New Approaches to Optical Packet Switching in Carrier Networks

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Several approaches to packet switching in the optical domain are described. The motivation, definition, technology requirements, and tradeoffs for these classes of optical packet switching are examined. Some key problems and topics for research are summarized.

Introduction The concept of an all-optical packet switched network has been around for a least a decade[1]. The vision can be briefly summarized as one that would eliminate electronic signal processing at transit packet routing nodes, and instead utilize optical switches to select and route packets further along the network. The use of optical switching would minimize the data rate dependence and format dependence of electronic switching thus permitting the packet payload data rate to be mostly independent of the switching technology. Since the data plane would be optical, it would be necessary to encode the packet destination or routing information in some manner that is transparent to the dataplane itself, such as placing such header information on a subcarrier or separate optical wavelength[2]. Packet networks always suffer from contention – where two packets attempt to emerge at the same time from a single exit port of a router. Because there is no optical equivalent to electronic memory (which permits very fine control of packet delay and long-term packet buffering) deflection techniques were proposed to minimize the chance of packets lost due to contention[3]. The use of additional wavelengths to minimize the number of delay lines was also proposed[4].

Optical Packets. Two definitions for optical packets currently are in use. 1) Packet over Sonet/ SDH (POS), which is an industry-standard format and consists of PPP-framed packets encapsulated in the synchronous payload envelope of a SONET or SDH frame. The frame is then scrambled and no gaps exist in the optical envelope. 2) Optical burst over lambda, where optical packets are directly modulated onto a wavelength including gaps, void of optical energy, between the packets. This format is not standardized, and different researchers have used different formats. Architecturally, the key difference between then is that POS cannot be optically switched since the packets cannot be individually distinguished and descrambled at the optical level, and remnants of SONET/SDH header would be removed as well. Thus POS must be processed electronically prior to packet routing. Optical bursts however are identifiable by the optical energy gaps between consecutive packets, and no state (such as scrambling sequence) is shared between consecutive packets thus allowing those packets to be independently utilized at different endpoints in the network.

Granularity. One of the problems faced in the construction of an optical packet router is the need for a large, fast optical switching function. An alternative approach to switching packets optically is to switch long-term flows of packets. In this case the optical dataplane can be composed of large, but slow optical switches, such as MEMs. Also, SONET ADM terminals can be used to switch long-duration packet flows. A MEMs device can switch in the millisecond range, but its control plane would likely be much slower. A SONET terminal would probably takes tens of seconds at best to be re-provisioned. This technique is referred to as *coarse-grained* switching. In contrast a packet-by-packet switch can individually remove and insert packets between individual streams, which is referred to as *fine-grained* switching.

Approaches. The different solutions for the optical dataplane can be roughly categorized into three basic techniques:

- Optical Cross-connect (OXC) plus GMPLS. In this technique, the OXC performs coarse-grained switching of packet flows under control of a flow setup control plane using GMPLS (to discover topology) and likely an Optical UNI (to signal the flows) defined by OIF. This technique permits good transparency of the optical path, but suffers from the inefficiency of switching flows with a very slow control network. In order to prevent build up of latency while waiting for a flow path to be established, various methods of reserving, predicting, and holding flows can be utilized. Unfortunately Internet flow statistics are badly behaved, and such a technique usually requires the consumption of excess network resources to minimize blocking or contention.

- All-Optical routing aims to prevent the flow-based problems of OXC networks by providing fine-grained switching with rapid packet detection and routing. This fine-grained technique unfortunately requires packet synchronization and suffers from contention due to the lack of practical optical buffer memory.
- Hybrid Optical Routing. This technique uses electronic processing to format and buffer packets, and provide header lookup, while using an optical switch to interconnect the electronic line cards in the router. Topologically such a router is the same as current all-electronic IP routers, but it uses optical switching technology to solve the internal interconnect issues inherent in large switching fabrics of large capacity.

Technologies. Further development of optical routing requires progress in several key technologies. A Large, fast optical switch enables the router, while optical transparency, low loss, good crosstalk, and minimal polarization and dispersion defects reduce the need to regenerate the optical packet. Fast burst-mode optical receivers have been proposed, but the realization of such a burst mode receive is compromised by pragmatic effects such as path-dependent optical loss resulting in packet-to-packet amplitude variation and potentially optical noise contamination of the inter-packet optical gap. Wavelength conversion is needed to exploit the use of parallel optical channels to help reduce packet loss due to optical contention. Optical 2R or 3R regeneration is needed to help manage the analog distortion that occurs when optical packets traverse different physical paths in a network and suffer varying dispersion and loss.

Protocols. The Internet makes heavy use of the TCP protocol to provide a reliable channel on top of an unreliable IP packet transport mechanism. It does this by keeping stateful information in the endpoints of the packet path. TCP considers the loss of packets to be symptomatic of congestion, and it invokes a back-off algorithm in order to relieve downstream congestion. This protocol suffers from long detection and correction times since the minimum possible detection time is related to the round-trip path delay. Thus, the packet loss rate must be very low to provide high useful TCP flow throughput (called "*goodput"*). This implies that queuing of packets at intermediate nodes is required in order to minimize the packet loss rate. End nodes in an all-optical network can however isolate the TCP state in the endpoints from these effects. Significant research on effective techniques that maximize goodput while minimizing latency and complexity are needed to help address the packet loss and contention problems inherent in all-optical routing.

Conclusion. All-Optical packet routing remains a dream that is hampered by ineffective or costly solutions to synchronization, contention, and buffering problems. It requires new optical line formats to be used. Research addressing contention resolution and fundamental changes to end-point protocols would be valuable. OXC/GMPLS networks are practical but do not address routing and facility utilization problems efficiently. Hybrid optical routers provide pragmatic solutions to contention, header processing, and buffering, but require electronic processing of all optical streams. They utilize existing industry standard formats.

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