Analysis of Path Switching Performance Metrics for Optical Hybrid Switching Networks

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Outline

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Problem Statement

- **Compared to electrical cabling, optical fiber with wavelength division multiplexing (WDM) allows much higher bandwidth and can span longer distances**
  - WDM is a promising solution to handle the fast-growing Internet traffic that is demanding more and more capacity.
  - WDM can employ different switching granularities in order to utilize the vast capacity of fiber links e.g., packet, burst and path (circuit) switching
- **Optical packet switching**
  - Advantage:
    - » Allows higher utilization of WDM channels thanks to its high statistical multiplexing gain and flexibility
  - Disadvantages:
    - » Has higher switch cost as it needs ultra-fast switching fabric to achieve high granularity.
    - » The current optical buffering technology is not mature enough to provide large and fast buffering space to optical packet switching.

Problem Statement (2)

- **Path switching**
  - Advantages:
    - » Low switch cost and power requirements as its switching speed and frequency is lower.
    - » It does not need optical buffering at the core nodes as there is no contention of packets
    - » it has an easier and more effective QoS support for flows with strict QoS requirements.
  - Disadvantages:
    - » Has lower utilization efficiency in the dedicated channel because a connection may or may not use the capacity.
    - » Needs prior reservation of channels that adds an additional delay to flow completion time.
- **A possible solution to these issues is using a hybrid-architecture combining path and packet switching to exploit the best of both worlds**
  - There are open questions like optimum ratio of path and packet-switching wavelengths and the optimum flow size threshold in order to minimize the transfer time of flows.
  - Optimization of these parameters requires fast and easy calculation of performance metrics for path and packet-switched networks.

Objective

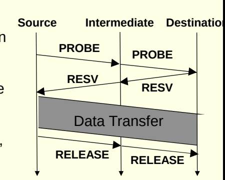
- **Analytical calculation of blocking probability as a performance metric in path switched networks.**

Advantages

- **Estimation of optimum ratio of path and packet-switching wavelengths in a path-packet integrated architecture for**
  - Decreasing the file transfer delay and increasing the efficiency
  - Decreasing the node cost
  - Decreasing the power requirements (ECO)

Wavelength Reservation (1)

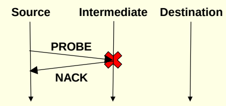
- The maximum number of simultaneous connections on a fiber is limited, so the wavelength reservation algorithm has a big impact on the blocking probability.
- One of the most popular reservation algorithms in the literature is destination-initiated reservation (DIR)
- When there is a connection request, source node sends a PROBE packet, which collects a list of idle wavelengths along the path.
- Destination node selects one of the wavelengths, which is idle on all links in order to satisfy the wavelength-continuity constraint and sends a RESV packet to source node.
- 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, source node sends a RELEASE packet to remove the reservation of the reserved wavelength.



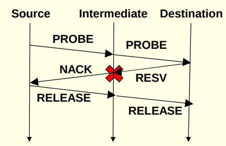
Successful Reservation

Wavelength Reservation (2)

- In case there is no idle wavelength left in the list of PROBE packet, node sends a NACK packet to the source. 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 NACK packet and reservation is no longer done in the rest of the path.
- If the source node receives a NACK packet, again it drops the connection request and sends a RELEASE packet to the destination to release the reservations done by the RESV packet.



Forward Blocking



Backward Blocking

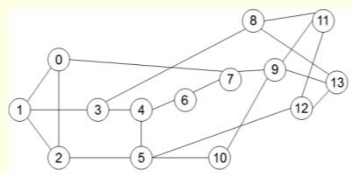
Analytical Solution (1)

- **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 as follows:**
  1. Initialize the blocking rate for all the node pairs to zero. Initiate state dependent arrival rates as if there is no blocking in the network.
  2. Calculate the wavelength occupation times
  3. Calculate the state (wavelength occupation ratio) dependent flow arrival rates
  4. Derive the new blocking probability for each node pair. If the difference between the old and new value of blocking rate for each node pair is small, then finish the iteration. Otherwise, return to step 2.

Analytical Solution (2)

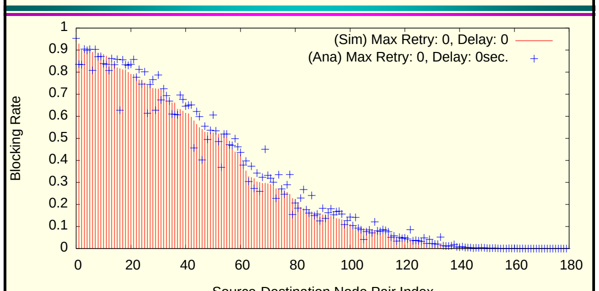
- **The forward reservation blocking rate calculation is based on an analytical model proposed by A. Birman**
  - It is used by many analytical models in the literature
  - Applies Erlang-B formula for calculating blocking probability.
  - Satisfies the wavelength continuity constraint
  - However, it assumes that the distribution of assigned wavelengths at each link is mutually independent
    - » May cause a high error rate at some sparse and ring topologies
- **Backward blocking rate is calculated by incorporating the wavelength reservation duration and propagation delays in the analysis to estimate the blocking due to outdated information.**
  - First proposed in a paper in year 1999 by Prof. Arakawa
  - We further improved and extended Arakawa's backward blocking analysis for more precise results and adapted to use it with Birman's method for an iterative calculation.

Numerical Results



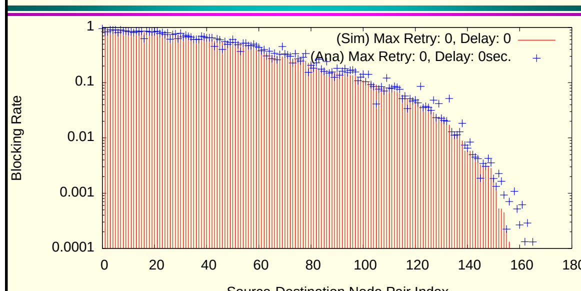
- **NSFNET topology with 14 nodes and 21 links**
- **182 s-d pairs**
- **16 Wavelengths**
- **Wavelength speed 10Gbit/s**
- **Link propagation delay is 10 ms**
- **Flow size is exponentially distributed with a mean value of 0.1 seconds.**
- **Applied the traffic matrix from**
  - R. Ramaswami and K. N. Sivarajan, "Design of logical topologies for wavelength-routed optical networks," IEEE J. Select. Areas Commun., vol. 14, pp. 840–851, June 1996

High Traffic (linear scale graph)



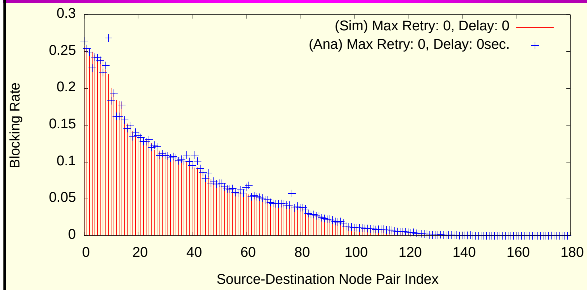
- **Analytical and simulation results of blocking rates sorted in descending order by simulation results for each s-d pair in the network.**
- **Most of the analytical solutions in literature have problems when estimating blocking rate at highly loaded links**
- **Our analysis can calculate them with low error rate**

High Traffic (log scale graph)



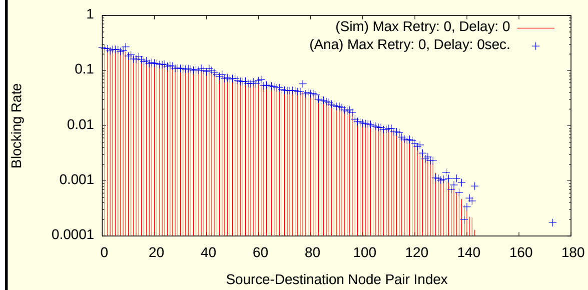
- **Plotted the same graph in log scale to show s-d pairs with low blocking rates**

Low Traffic (linear scale graph)



- **Decreased the traffic matrix by 4 times**
- **Analytical result is very close to simulation result**

Low Traffic (log scale graph)



- **Plotted the same graph in log scale to show low blocking rates**
- **Analytical result is very close to simulation result**

Conclusions

- Simulation results on mesh network show that the proposed analytical model can calculate the blocking rates at both high and low link loads
- The precision of the analytical method is higher when link loads are lower

Future Work

- Increase the accuracy of forward blocking calculation
- Extend the analytical model to incorporate the retrial of blocked connections
- Calculate the average flow reservation time

Thank you