714 (2005).
3. H. Lim, K.-S. Yu, C. Oh, and C.-S. Park, in *Proceedings of International Conference on Transparent Optical Networks 2006* 169 (2006).
4. G. Wang, H. Wang, and Y. Ji, Chin. Opt. Lett. **6,** 628 (2008).
5. A. K. Garg and R. S. Kaler, Chin. Opt. Lett. **6,** 244 (2008).
6. L. Tančevski, A. Ge, G. Castanon, and L. Tamil, in *Proceedings of Optical Fiber Communication Conference* **3,** 180 (1999).
7. F. Callegati, in *Proceedings of Computer Communications and Networks 2000* 448 (2000).
8. S. J. B. Yoo, J. Lightwave Technol. **24,** 4468 (2006).