INTRODUCTION

- Wavelength continuity constraint in wavelength routed WDM networks
  - Inefficient utilization of wavelength channels
  - Poor blocking performance

- Ways to improve performance
  - Use optical wavelength converters at intermediate nodes
    - Very expensive
  - Use wavelength rerouting
    - Viable and cost-effective
    - Can only alleviate the wavelength continuity constraint but cannot eradicate it
WAVELENGTH REROUTING

- A new connection request is accommodated by migrating a few existing lightpaths to new wavelengths while maintaining their path.

Example 1

(a) A network state with two lightpaths
(b) Wavelength rerouting of lightpath p₂

New request: <1,3>
Without wavelength rerouting: a route 1-2-3 is available, but it is not wavelength-continuous; hence request blocked.
With wavelength rerouting: request accepted.
ISSUES IN WAVELENGTH REROUTING

- During the rerouting process there will be low or even zero throughput.
- Transmissions along the rerouted lightpaths must be temporarily shut down to prevent data from being lost or misrouted.
- Minimization of these disruptions is imperative for rerouting.
- Wavelength rerouting basically has two components:
  - Lightpath migration – deals with migration of lightpaths.
  - Rerouting algorithm – determines the lightpaths that can be rerouted and selects a few to create a wavelength-continuous route to satisfy a request.
LIGHTPATH MIGRATION

Basic operations used for lightpath migration

- Wavelength retuning (WR)
  - Retunes the wavelength of a lightpath maintaining its path
  - Computationally simpler algorithms can be developed
  - However, it does not bother if the path on the new wavelength is vacant or not

- Move-to-vacant (MTV)
  - Reroutes a lightpath to a vacant route with no other lightpaths
  - Does not interrupt other lightpaths
  - Preserves transmission on the old route during setup of the new route and so disruption period is reduced
  - Requires a complex algorithm
LIGHTPATH MIGRATION (Contd..)

- **Move-to-vacant wavelength retuning (MTV-WR)**
  - Moves a lightpath to a vacant wavelength on the same path
  - Has the advantages of both MTV and WR operations

- **Implementation of MTV-WR**
  - The controller sends control messages (information about new wavelength) to the intermediate switches on the path of the rerouted lightpath
  - The source node appends an end-of-transmission (EOT) control packet after the last packet on the old wavelength and holds the first packet on new wavelength for a guard time
  - Upon detecting the EOT packet, the destination node tunes its receiver to the new wavelength
  - Guard time determines the disruption period (typically $\mu$s)
  - This disruption time is much less compared to rerouting-after-shutdown (RAS)
REROUTING SCHEMES: PARALLEL MTV-WR

- Moves each of the rerouted lightpaths to a vacant wavelength on the same path in parallel
- Rerouted lightpaths should be on a disjoint set of links
- Overall delay is the max. delay of all migrated lightpaths
- Example 2

New request: <2,3>

a) Before using Parallel MTV-WR

b) After using Parallel MTV-WR
REROUTING SCHEMES: SEQUENTIAL MTV-WR

- Moves lightpaths in sequence (in different passes) to vacant wavelengths, maintaining their path
- Overall delay is sum of delays in different passes
- Complex algorithm is needed
- Example 3

a) Before using Sequential MTV-WR

New request: <1,4>

b) After using Sequential MTV-WR
AUXILIARY GRAPH (AG) ALGORITHM

- **Objective**
  - to minimize the weighted number of rerouted lightpaths in networks with the parallel MTV-WR rerouting scheme
- New requests arrive randomly as a Poisson process
- It uses a layered graph representation of the network
  - A network with $N$ nodes and $W$ wavelengths per fiber is represented as an undirected graph with $W$ subgraphs, each with $N$ nodes
  - A subgraph corresponds to a wavelength, referred to as a layer or a wavelength plane
  - A weight proportional to the # of hops used is assigned to an edge used by a *retunable lightpath*
  - A tiny value is assigned to a free edge as its weight
DESCRIPTION OF ALGORITHM AG

- It works in two phases
  - Phase 1 selects a route that does not require rerouting
    - Conventional shortest-path-finding algorithm, like Dijkstra’s algorithm is used
    - Only free edges are considered while finding a shortest path
  - Phase 2 is invoked when phase 1 fails
    - It has three stages
    - In stage 1, all the retunable lightpaths are identified
    - In stage 2, an auxiliary graph with crossover edges is constructed for every retunable lightpath
    - A crossover edge between nodes x and y for a retunable lightpath p is created whenever there exists a path of length 2 or more between x and y comprising only the edges of p
    - Crossover edges are also assigned a weight equal to the hop count of the lightpath
In stage 3, shortest paths are found using a conventional shortest-path-finding algorithm on each of the W subgraphs and the one with the least cost is chosen.

Every intersecting lightpath is counted only once, independent of how many of its edges are used.

If no path with a finite cost can be found, request is rejected.

The chosen path requires that a minimum weighted number of lightpaths be rerouted.

Solution using this algorithm can be obtained in polynomial time as opposed to a general rerouting problem which is NP-complete.

Computational complexity

- Worst-case complexity of phase 1 is $O(N^2W)$
- It has been shown that the worst-case complexity of phase 2 is $O(N^2W^2)+O(N^3W)+O(N^2W)$

A variation of this algorithm with less complexity has been proposed [Ref. 3]
AG ALGORITHM: EXAMPLE 4

Assumptions:
- lightpaths $p_1$ and $p_2$ are retunable
- no finite-cost path exists between 2 and 9 on other wavelengths

Let's say a new request between nodes 2 and 9 arrives
- Phase 1 fails, stage 1 of phase 2 finds $p_1$ and $p_2$ retunable, stage 2 of phase 2 creates auxiliary graph, stage 3 finds the shortest path as 2-3-7-9 on $G_{aux}$ (equivalent to 2-3-7-8-9 on G) on this wavelength
- Repeat this on other wavelengths and find the shortest route of all
PERFORMANCE OF AG ALGORITHM

Simulation

- 21 node, 26 bi-directional-link ARPA2 network
- Poisson arrival process
- Input traffic was generated uniformly from each of 21 nodes and was destined to each of the other 20 nodes with equal probability
- The curves show that wavelength rerouting can improve blocking probability while the performance is close to that of wavelength conversion
LIMITATION OF ALGORITHM AG

This algorithm fails to choose the minimum number of weighted rerouted paths for unidirectional lightpaths.

**Example 5**

a) A graph with unidirectional paths

b) The corresponding auxiliary graph

Assume lightpaths p1, p2 and p3 are retunable
Say a new request from node 8 to node 5 arrives:
The algorithm will choose path 8->4->5 with a cost 4
However, there exists a path 8->6->9->7->3->5 with a lesser cost of 3.3
REFERENCES


HOMEWORK

1. Mention one disadvantage each for WR and MTV schemes and explain how they are overcome in MTV-WR scheme

2. The adjacent figures depict a state of network with three wavelengths $W_0$, $W_1$ and $W_2$ per fiber link. Use parallel MTV-WR and sequential MTV-WR schemes to determine whether a new request $<1,4>$ is accepted or rejected in each case

Hint: One will accept and the other will reject

Note: I formulated the problem myself, and so there is every possibility that it might not have a valid solution