Computing Flow Completion Time in Optical Path/Packet Integrated Networks

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Abstract

Using an analytical model to compute the flow transfer times in a hybrid path/packet switching WDM network, we show that the transfer time of TCP flows can minimized by using only a few packet-switching wavelengths.

I. 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]. However, the optimum ratio of path and packet-switching wavelengths should be optimized. Several analytical models for calculating the forward and backward blocking rate in path switching have been proposed in the literature. Most of them are based on Reduced Load Approximation (RLA) method, which calculates the blocking rates in an iterative manner. In [3], we proposed a novel analytical method for calculating the blocking rate in the path network. In this paper, we extend the analytical model in [3] for fast and easy calculation of hybrid switching parameters like the optimum ratio of path and packet wavelengths.

II. A Model of path/packet integrated network

Each node in path/packet integrated network consists of IP router and OXC connected by optical fibers. 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. RSVP-based wavelength reservation protocol is used for lightpath establishments.

Each end-host connecting with the node has two network interfaces; one for inject IP packets into the packet switched network and one for establish a lightpath between two end-hosts. When the 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 the 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 a new coming flow in the circuit switched network. If the lightpath establishment succeeds, the sender host transfers the flow by using the full transmission capacity of a wavelength. If the lightpath establishment fails, the sender host gives up transferring the data via circuit switched network and transfers the data via the packet switched network. In this case, the sender host uses the TCP protocol during the data transfer.

III. Analytical model

New flows first try to reserve a path, so we should calculate the path blocking rate. We model the number of busy wavelengths on a link of path switching network by a birth-death process (*M/G/c/c* queuing system, also known as the Erlang loss model). The reader is referred to [3] for our analytical model for calculating the blocking rate in the path network

The flows that fail reservation on the path network are carried by the packet network. We used the TCP performance model from [4] to calculate the transfer time of TCP flows on the packet network. The reader is referred to [4] for the equations. The model requires the packet drop rate along the path. When there is optical

RAM buffering with wavelength conversion in the packet network, the packet drop rate on each link is calculated by solving the *M/M/c/K* queuing model where *c* is the number of packet wavelengths and *K* is sum of buffer size and number of packet wavelengths. When there is no buffering, the packet drop rate is calculated by *M/M/c/c* if there is wavelength conversion and by *M/M/1/1* if there is no wavelength conversion. The TCP throughput and packet drop rates in the network are estimated by using the RLA method iteratively.

IV. Numerical Results

We evaluated the performance of the analytical method on the European Optical Network (EON) topology with the 19 nodes and 39 bidirectional links. Each link carried 16 wavelengths in both directions. The hop delay depends on the propagation delay due to link distance and processing delays influenced by the switching technology used and hardware speed. We used a 10 ms hop delay, which seemed an appropriate value. For the sake of simplicity, we used the same hop delay for reservation packets, data flow on path network and data packets on the packet network on each hop in this paper, but they can be assigned to different values if necessary. The flow holding time had a mean value of 0.1 s. The Erlang loss model is insensitive to connection holding time distribution, but we applied an exponential holding time distribution. We applied a uniform traffic matrix. Flows between each node pair arrived according to a Poisson process. The total reservation request arrival rate in the network was 650 flows/s. Path network allowed two times retrial of failed reservation attempts, which means that the reservation algorithm attempted to do a reservation a maximum of three times.

In a hybrid network architecture, one of the aims is to minimize the overall flow completion time, so the reservation delay is an important metric for a path switching layer. Fig. 1 plots the average flow transfer times for a flow sized (a) 10^9 Bits and (b) 10^6 Bits. The x-axis shows the number of wavelengths assigned to the packet network. Red line shows the case when there is no buffering and WC (wavelength conversion) in the packet network. Green line shows the case when there is WC, but there is no buffering. Blue line shows the case when each link has a buffer sized 5 packets and WC. When the flow size was 10^9 Bits, the flow transfer time was minimized with 4 packet wavelengths when there was WC, but there was no buffering. On the other hand, the flow transfer time was minimized with a single packet wavelength in the rest of analytical results for both flow sizes. When there was a single packet wavelength and no buffering, the drop rate was the same for the case with and without WC, as expected. We can see that the wavelength conversion ability greatly decreased the packet drop rates as we increased the number of packet wavelengths.

V. Conclusions

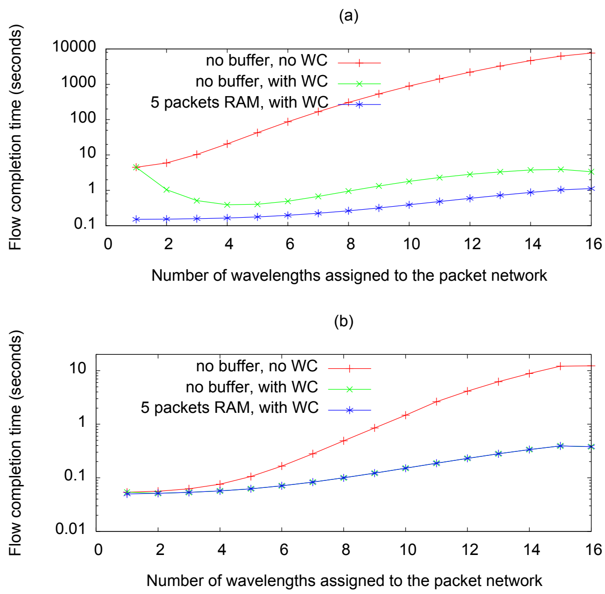

Fig. 1. The average flow transfer time for a flow with size (a) 10^9 Bits and (b) 10^6 Bits.

In this paper, by using an analytical method based on reduced load approximation, we calculated the flow completion time in hybrid path/packet switching optical WDM networks with destination-initiated reservation and retrial. Such an analytical method can be very useful in the fast calculation and optimization of the traffic splitting parameters for hybrid optical architectures. We presented some analytical results on a mesh EON network and showed that using only a few packet wavelengths can minimize the flow transfer time.

As a future work, we will extend our analytical model with fiber delay line (FDL) based buffering, and we will compare the analytical results with simulation results. Then we will work on an architecture that can adaptively change the ratio of path and packet wavelengths in the network depending on the traffic.

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