Research on performance of multicasting in optical packet switched networks

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Different multicasting schemes in optical packet switched networks are discussed, including the parallel mode, serial mode, and hybrid mode multicasting schemes. Simulated modeling technique is applied to compare the network-level performance of the three multicasting schemes. A conclusion can be drawn from the results that since the hybrid-mode multicasting scheme can increase the multicast success ratio and reduce the packet retransmission times compared with the other two schemes, it is the best choice for delivering multicasting sessions in the optical packet switched networks.

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With the advent of many new applications, such as content delivery, Internet protocol television (IP-TV), video on demand, etc., which require the transmission of real-time multimedia from one source to many destinations, multicasting technology has become increasingly important and popular in the communication networks. Since multicasting can be supported more efficiently in the optical domain by utilizing the inherent light-splitting capacity of optical devices than by copying data in the electronic domain, researches on delivering multicast sessions in the all-optical networks have received more attention in recent years[1−12].

The initial approach to implement the all-optical multicasting is proposed in the wavelength-routed optical networks and based on the wavelength paths. It also refers to the light-trees[3]. The uses of light-tree can better support the bandwidth-intensive applications that require high bandwidth and a relatively long duration with guaranteed quality of service (QoS). After that, since the optical packet switching (OPS) is more suitable for the high bursty traffic than the optical circuit switching (OCS), packet based all-optical multicasting schemes and switch fabrics have received more attentions in recent years. Up to now, three different packet-based all-optical multicasting schemes have been proposed to implement the multicasting in the optical packet switched networks, including the parallel-mode (PM)[3−7], serial-mode (SM)[8−10], and hybrid-mode (HM)[11−12] multicasting schemes. In this letter, we first review the three multicasting schemes and discuss their respective strength and weakness. After that, we compare their performance by computer simulations. Different from our previous work[11], background traffic is considered in the simulations and both transmitter-side and receiver-side performance are investigated, such as the multicast success ratio, the packet loss ratio, and the average multicasting transmission latency. In the following parts of this letter, the three multicasting schemes will be discussed first and then detailed performance analysis will be presented.

Due to the lack of the optical random memory (ORAM), traditional approach to perform the multicasting in the optical packet switched network is based on the PM multicasting scheme. It can produce multiple simultaneous copies of the input optical multicast packet and export them to the downstream links at the same time. According to the different structures of multicast modules, the PM scheme can be divided into two types, the embedded PM scheme and the separated PM scheme.

The embedded PM scheme is illustrated in Fig. 1(a). It consists many 1-to-n optical power splitters embedded in the optical switch matrix[3]. In this type of multicast scheme, the output optical signals will suffer from the power loss due to the splitting operation. Recently, this problem has been solved by the proposed active vertical coupler (AVC) based optical crosspoint switch (OXC)[4], which can implement scalable multicast operations optically without excess splitter loss. However, since wavelength converters are not arranged at the output ports of those active vertical couplers, all the copies of an input optical multicast packet will be exported on the same wavelength in this structure. Consequently, conflicts between the copies of the optical multicast packet and other unicast packets, which are also processed by the optical switch matrix, will increase and, therefore, the network performance will be impaired.

The separated PM scheme[6−7] uses a separated optical multicast module to produce multiple copies of an optical multicast packet, as shown in Fig. 1(b). In this scheme, the input optical multicast packet will be first switched to the separated PM multicast module, normally a single device which can provide the one-to-many wavelength conversions simultaneously[7]. Then, by power splitting and wavelength conversion, the multicast module can produce n copies of an input optical multicast packet on n different wavelengths and then export these copies to the optical switch matrix. Owing to the utilization of a certain number of active components such as lasers and switches, this scheme can remove the excessive power loss caused by the splitting operation. However, since the number of the wavelengths exported from the multicast module is limited by the total signal power or the dispersion of the nonlinear medium[4], the total number of the copies of the input packet generated by the multicast module is limited in this scheme.

In addition, as illustrated in Fig. 1, since both of the two PM multicasting schemes are strictly restricted to time, when all the copies of an optical multicast packet are exported simultaneously, conflicts between those copies and other optical unicast packets are hard to avoid. That will lead to the packet retransmission and impair the network performance.

The SM multicasting scheme[8] is illustrated in Fig. 2(a). It uses a separated multicast module to realize the duplication and storage of the input optical multicast packets and export the copies of these packets to the downstream links serially. The main structure of the SM-based multicast module is a 3-dB-splitter-embedded and optical-switch-controlled all-optical loop[9]. Since the copies of the input optical multicast packets are exported one by one in this scheme, compared with the PM scheme, conflicts between the copies of the optical multicast packet and other unicast packets will be decreased in the SM scheme and the number of the copies received by the destination nodes will be increased.

However, due to the use of an all-optical loop (for buffering the optical multicast packets) and the erbium-doped fiber amplifiers (EDFA) (for compensating the power loss caused by the optical power splitter), noise and signal impairments will increase in the SM scheme. In addition, as the copies of the optical multicast packets are exported serially, an extra multicast delay will be brought into this scheme.

To reduce the signal impairment and the extra delay caused by the SM scheme, we proposed a HM multicasting scheme in Ref. [11]. As shown in Fig. 2(b), it combines the PM scheme and SM scheme, realizes the duplication and storage of the input optical multicast packets, and exports multiple copies each time. Since each time there are multiple copies exported in the HM scheme, the average extra delay caused by the optical loop will be lower than that in the SM scheme.

Finally, it should be pointed out here that both the SM and HM schemes have the limitation to the packet inter-arrival time of the input multicast traffic[9]. This is because the multicast modules based on the two schemes cannot process two or more optical multicast packets at the same time. In other words, a multicast node must have enough SM- or HM-based multicast modules to satisfy the requirement of the input multicast traffic.

By computer simulations, we investigate the performance of the three multicasting schemes in the optical packet switched network. Network model is shown in Fig. 3(a). There are four wavelengths in each downstream path and the data rate of each wavelength is

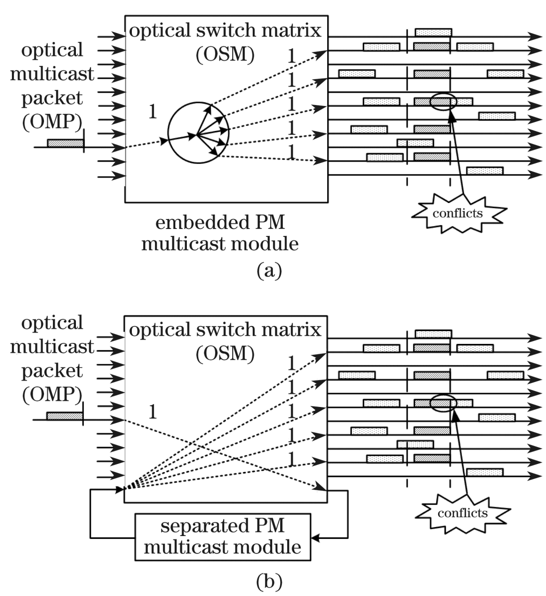

Fig. 1. Embedded (a) and Separated (b) parallel mode multicasting schemes.

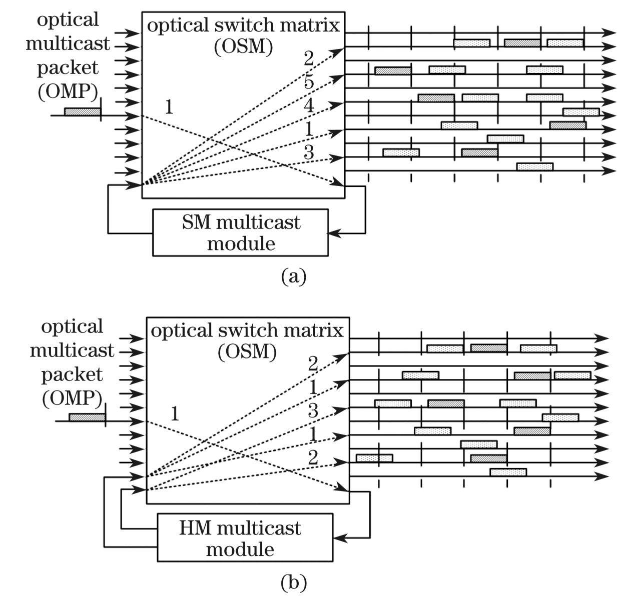

Fig. 2. SM (a) and HM (b) multicasting schemes. Numbers 1 to 5 are the operational steps of the optical switch matrix.

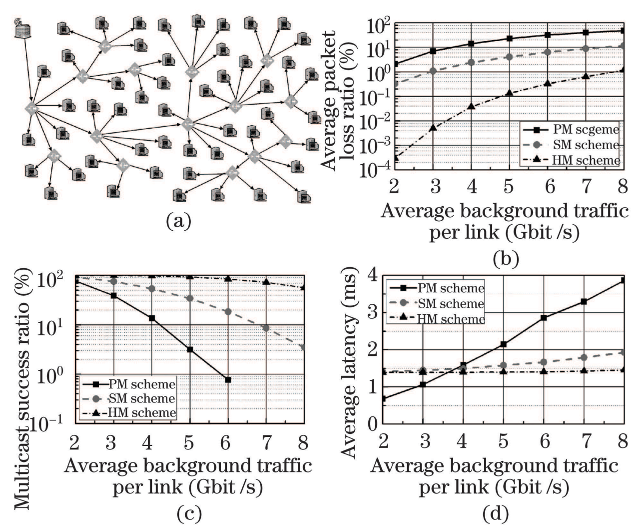

Fig. 3. Network model (a) and simulation results of packet loss ratio (b), multicast success ratio (c), and average latency (d).

2.5 Gbit/s. Different from our previous works[8,11], background traffic is considered in simulations and it is defined as a traffic with a fixed packet length of 10 kbit and a variable exponential-distributed packet inter-arrival time on each downstream path. Since multicast traffic, such as content delivery, IPTV, video conferences, and so on, is generally characterized as a static data flow with a certain packet length and a certain packet inter-arrival time, a constant bit rate (CBR) multicast traffic with a fixed packet length of 10 kbit and a fixed packet inter-arrival time of 125 μs is considered in the simulations. Other settings are the same as those in Ref. [11]. The latency of the fiber delay line (FDL) in the SM-based multicast module is assumed to be 10 μs (assume that the maximum processing time of the multicast module is less than 5 μs). Concerning the HM-based multicast module, we assume that the latency of its FDL[11] is the same as that of the FDL in the SM-based multicast module. To limit the transmission delay, the times of the copies of an optical multicast packet exported from the HM-based multicast module are assumed to be the same as those from the SM-based multicast module, which means that the SM scheme and HM scheme have the same maximal extra multicast delay. Moreover, retransmission scheme is adopted in the simulations. If the source does not receive all the acknowledgements of an optical multicast packet from all the destination nodes in 10 ms, it will send the packet again and there are only three times of retransmission for each packet.

On one hand, we investigate the packet loss ratio and the multicast success ratio of the three multicasting schemes with different background traffic loads and under the condition that no retransmission scheme is adopted in the simulations. The results are shown in Figs. 3(b) and (c), respectively. The packet loss ratio investigates the performance of the multicasting schemes from the receiver side. It is defined as the ratio of the number of the optical multicast packets that have not been received by the destination nodes to the number of the packets that should have been received by all the destination nodes. The multicast success ratio investigates the performance of the multicasting schemes from the transmitter side. It is defined as the ratio of the number of the optical multicast packets that have been successfully received by all the destination nodes to the number of the optical multicast packets that have been sent by the source node. From Figs. 3(b) and (c), we can see that due to the lack of conflict solution schemes, more packets are dropped in the PM scheme than in the other two multicasting schemes. As a result, the multicast success ratio and the packet loss ratio of the PM scheme is the lowest. Whereas, since each time more copies are exported from the HM multicast module than from the SM multicast module, the downstream links in the HM scheme will have more opportunities to be scheduled than those in the SM scheme. Consequently, the HM scheme can obtain the highest multicast success ratio and the lowest average packet loss ratio among the three multicasting schemes.

On the other hand, we investigate the average latency of the multicast traffic with different background traffic loads and under the condition that retransmission scheme is adopted in the simulations. Simulation results are presented in Fig. 3(d). Retransmission scheme is the same as that in Ref. [11]. From Fig. 3(d), we can see that when the background traffic is low, since seldom packets need to be retransmitted, the average transmission latency of the optical multicast packets transmitted by the PM scheme is lower than that by the other two schemes. Whereas, with the growth of the background traffic, multicast success ratio of the three schemes will decrease and the retransmission scheme will take effect due to the packet loss. Since the PM scheme has the lowest multicast success ratio among the three schemes, more packets need to be retransmitted. Consequently, the PM scheme has the highest average multicast delay in the three schemes while the HM scheme has the lowest delay owing to its highest multicast ratio.

In conclusion, we discuss three packet-based all-optical multicasting schemes, and hybrid mode multicasting scheme, and investigate their performance in the OPS network. From the simulation results, a conclusion can be drawn that when delivering multicasting sessions in the OPS networks, the hybrid mode multicasting scheme is the best choice due to its best performance in the three schemes.

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