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Wavelength Resource Allocation for Optical Path/Packet Integrated Networks

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Abstract Hybrid optical architectures combining path and packet switching can be good candidates for future optical networks because they exploit the best of both worlds. In this paper, we explore a hybrid path/packet switching optical WDM architecture with dynamic wavelength allocation. We show that a hybrid network can minimize the average transfer time of TCP flows.

Key words Blocking probability, wavelength-division multiplexing, wavelength allocation, hybrid switching

1. Introduction

WDM can use different switching granularities in order to utilize the vast capacity of fiber links, e.g., packet, burst, and path (circuit) switching, where each of them have pros and cons. While optical packet switching allows higher utilization of WDM channels thanks to its high statistical multiplexing gain and flexibility, it has disadvantages like higher switch cost as it needs ultra-fast switching fabric to achieve high granularity. Moreover, the current optical buffering technology is not mature enough to provide large and fast buffering space to optical packet switching. On the other hand, path switching has many advantages over packet switching like low switch cost and power requirements as its switching speed and frequency are lower. Moreover, it does not need optical buffering at the core nodes as there is no contention of packets, so it has an easier and more effective QoS support for flows with strict QoS requirements. However, path switching has lower utilization efficiency because a connection may or may not use all the capacity in the dedicated channel. Moreover, path switching needs prior reservation of channels, which adds an additional delay to flow completion time.

A hybrid architecture combining path and packet switching is a possible solution to these problems by exploiting the best of both worlds [1, 2]. There are two main approaches in the literature for realizing a hybrid architecture. One of them is carrying both packet and path traffic on the same wavelength [3, 4]. All wavelengths are principally used by paths. The packet traffic is inserted into idle periods left from the path traffic on the same wavelength. The second approach is to use separate wavelengths for path and packet switching and distribute the traffic between them [5]. In this paper, we propose a hybrid path/packet switching optical WDM architecture using the second approach. In our architecture, the network changes the ratio of path and packet wavelengths according to the traffic characteristics, dynamically. Therefore the network can adapt itself to the current traffic in order to minimize the average transfer time of TCP flows.

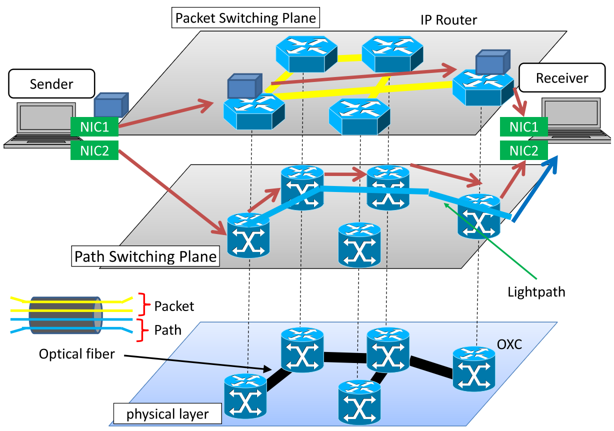

Fig. 1 A network architecture

The paper is organized as follows. In Section 2., we present a model of the path/packet integrated network. In Section 3., we present the simulation results. Section 4. concludes the paper.

2. A model of Path/Packet Integrated Network

2.1 The Network Architecture

Each node in path/packet integrated network consists of IP router and OXC connected by optical fibers. The node architecture is described in [2]. The path/packet integrated network provides a packet switched network and a circuit switched network by allocating wavelengths for each network. For the packet switched network, the virtual network topology is constructed by configuring a set of lightpaths based on a long-term measurement of traffic volume. When a packet arrives at a node, the packet is forwarded to the next node in the VNT. In the circuit switched network, when a data transfer request arises, lightpaths are established between source and destination nodes on-demand basis (Fig. 1).

Each end-host connecting with the node has two network interfaces; one for injecting IP packets into the packet switched network and one for establishing a lightpath between two end-hosts. When a data transfer request arises, the end-host selects the packet switched network or the circuit switched network to transfer the data. Various strategies to select the network can be considered. We believe that the optimal strategy highly depends on the traffic characteristics, so a highly sophisticated strategy may be necessary. Instead of chasing the sophisticated strategy, we take a simple strategy to select the network because our primary concern of the current paper is to develop an adaptive wavelength allocation method for optical path/packet integrated networks.

Our simple strategy to select the network is as follows. The sender host first tries to transfer the data in circuit switching network by establishing a lightpath. When the lightpath establishment succeeds, the sender host transfers the data with the full transmission capacity of wavelengths. The wavelength is dedicated to a single flow, so there is no need for TCP congestion control. When the lightpath establishment fails, the sender host gives up transferring the data via circuit switched network and transfers the data via the packet switching network. In this case, the sender host uses TCP protocols during the data transfer.

We apply band switching in the packet network, which means that several wavelengths are grouped together as a band. Therefore, a packet is carried by distributing its data over a band of multiple wavelengths. In this paper, 10 path wavelengths are grouped to create a one packet wavelength.

2.2 The Path Reservation

We used destination-initiated reservation (DIR), which is one of the most popular reservation algorithms in the literature [6]. RSVP-TE [7] signaling protocol in GMPLS [8] networks uses DIR for wavelength reservation. In DIR, when there is a connection request, the source node sends a PROBE packet, which collects a list of idle wavelengths along the path. The destination node selects one of the wavelengths, which is idle on all links in order to satisfy the wavelength-continuity constraint [9] when there is no wavelength conversion ability in the network. In case there is no idle wavelength left in the list, the node sends a P_NACK packet to the source, which causes the connection request to be dropped at the source, and this is called forward blocking. If the destination selects an idle wavelength, it sends a RESV packet to the source node in order to reserve it along the path. However, a previously idle wavelength may have been reserved by another connection when the reservation packet arrives. This is called backward blocking. In this case, the RESV packet is converted to a R_NACK packet, and reservation is no longer done in the rest of the path. If the source node receives a R_NACK packet, it again drops the connection request and sends a RELEASE packet to the destination to release the reservations done by the RESV packet. A RELEASE packet may also be sent from the failed node for faster release instead of the source node, but in this work, we use the conservative method, in which a RELEASE packet is sent by source nodes [10]. If the source node receives a RESV packet, it means that the selected wavelength has been reserved successfully along the path, so it sends the data over this wavelength. When the flow is finished, the source node sends a RELEASE packet to remove the reservation of the reserved wavelength.

2.3 The Wavelength Allocation

One of the nodes in the network works as a controller node. It collects the traffic information in the network by exchanging control packets with other nodes in the network. After each control period in the network, the edge routers send traffic statistics (namely average flow speed in the path and packet wavelengths and the utilization ratio of packet wavelengths) to the controller node. Using this traffic information the controller node increases or decreases the number of packet wavelengths in the network by one after each control period.

In order to detect and prevent congestion in the packet network, the controller node first checks the maximum wavelength utilization in the packet network. The reason is that the maximum achievable utilization of path switching wavelengths may be low when the average time spent for path reservation is high and the average transfer time of flows is short. When the flow arrival rate is high, this may cause congestion in the packet switching wavelengths because the blocking rate in the path network increases and the flows start to build up in a limited number of packet wavelengths. However, most of the core packet networks on the Internet are operated at low utilization. Therefore, the controller compares the maximum wavelength utilization in the control period with a threshold parameter. If the maximum utilization is higher than the threshold, the network controller increases the number of packet wavelengths. If the packet wavelength utilization is lower than the threshold, then the controller calculates the average flow transfer time (goodput) in the last control period and compares it with the result of previous control period. If the goodput has increased, then the controller gives the same decision as the previous control period, otherwise gives the opposite decision. For example, let's assume that the number of packet wavelengths was decreased from 5 to 4 in the previous control period. If the goodput in the current control period is higher than the previous one, the controller assumes that the previous decision was correct, so the controller further decreases the packet wavelength count to 3. If the new goopdput is lower, the controller node assumes that the previous path/packet ratio was better, so it increases back the packet wavelength count from 4 to 5. As a result, the system tries to converge to the optimum path/packet ratio.

If a packet wavelength is converted to path by the controller node, the edge nodes stop sending packets to this packet wavelength and assign the flows on this wavelength to other packet wavelengths. The core nodes may dismiss the in-flight packets on these wavelengths or convert them to an other wavelength if there are wavelength convertors. The minimum number of packet wavelengths in the network is one, so there is always at least one packet wavelength if the path reservation of a new-coming flow fails. If a band of path wavelengths are converted to a packet wavelength, the situation is a bit more complex. The end-hosts using these wavelengths are informed by the edge nodes about this change. Therefore the

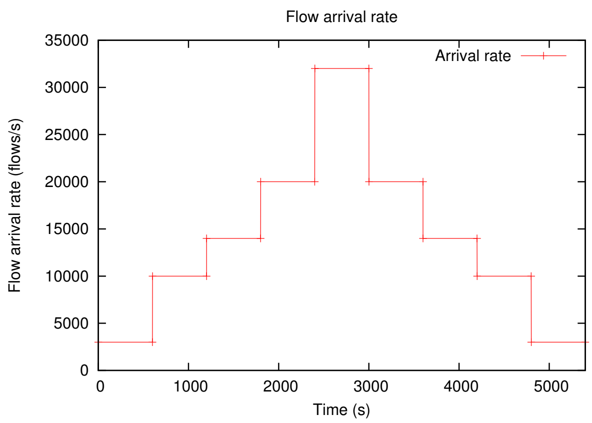

Fig. 2 The flow arrival rate.

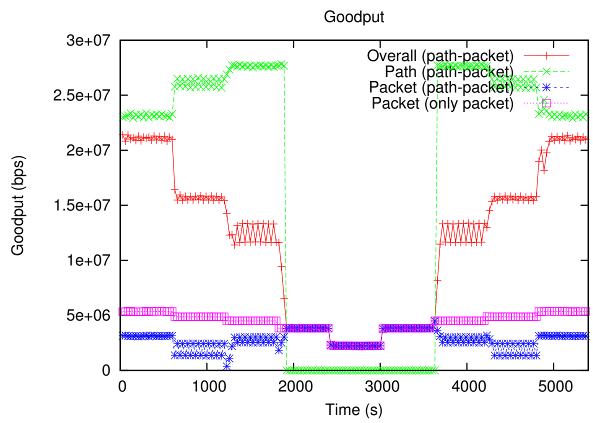

Fig. 4 The average flow goodput.

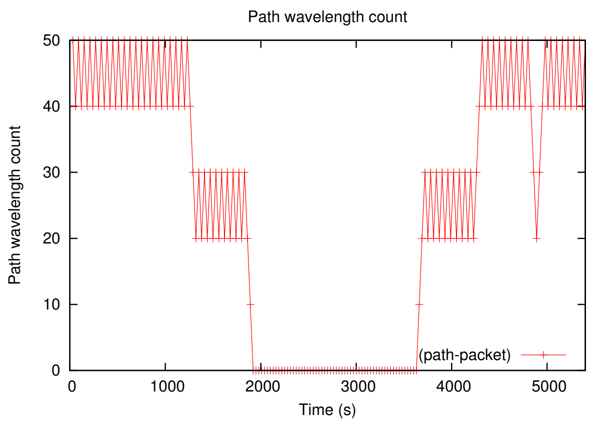

Fig. 3 The number of path wavelengths.

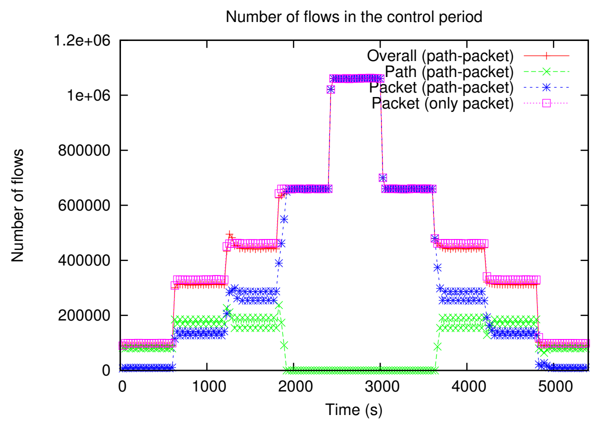

Fig. 5 The total number of flows in the control period.

end-hosts stop their flows and tries to send the remaining part like a new flow. The end-host retries to reserve a path wavelength and uses the packet wavelength if the reservation fails. The source end-host sends a FORCE_RELEASE packet to the destination, so the core nodes remove the path reservation and the destination computer waits for the arrival of a new flow to receive the rest of the file. When all the reservations on the "to be converted" path wavelengths of a node is clear, the node sends a control packet to the controller node signaling that it is ready for the conversion. When the master node receives a clear message from all nodes, it sends a final control packet to signal all nodes to convert and start using this band of wavelengths for packet network.

3. Simulation Results

We evaluated the performance of the proposed hybrid architecture on a 5-node ring topology by simulation. Each link carried 60 wavelengths with band switching (10 path wavelengths create a one packet wavelength). Therefore there can be maximum 6 packet wavelengths. Each path wavelength is 100Mbps and packet wavelength is 1Gbps, so the link capacity is 6Gbps. Average flow length is 1Mbit. Flows use TCP NewReno on the packet wavelength. Control period is 30 seconds. The maximum size of data packets is 1500Bytes. Core nodes provide 60KBytes of RAM buffering to each packet wavelength on their output links to solve contentions. All links have a 10 ms hop delay. When calculating the average goodput in a control period, we used the data from only the flows which started and finished in that control period. Packet wavelength utilization threshold of the wavelength assignment algorithm is set to 50%.

Fig. 2 shows the applied traffic (flow arrival rate) to the network in the simulation. X-axis is the time in seconds and y-axis is the flow arrival rate in flow/s. At the beginning of the simulation, the arrival rate is low (3000 flows/s), but it gradually increases to a very high flow arrival rate (32000 flows/s) at 2400s, which almost fully utilizes the links, then decreases again to a low arrival rate.

Fig. 3 shows the number of path wavelengths in the network. Initially the network is under-utilized, so the network assigns all wavelengths to the path network. After 1200s, the utilization of packet wavelengths pass the threshold parameter 50%, so the network assigns most of the wavelengths to the packet network. After 1800s, the high flow arrival rate causes congestion in the packet network, so the controller assigns all the wavelengths to the packet network. The maximum achievable utilization of path wavelengths is only around 30%, so only the packet wavelengths can carry the high traffic fully. Therefore, the network operates like a pure packet switching network. Later, the flow arrival rate decreases, so the number of path wavelengths increases gradually. We see that the path wavelength count in Fig. 3 shows a zigzag behavior oscillating around the optimum path/packet ratio. We used a simple tracking algorithm that always changes the path/packet ratio for converging to a point around the optimum ratio in network with a dynamically changing traffic. A more complex algorithm can decrease the oscillations by changing the wavelength ratio only when some thresholds are exceeded.

Fig. 4 shows the average flow goodput in a path/packet integrated network and a network with only packet-switching. When the flow arrival rate is high, the overall flow goodput of path/packet integrated architecture is around 4 times the goodput of packet-only switching network. As the flow arrival rate increases, the ratio of flows carried by the path wavelengths decreases, so the average goodput decreases. When the high flow arrival rate causes high congestion at 1800s, all path wavelengths are converted to packet wavelengths, so the path/packet integrated architecture gives the same goodput as the packet-only network. We see that the flows carried over the path network get the highest goodput as expected. Their goodput increases as the flow arrival rate increases until 1800s. The reason is that as the flow arrival rate increases, the ratio of single hop flows in the path network increases because the blocking rate of flows with two hops increases faster than single hop flows with increasing traffic arrival rate due in DIR-based reservation algorithm. As the single-hop flows spend less time for reservation, they have higher goodput, which increases the average goodput in the path network.

Fig. 5 shows the total number of active flows in the network during a control period. When the flow arrival is low, most of the flows are carried in the path network. As the flow arrival rate increases, the ratio of the flows in the packet network increases due to higher blocking in the path network. When the arrival rate is high at 1800s, the number path switching wavelengths decreases to zero, so all flows are carried in the packet layer.

In general, we see that the optimum ratio of path/packet ratio changes with traffic intensity and our algorithm can converge to a better path/packet ratio, which gives higher average goodput than a packet-switching only network.

4. Conclusions

In this paper, we proposed a hybrid path/packet switching optical WDM architecture with dynamic wavelength allocation. We showed that the optimum ratio of path and packet wavelengths may change with traffic. The simulation results revealed that our hybrid network can decrease the average transfer time of TCP flows by adaptively changing the ratio of path and packet wavelengths.

As a future work, we will try to improve our algorithm for faster convergence and lower oscillation. The current algorithm tries to reserve a path for all incoming flows, but we will work on a better algorithm that tries reservation only for the flows which benefit from path switching the most. We will test the hybrid architecture on more complex network topologies and traffic scenarios.

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