Efficient Contention Resolution Algorithms for Recirculation Multicast Based Optical Router Switch Architecture

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Abstract: This paper presents multicast contention resolution algorithms for the multicast optical switch architecture employing recirculation multi-wavelength conversion. Simulation results demonstrate that the proposed algorithms effectively improve the optical network performance.

Keywords: Optical packet switching, contention resolution

1. Introduction

Future all-optical Internet expects to support multicast applications including multimedia streaming and video conferencing. As a result, multicast is a desirable feature in optical routers since it requires far less network capacity to transport packets as opposed to multiple unicast connections [1]. Previously reported multicast optical switch architectures with light-splitting and broadcast-and-select structures suffer from excessive power losses due to power splitting. Recently, multicast optical router switch architecture employing recirculation multi-wavelength converters (MWC) [2] received strong interest [3], since MWC based scheme does not incur excessive losses and provides optical signal regeneration. This paper presents efficient contention resolution algorithms for recirculation MWC based multicast optical switch architectures to improve the performance.

2. Multicast Contention Resolution Algorithms

2.1 Recirculation MWC Based Optical Router Architecture

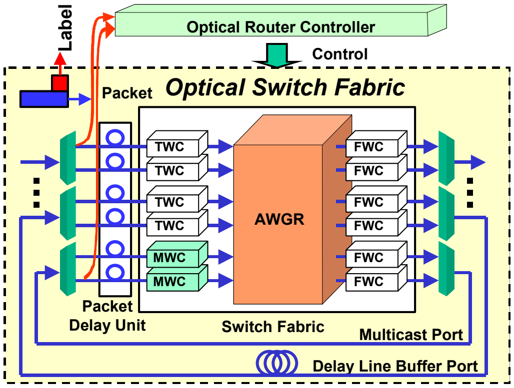


Figure 1 : Multicast optical router switch architecture

Figure 1 shows the overall architecture of the recirculation MWC based optical switch fabric architecture [3]. The switch fabric consists of tunable wavelength converters (TWC), a uniform loss and cyclic frequency (ULCF) arrayed waveguide grating router (AWGR), fixed wavelength converters (FWC), and newly introduced multi-wavelength converters (MWC) [2]. The optical router contains recirculation multicast ports, which utilize MWC technology to generate multiple copies of an incoming optical packet. MWC achieves this by simultaneously duplicating the input signal onto multiple wavelengths. Since MWC does not incur excessive losses due to power splitting, and offers an opportunity for optical signal regeneration compared with the light-splitting based multicast schemes. In addition, the optical router also consists of recirculation fiber delay line ports as an optical buffer [3-4].

2.2 Multicast Contention Resolution Algorithms

When multicast packets arrive, they first contend for recirculation multicast ports. If successfully winning the contention, the packets will be recirculated back to the MWC based multicast port for duplication. The duplicated packet copies will further contend for desired output ports with other unicast or multicast packets. As a result, multicast contention resolution algorithms must resolve both the recirculation multicast port contention and the output port contention.

Algorithm 1 - Concurrent Multicast Packet Dispatching Scheme (CMPD)

Figure 2 shows *CMPD* consits of both the multicast port contention resolution flow and output port contention resolution flow. During the multicast port contention resolution period, contention resolution methods [4] of the wavelength domain wavelength conversion and time domain fiber delay line buffers are sequentially applied to resolve contention. In the output port contention period, *CMPD* concurrently dispatches multiple copies of the incoming multicast packet to all of the desired output ports. Wavelength conversion is employed to resolve the multiple output port contention. The successful switching will require each destination output port to have at least one free wavelength channel simultaneously.

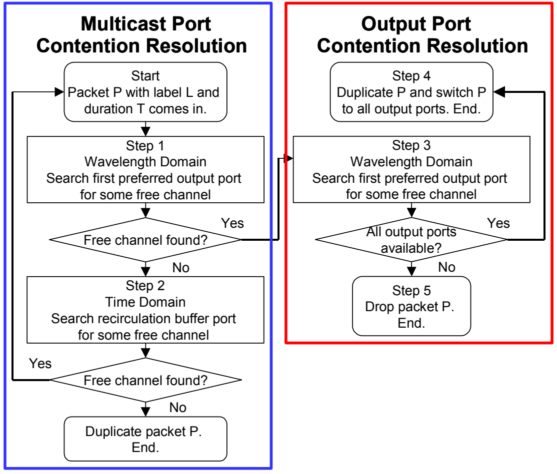


Figure 2 : Flow chart of CMPD

CMPD consists of five steps in resolving contention.

Step 1. The router controller forwards the multicast packet from the input port to one of the multicast ports. In this step, if multiple multicast packets are contending for the same wavelength on the same multicast port, wavelength conversion is used for resolving the multicast port contention in the wavelength domain.

Step 2. If all wavelength channels on all multicast ports are occupied, the switch control attempts the time domain fiber delay line buffers, i.e. to switch the multicast packet to one of the fiber delay line ports for buffering.

Step 3. If the multicast packet is switched to one multicast port successfully, the switch control will check the availability of all desired output ports simultaneously while employing the wavelength domain wavelength conversion in resolving the contention for any specific wavelength on each output port.

Step 4. If all desired output ports are available at the same time, the MWC at the multicast port will duplicate the packets onto multiple wavelengths that will forward the copies through the switch fabric to desired output ports.

Step 5. If none is available, the multicast packets will be dropped.

Algorithm 2 - First Available First Dispatching Scheme (FAFD)

For multicast sessions with high degrees of connectivity, the probability of blocking for the *CMPD* scheme could be high. *FAFD* is further proposed to improve the performance. The key difference with *CMPD* is that, during the output port contention period, *FAFD* dispatches the multicast packet copies to currently available output ports first, while it buffers one additional copy in fiber delay line buffers and waits for other desired output ports to be free. This way, *FAFD* does not require all of the destination ports to be free at the same time and avoids the situation when one busy output port blocks the entire multicast session.

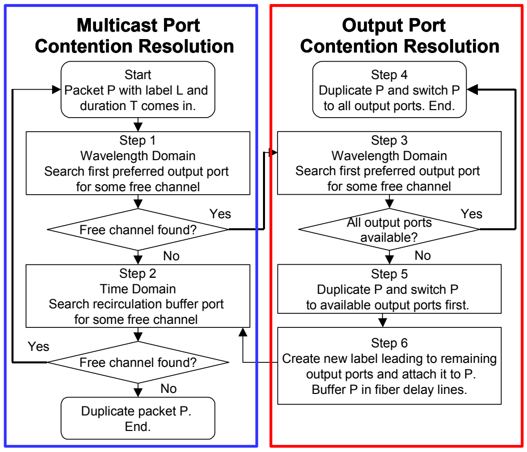


Figure 3 : Flow chart of FAFD

Figure 3 shows *FAFD* employs six steps to resolve contention.

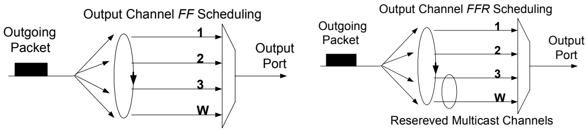
Steps 1 to 4 are the same as those in *CMPD*.

Step 5. If some, but not all desired output ports are available simultaneously, the router controller will instruct the MWC to duplicate the packet and forward the copies to the available output ports first.

Step 6. A label with an updated field is attached to an additional copy of the multicast packet. This field indicates remained output ports to be sent for the current multicast packet. This label will lead the packet to the delay line buffer port for buffering. The flow returns to Step 2.

2.3 Output Channel Scheduling Schemes

If multiple wavelength channels on the incoming packet's desired output port are available simultaneously, the router controller selects a specific output channel for the incoming packet. Figure 4 (a) shows that for the first-fit channel scheduling scheme (*FF*), the router controller scans all the available wavelength channels on the desired output port and schedules the incoming packet to the first available output channe. Figure 4 (b) shows that for the first-fit scheme with reserved multicast output channels (*FFR*), some output channels are specifically reserved for multicast packets only to increase the throughput of multicast packets at the price of a reduced maximum number of available channels for unicast packets.



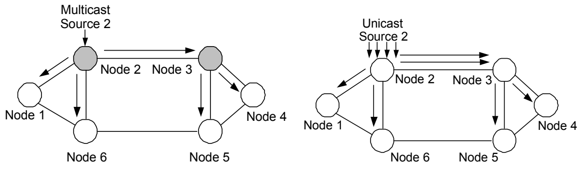
(a) (b)

Figure 4 : Output channel scheduling scheme (a) FF, (b) FFR

3. Simulation Analysis

Simulation proceeded to compare the performance of the proposed multicast contention resolution algorithms *CMPD* and *FAFD* combining output channel scheduling schemes *FF* and *FFR* with multiple unicast connections scheme (*UCAST*) proposed in [4], using a realistic IP packet length distribution and self-similar traffic model.

3.1 Simulation Topology and Configuration



(a) (b)

Figure 5 : (a) Multicast simulation network with one multicast traffic source, (b) unicast simulation network without multicast-capable nodes

Figure 5 (a) shows the six-node network with multicast application traffic input. Node 2 and node 3 are two optical router nodes utilizing recirculation multicast. The directional lines in Figure 5 (a) show the multicast tree, starting from node 2 and ending at the four destination nodes (node 4, node 5, node 6, and node 1). Upon the arrival of the multicast packet from traffic source 2, node 2 makes three copies of the multicast packet. Multicast node 2 forwards one copy to node 2, one copy to node 6, and the last copy to multicast node 3. Then node 3 will make 2 copies and forward them to node 4 and node 5.

For comparison, Figure 5 (b) shows that to achieve the same goal with the unicast scheme (*UCAST*) proposed in [4], the traffic source 2 sends four individual copies to each of the four destination nodes (node 4, node 5, node 6, and node 1). Node 2 forwards one copy to node 1, one copy to node 6, and the other two copies to node 3. Node 3 further forwards the two copies to both node 4 and node 5.

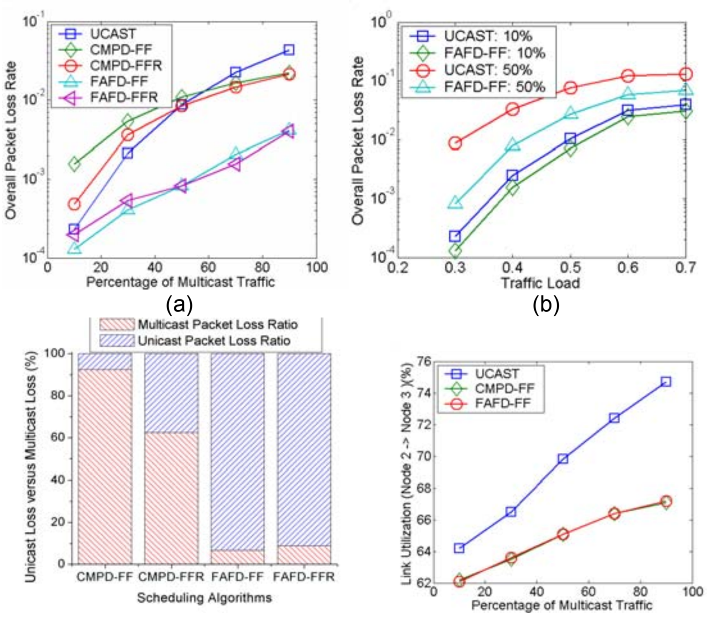
Simulation configurations are listed in Table I.

TABLE I
SIMULATION CONFIGURATIONS

Type	Port	Channel	Switch Size	Buffer Port	Multicast Port	Reserved Channel
UCAST [5]	5×5	4	20×20	1	0	0
CMPD-FF	6×6	4	24×24	1	1	0
CMPD-FFR	6×6	4	24×24	1	1	1
FAFD-FF	6×6	4	24×24	1	1	0
FAFD-FFR	6×6	4	24×24	1	1	1

UCAST stands for the unicast algorithm proposed in [4]

3.2 Analysis of Simulation Results



(a) (b) (c) (d)

Figure 6 : (a) Packet loss rate under various percentages of multicast traffic, (b) packet loss rate under various traffic loads, (c) contribution of both unicast and multicast packet loss to overall packet loss, (d) link utilization between node 2 and node 3

Unicast versus Multicast

Figure 6 (a) shows simulated overall packet loss rate where the percentage of multicast traffic (arriving at node 2 from traffic source 2) varies from 0.1 to 0.9 in the simulation and the background traffic load is set as 0.3. Figure 6 (a) shows that *FAFD* always achieves lower packet loss rates than *UCAST*, and that even larger performance gain relative to *UCAST* is achieved as the percentage of input multicast traffic from traffic source 2 increases from 10% to 90%. The *FAFD* overall packet loss rate curve in Figure 6 (a) increases much more slowly than the *UCAST* packet loss rate curve as the input multicast traffic percentage increases. The *FAFD-FF* overall packet loss rate increases from 1.29E-4 to 4.20E-3 as the percentage multicast traffic increases from 0.1 to 0.9. For comparison, *UCAST* overall packet loss rate increases from 2.31E-4 to 4.34E-2 at the same time. Figure 6 (a) also shows that *CMPD* performs better with lower packet loss rates than *UCAST* when the percentage of the input multicast traffic is large.

Multicast Scheduling Algorithms: CMPD versus FAFD

Figure 6 (a) further demonstrates that *FAFD* achieves lower overall packet loss rate than *CMPD* for a given percentage of input multicast traffic. As the percentage of input multicast traffic from the traffic source 2 increases from 10% to 90%, the *FAFD-FFR* overall packet loss rate increases from 1.97E-4 to 4.05E-3, while the *CMPD-FFR* overall packet loss rate increases from 4.80E-4 to 2.13E-2, indicating that *FAFD* resolves contention more effectively.

Output Channel Scheduling Schemes: FF versus FFR

Figure 6 (a) shows that *CMPD-FFR* achieves lower overall packet loss rates than *CMPD-FFR* for a given percentage of input multicast traffic. As the percentage of input multicast traffic increases from 10% to 90% at node 2, the *CMPD-FFR* overall packet loss rate increases from 4.80E-4 to 2.13E-2, while the *CMPD-FF* overall packet loss rate increases from 1.57E-3 to 2.21E-2, indicating larger gains are achieved by *FFR* for light multicast traffic loads. Both *FAFD-FF* and *FAFD-FFR* achieve similar packet loss rates for a given percentage of input multicast traffic.

Figure 6 (b) further confirms that for a given percentage of input multicast traffic, such as 10% or 50%, *FAFD-FF* achieves lower packet loss rates than *UCAST* under various traffic loads.

Figure 6 (c) illustrates the contribution of both unicast packet loss and multicast packet loss to the overall packet loss at a given multicast packet percentage of 10%, indicating that less than 10% packet losses are contributed by multicast packets for *FAFD-FF* and *FAFD-FFR*, while the majority of packet losses are due to multicast packet contention for *CMPD-FF* and *CMPD-FFR*. Figure 6 (c) shows *FFR* may effectively decrease the multicast packet loss ratio while combining with *CMPD*.

Link Utilization Analysis

Figure 6 (d) shows that, for the link between node 2 and node 3, both *CMPD* and *FAFD* achieve lower link utilizations than *UCAST*. Both the *FAFD* utilization curve and the *FAFD* utilization curve go up much slower than the *UCAST* curve as the input multicast traffic percentage increases, indicating proposed multicast contention resolution algorithms efficiently utilize the link bandwidth.

4. Conclusion

This paper proposes multicast contention resolution algorithms and channel scheduling schemes for the recirculation multicast port optical router switch architecture with MWC. The simulation results with self-similar traffic demonstrate that the proposed algorithms effectively reduce packet loss rates and use link bandwidth more efficiently.

5. Acknowledgment

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6. References

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