Routing in All-Optical WDM Networks

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Outline

1. Introductions
   - Background information
   - Routing in all-optical WDM networks
2. Research Topics
   - Traffic intensity based alternate routing
     - Traffic intensity based fixed-alternate routing
     - Traffic intensity based dynamic-alternate routing
   - Finding routing paths for alternate routing
   - Splitter placement for multicast routing
3. Conclusions

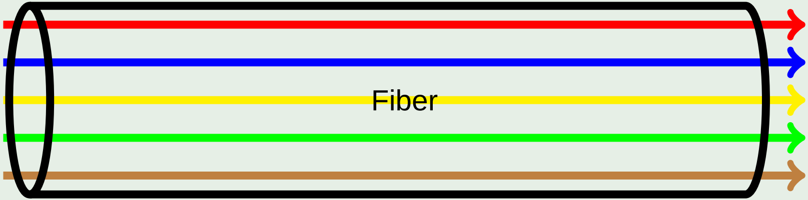
Introductions

- A number of multimedia applications require a vast amount of bandwidth
- An optical fiber can provide a large amount of bandwidth by using wavelength division multiplexing (WDM) technology

Wavelength Division Multiplexing

Wavelength division multiplexing technology is able to divide the vast amount of bandwidth into a number of high speed channels

Example



All-Optical WDM Networks

- Optical networks are promising transport networks for providing vast amount of bandwidth
- All-optical WDM networks in which the signals remain in the optical domain throughout the networks are desirable for providing large amount of bandwidth

Lightpath

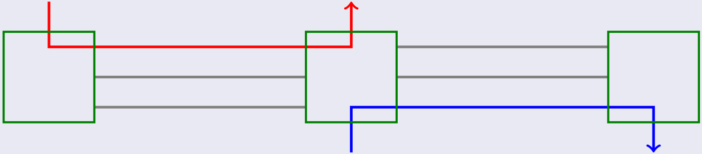
- In all-optical WDM networks, each of the connections going through a link is assigned a wavelength
- A connection that is assigned the same wavelength on all links along its path is called a lightpath

Lightpath Establishment

Available wavelength

A wavelength which is not occupied by a connection

Example: Two links and three wavelengths

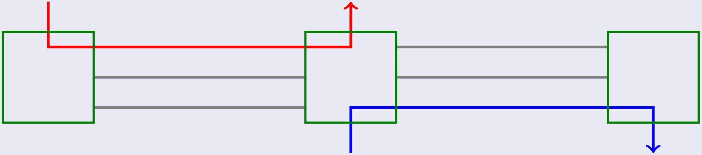


Lightpath Establishment

Common available wavelength

A wavelength which is available on all links along the routing path

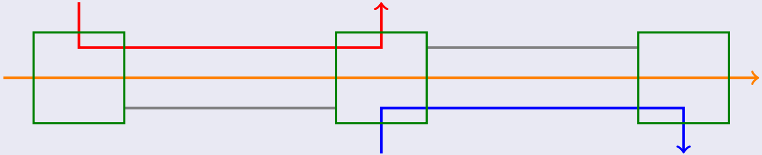
Example: Two links and three wavelengths



Wavelength Continuity Constraint

- A wavelength converter is needed to convert one wavelength to another wavelength
- If all nodes along the path of a connection are incapable of converting a wavelength to another, the connection must be assigned the same wavelength on all links along its path
- Otherwise, the connection is blocked

Example: Two links and three wavelengths on each link

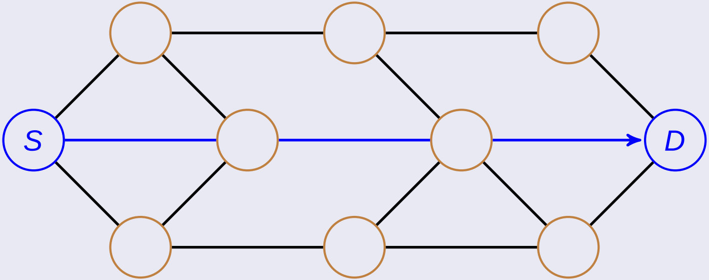


Routing in All-Optical WDM Networks

- Fixed Routing
- Alternate Routing
    - Fixed-Alternate Routing
    - Dynamic-Alternate Routing
- Exhaust Routing

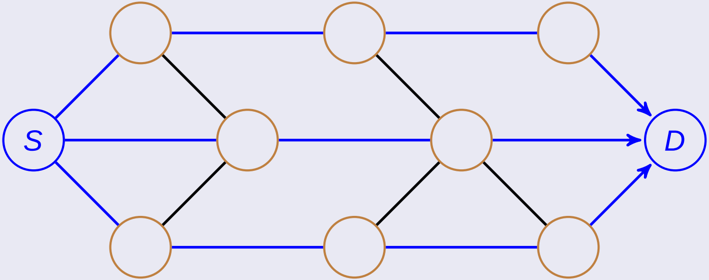
Fixed routing

A single routing path for a source-destination pair



Alternate routing

Multiple routing paths for a source-destination pair



Alternate routing

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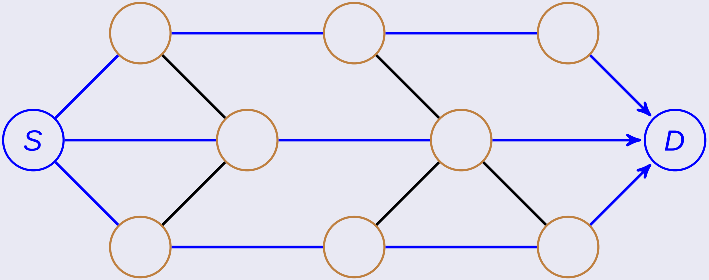


Question

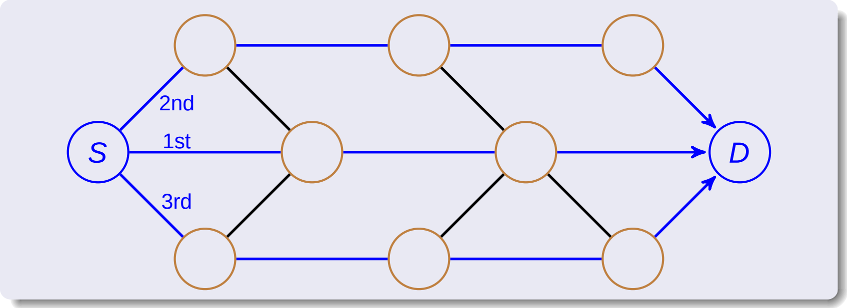
How to select the routing path for lightpath estabilishment?

Alternate routing

Fixed-alternate routing

Fixed-order for selecting the routing path

Hop-count based fixed-alternate routing (HC-FAR) : hop count of each routing path

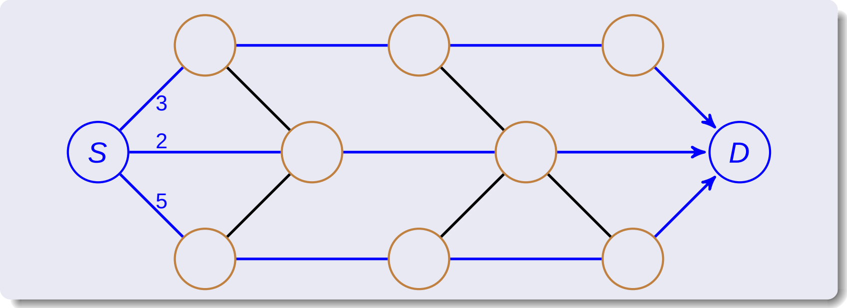


Alternate routing

Dynamic-alternate routing

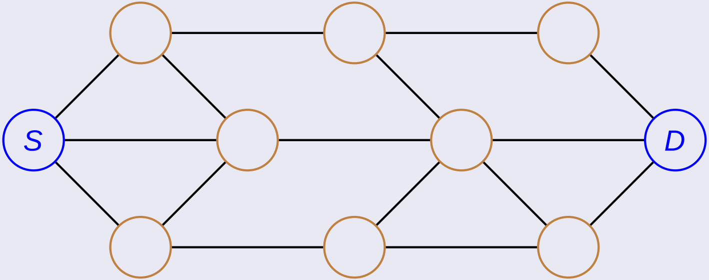
Select the routing path based on the collected information

Least-Loaded Routing (LLR): number of common available wavelength



Exhaust routing

No routing path for a source-destination pair is predetermined



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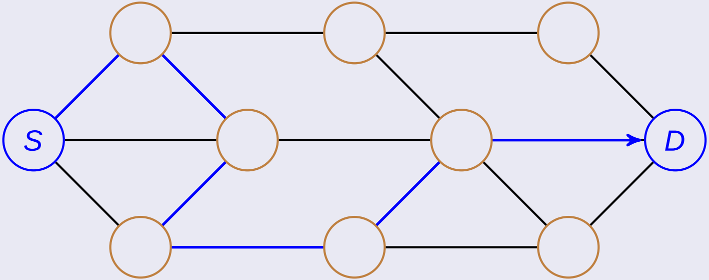


Research Topics

- Traffic intensity based alternate routing
- Finding routing paths for alternate routing
- Splitter placement for multicast routing

Research Topics

- Traffic intensity based alternate routing
  - Traffic intensity based fixed-alternate routing (TI-FAR)
  - Traffic intensity based dynamic-alternate routing (TI-DAR)

Background Information

- Among the three categories of routing algorithms, alternate routing algorithms are computationally efficient and able to yield low connection blocking probability

Motivation

- Given the traffic requirements of all source-destination pairs, it is desirable to route these traffic in the optimal way
- The key idea is to develop an approach to desigining alternate routing algorithm which is able to route the traffic in approximately the optimal way

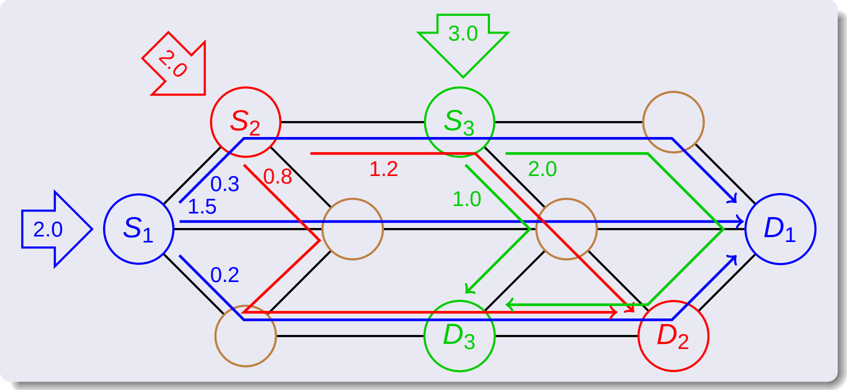
Optimal Traffic Pattern: Objective Function

- In all-optical WDM networks, exact calculation of connection blocking probability is difficult
- We use the approximate amount of blocked traffic intensity as the objective function which is closely related to the connection blocking probability

Objective Function: Approximate amount of blocked traffic intensity

Given the traffic pattern

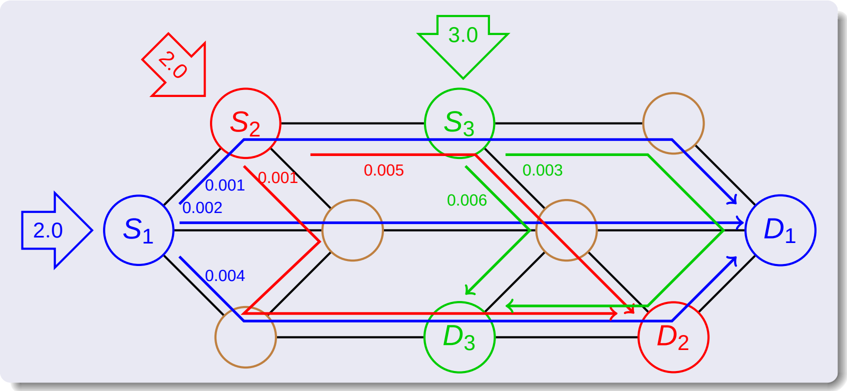
Connection requests are probabilistically assigned



Objective Function: Approximate amount of blocked traffic intensity

Compute the approximate blocking probability on each routing path

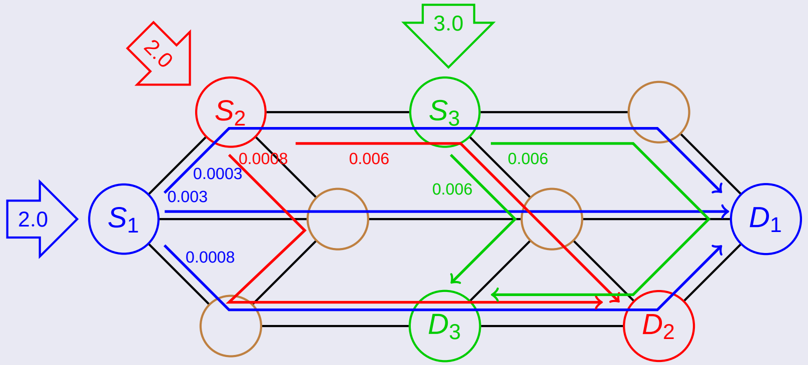
Ignoring the wavelength continuity constraint as an approximation



Objective Function: Approximate amount of blocked traffic intensity

Sum of the approximate amount of traffic intensity

Traffic intensity times the approximate blocking probability



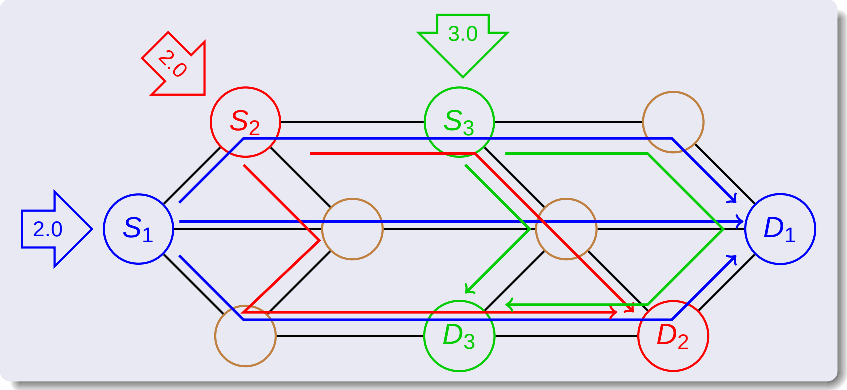
Objective Function: Approximate amount of blocked traffic intensity

- Bad News
  - Ignoring the wavelength continuity constraint
- Good News
  - Closed form
  - Convex function

Finding the Optimal Traffic Pattern

Given

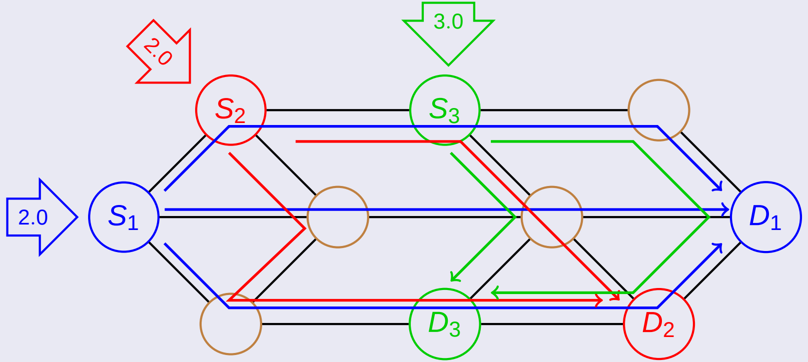
The traffic requirement and routing paths of each source-destination pair



Finding the Optimal Traffic Pattern

Objective

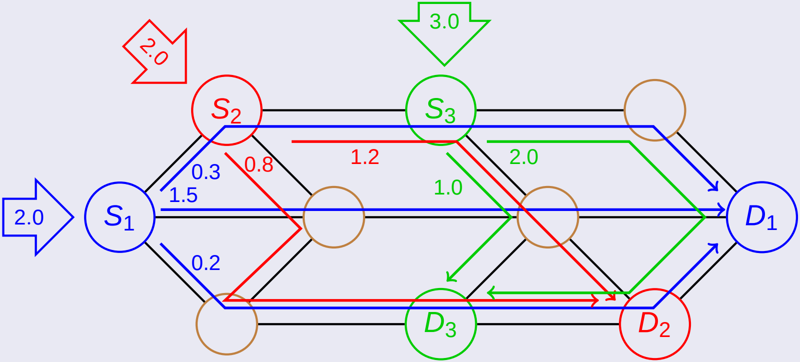
Approximate blocked traffic intensity, nonlinear, convex



Finding the Optimal Traffic Pattern

Solve the nonlinear multicommodity flow optimization problem

Flow deviation method



Traffic intensity based fixed-alternate routing

- Based on the optimal traffic assignments among the routing paths, a fixed-alternate routing algorithm is devised
- Previous Works
    - Hop counts of the routing paths
    - Revenues generated by the routing paths (in circuit-switched networks)
- Sort the routing paths according to the optimal traffic pattern

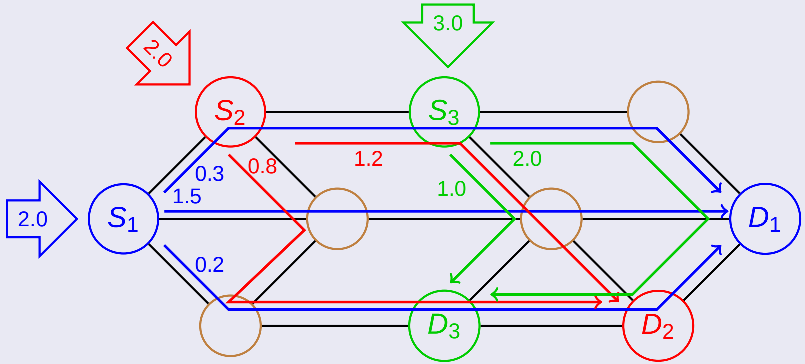
Traffic intensity based fixed-alternate routing

- Based on the optimal traffic assignments among the routing paths, a fixed-alternate routing algorithm is devised
- Previous Works
    - Hop counts of the routing paths
    - Revenues generated by the routing paths (in circuit-switched networks)
- Sort the routing paths according to the optimal traffic pattern (Offline)

Traffic intensity based fixed-alternate routing (TI-FAR)

The Optimal Traffic Pattern

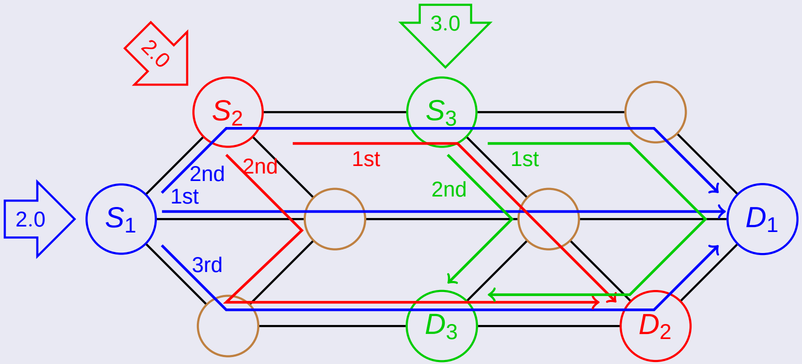
Solve the multicommodity flow optimization problem



Traffic intensity based fixed-alternate routing (TI-FAR)

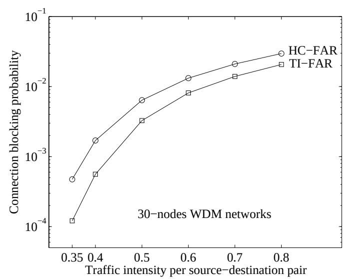
Find the order of the routing paths

According to the traffic pattern

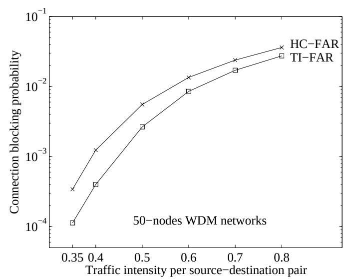


Simulation results: Connection blocking probability

30-nodes networks



50-nodes networks



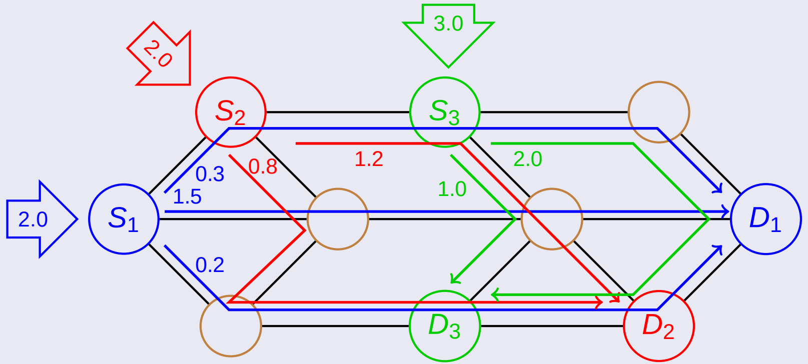
Traffic intensity based dynamic-alternate routing (TI-DAR)

- Based on the optimal traffic assignments among the routing paths, a dynamic-alternate routing algorithm is devised
- Previous works
    - Least-loaded routing (LLR)
    - Weighted least congestion routing (WLCR)
    - Less influence path first (LIPF)
- Main idea: route the traffic in approximately the optimal way

Traffic intensity based dynamic-alternate routing (TI-DAR)

The Optimal Traffic Pattern

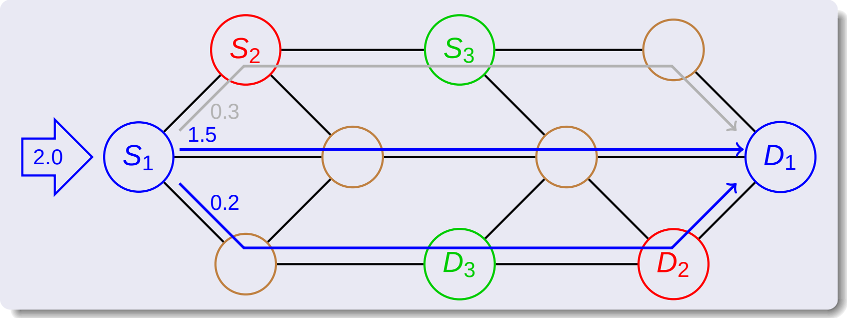
Solve the multicommodity flow optimization problem



Traffic intensity based dynamic-alternate routing (TI-DAR)

Check the common available wavelength(s) on each routing path

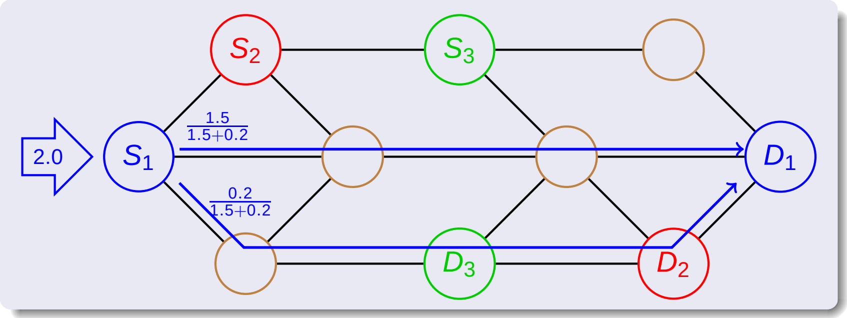
Find the routing paths(s) with common available wavelength(s)



Traffic intensity based dynamic-alternate routing (TI-DAR)

Find the probability that each path is selected

According to the traffic pattern



Simulation results: Connection blocking probability

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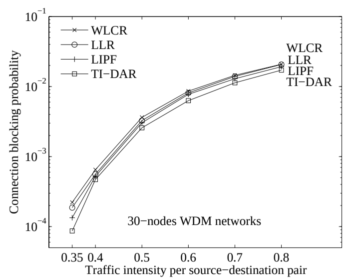

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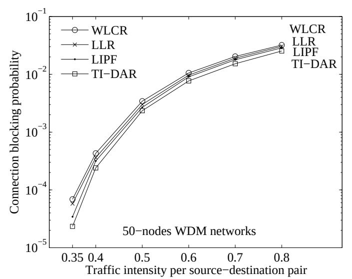


Conclusions

- A new approach to designing alternate routing algorithms for all-optical WDM networks has been proposed
- Two alternate routing algorithms TI-FAR and TI-DAR have been proposed
- The proposed alternate routing algorithm yields lower connection blocking probability than the previous works

Research Topics

- Traffic intensity based alternate routing
- Finding routing paths for alternate routing
- Splitter placement for multicast routing

Background Information

- It is desirable that the predetermined routing paths are link-disjoint for alternate routing
- Two disadvantages for not link-disjoint routing paths
  - Failure of the shared link(s)
  - Congestion on the shared link(s)

Previous Works

- The predetermined routing paths used in previous works are the k-shortest link-disjoint paths in terms of hop count
- Capacity-balanced alternate routing (C-BAR)
  - Minimize the overlapping among the routing paths
  - Minimize the deviation of the loads among the links
  - Not necessarily link-disjoint

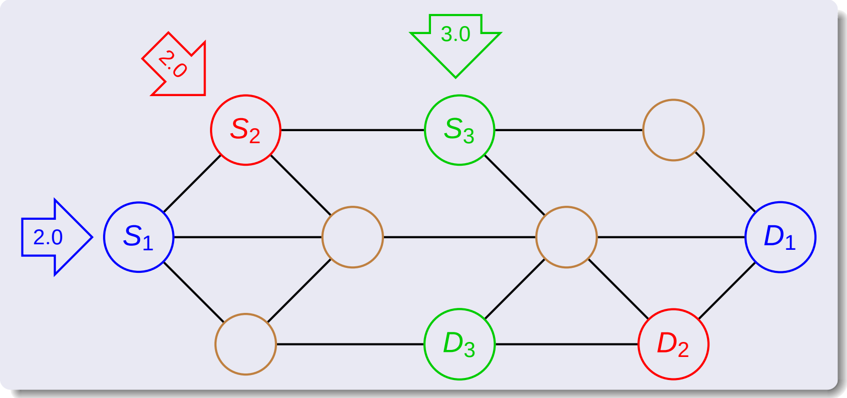
Motivation

- The k-shortest link-disjoint paths may have a number of shared links that may cause high connection blocking probability
- Depending on the topology and the traffic requirements , the best choice may not be the hop-count based k-shortest link-disjoint paths

The Proposed Method

Given

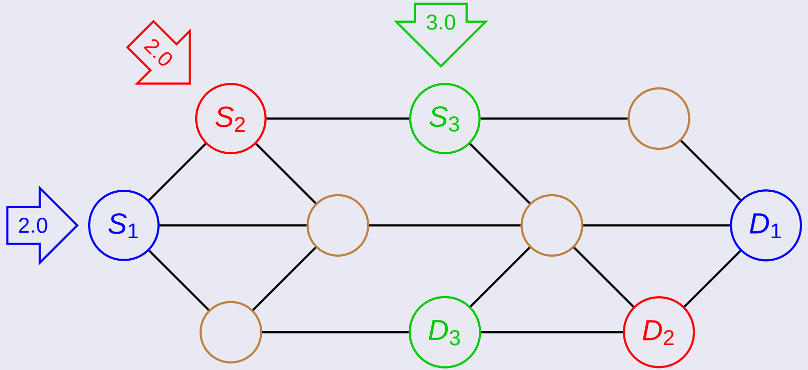
Traffic requirement of each source-destination pair



The Proposed Method

Objective

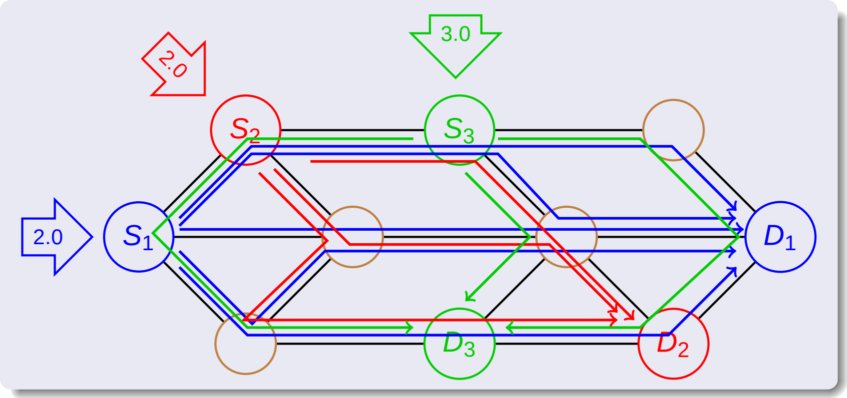
Approximate blocked traffic intensity, nonlinear, convex



The Proposed Method

Solve the nonlinear multicommodity flow optimization problem

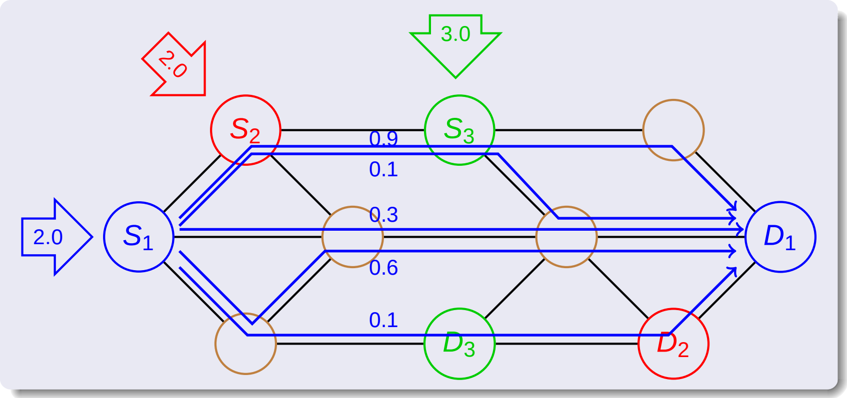
Flow deviation method



The Proposed Method

Find the link-disjoint routing paths

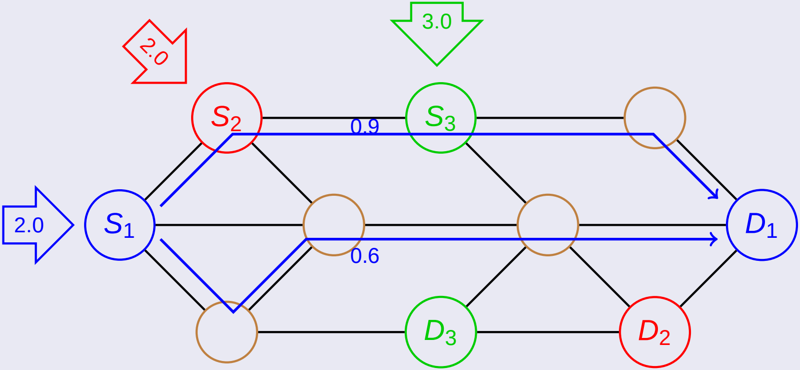
Sum of carried traffic intensities is maximized



The Proposed Method

Find the link-disjoint routing paths

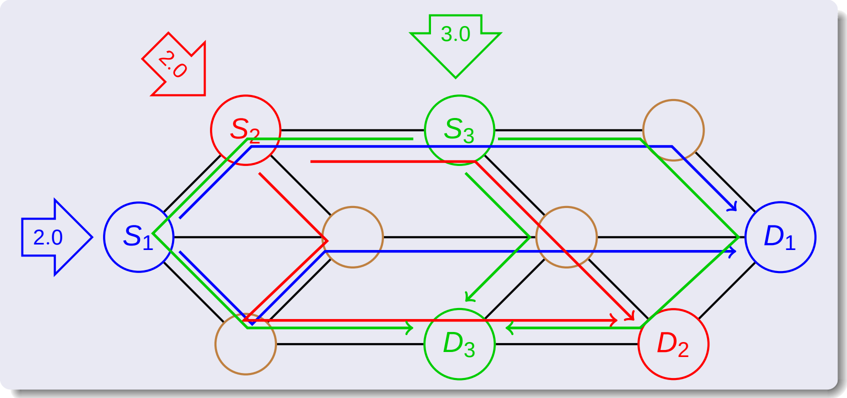
Integer zero-one programming problem



The Proposed Method

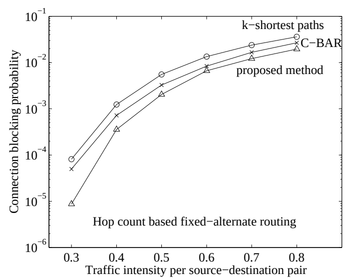
Find the link-disjoint routing paths

Find routing paths for each source-destination pair

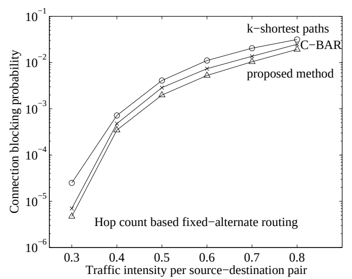


Simulation Results: Connection blocking probability for HC-FAR

without wavelength conversion

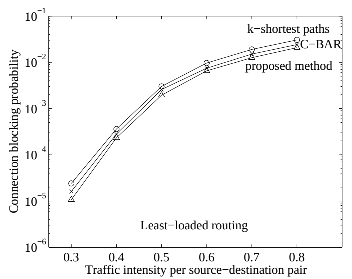


with wavelength conversion

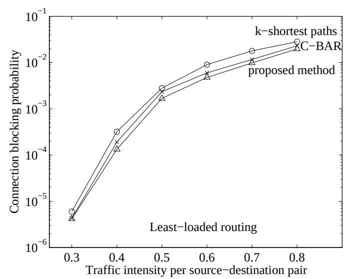


Simulation Results: Connection blocking probability for LLR

without wavelength conversion



with wavelength conversion



Conclusions

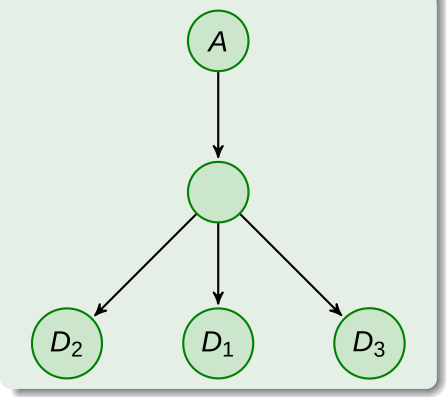
- We have proposed a paths finding algorithm according to the optimally assigned traffic intensities
- Our simulation results show that using the routing paths found by the proposed method yields lower blocking probability than using k-shortest link-disjoint paths and paths found by C-BAR

Research Topics

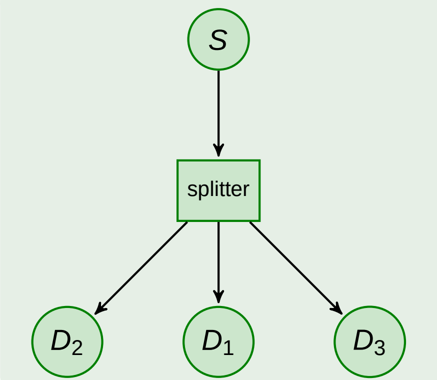
- Traffic intensity based alternate routing
- Finding routing paths for alternate routing
- Splitter placement for multicast routing

Light-tree

Lightpaths

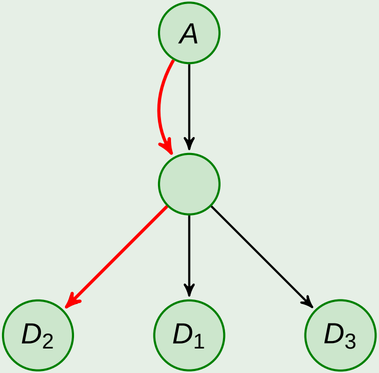


Lighttree

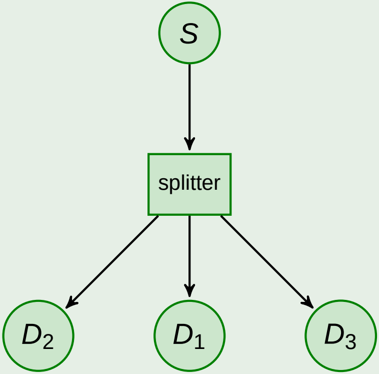


Light-tree

Lightpaths

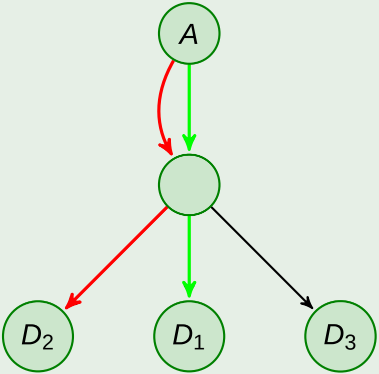


Lighttree

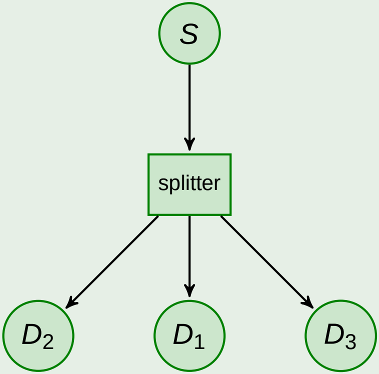


Light-tree

Lightpaths

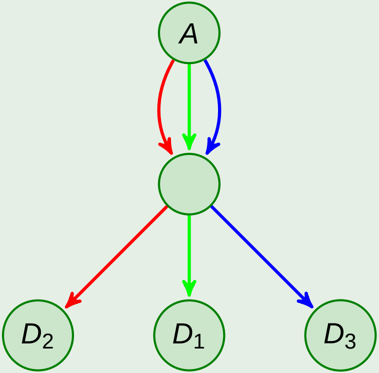


Lighttree



Light-tree

Lightpaths



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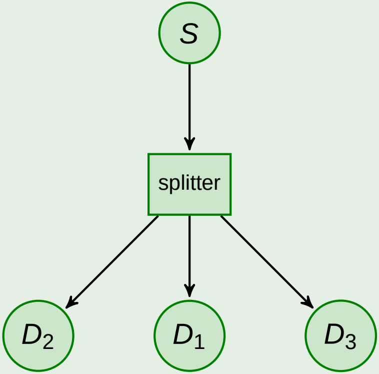
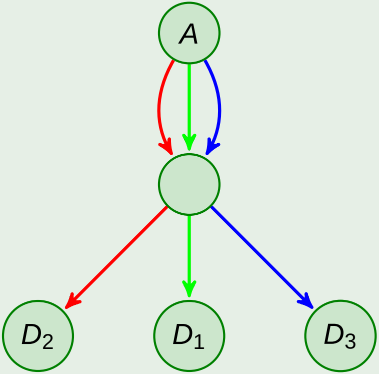


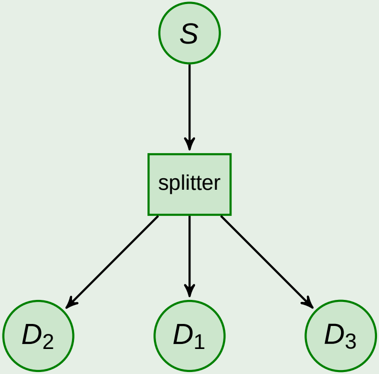
Light-tree

Lightpaths



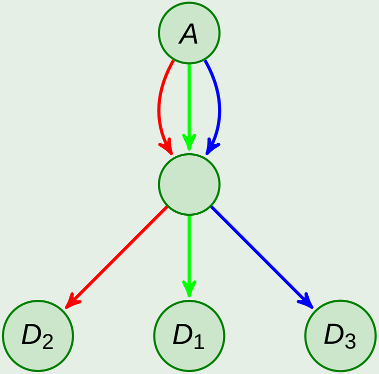
Waste of Bandwidth !!

Lighttree



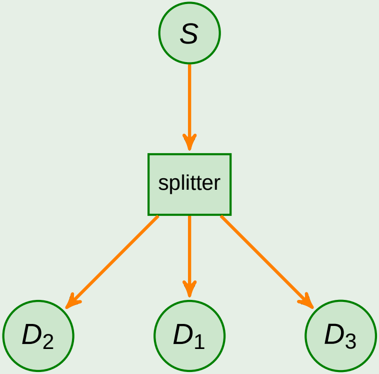
Light-tree

Lightpaths



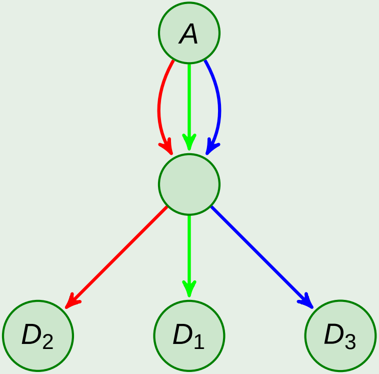
Waste of Bandwidth !!

Lighttree



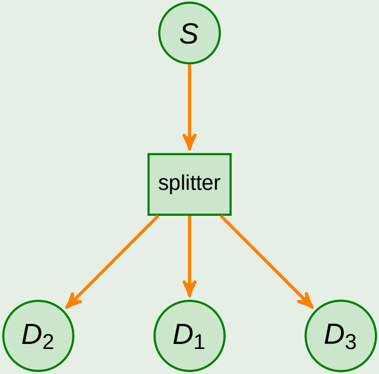
Light-tree

Lightpaths



Waste of Bandwidth !!

Lighttree



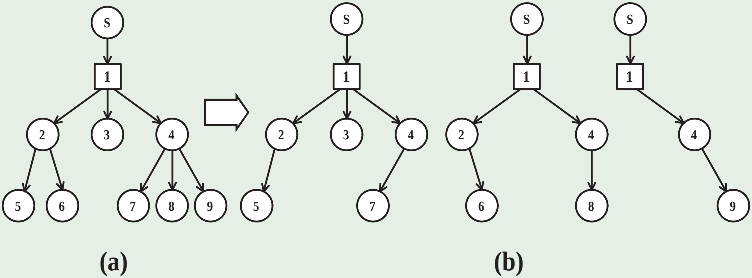
Saving Bandwidth !!

Sparse light splitting multicast routing

- A multicast capable node is much more expensive than a multicast incapable node
- To reduce the cost, splitters can be placed at a subset of selected nodes instead of all of the nodes
- Multicast routing algorithms in networks with sparsely placed splitters are called sparse light splitting multicast routing algorithms

Sparse light splitting multicast routing

Light-Forest



Splitter Placement Problem

- The performance of the multicast routing algorithm is highly affected by the locations of the splitters in the network
- How to place a given number of splitters at suitable locations such that the performance of the multicast routing algorithm can be improved is an important issue

Splitter Placement Problem

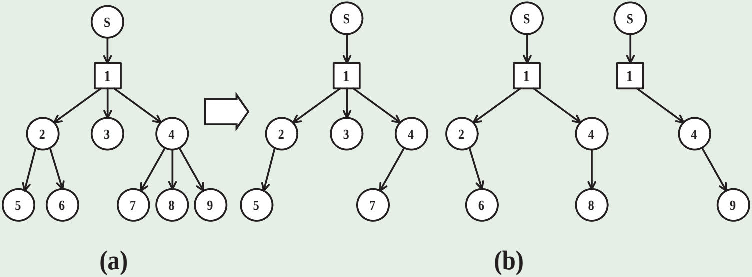
- We consider the splitter placement problem in all-optical WDM networks in which a light forest consisting of a collection of light trees rooted at the source node is used to realize a multicast connection.
- The objective of this research topic is to place a given number of splitters in the network such that the wavelength resource utilized by the multicast connections is minimized.

Previous Location Problems

- Location problems in graph theory
  - *p*-median problem
  - *p*-center problem
- Differences between the splitter placement problem and the location problems in graph theory

Wavelength Resource Usage

Example



14 = 6 + 5 + 3

The Splitter Placement Method

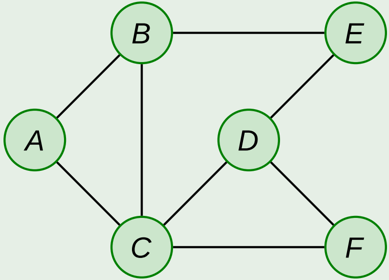
- The *k*-maximum degree method
- The *k*-maximum *WR* (Wavelength Reduction) method

The *k*-maximum degree method

Main idea

A node with more neighbor nodes is more likely to become a branch node of a multicast tree

Network

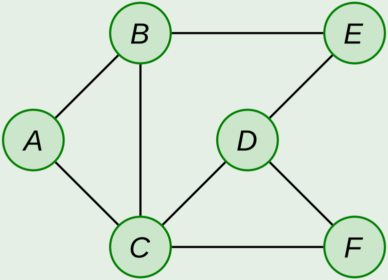


The *k*-maximum degree method

Main idea

A node with more neighbor nodes is more likely to become a branch node of a multicast tree

Network



Node Degrees

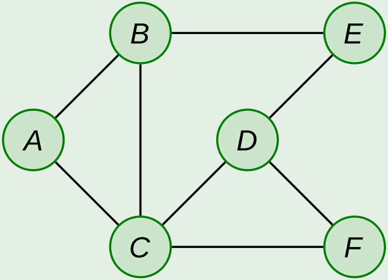
- Degree(A)=2
- Degree(B)=3
- Degree(C)=4
- Degree(D)=3
- Degree(E)=2
- Degree(F)=2

The *k*-maximum degree method

Main idea

A node with more neighbor nodes is more likely to become a branch node of a multicast tree

Network



Node Degrees

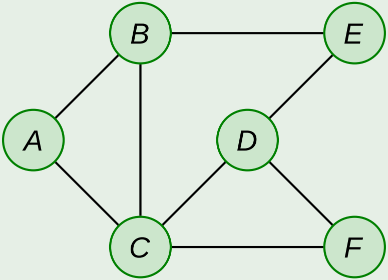
1. Degree(C)=4
2. Degree(B)=3
3. Degree(D)=3
4. Degree(A)=2
5. Degree(E)=2
6. Degree(F)=2

The *k*-maximum *WR* method

Main idea

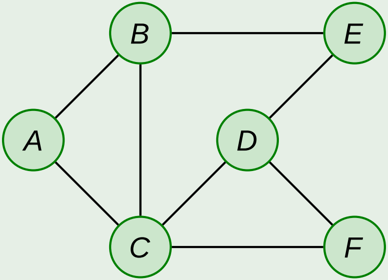
It is more beneficial to place a splitter at the node which may yield more reduction on the wavelength resource usage.

Network



The *k*-maximum *WR* method

Network

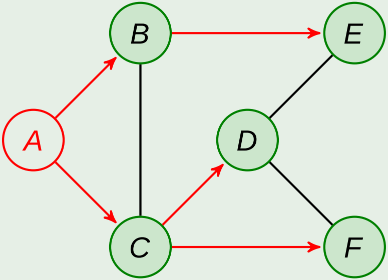


Calculation of Wavelength Reduction

Total Wavelength Resource=

The *k*-maximum *WR* method

Network

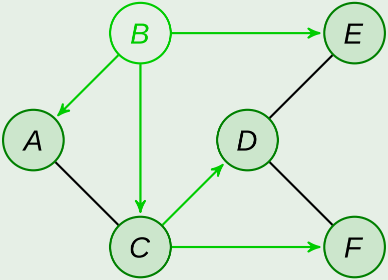


Calculation of Wavelength Reduction

Total Wavelength Resource=6

The *k*-maximum *WR* method

Network

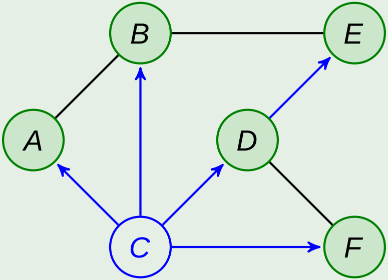


Calculation of Wavelength Reduction

Total Wavelength Resource=6+6

The *k*-maximum *WR* method

Network

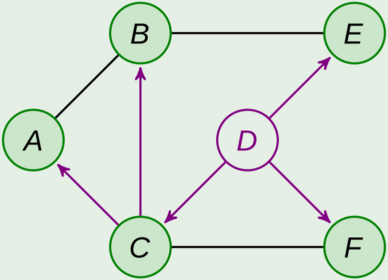


Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5

The *k*-maximum *WR* method

Network

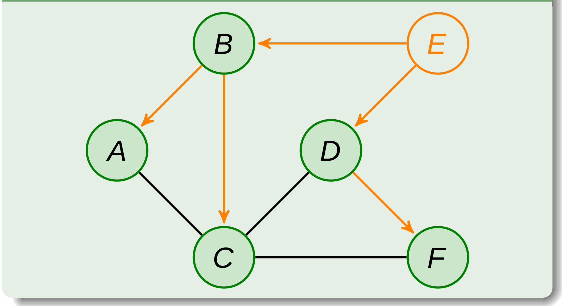


Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6

The *k*-maximum *WR* method

Network

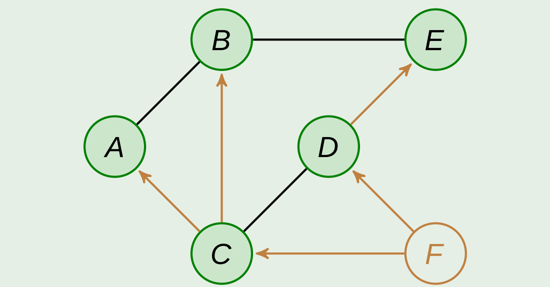


Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6

The *k*-maximum *WR* method

Network

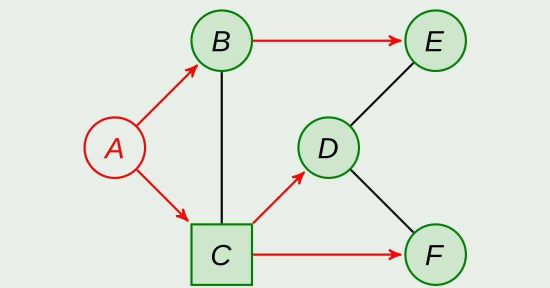


Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

The *k*-maximum *WR* method

Network



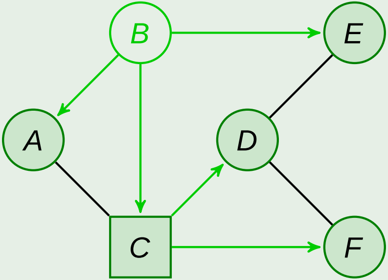
Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

Total Wavelength Resource=5

The *k*-maximum *WR* method

Network



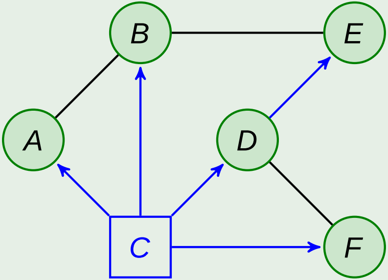
Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

Total Wavelength Resource=5+5

The *k*-maximum *WR* method

Network



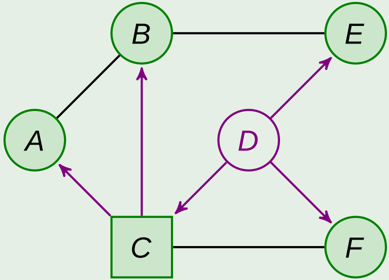
Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

Total Wavelength Resource=5+5+5

The *k*-maximum *WR* method

Network



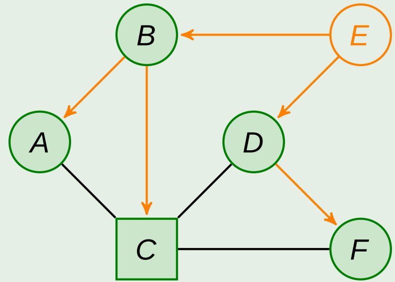
Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

Total Wavelength Resource=5+5+5+5

The *k*-maximum *WR* method

Network



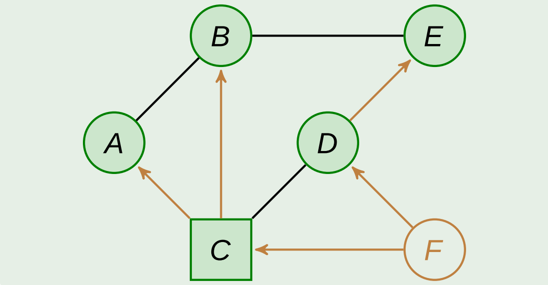
Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

Total Wavelength Resource=5+5+5+5+6

The *k*-maximum *WR* method

Network



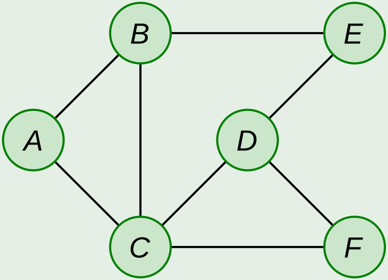
Calculation of Wavelength Reduction

Total Wavelength Resource=6+6+5+6+6+6=35

Total Wavelength Resource=5+5+5+5+6+5=31

The *k*-maximum *WR* method

Network

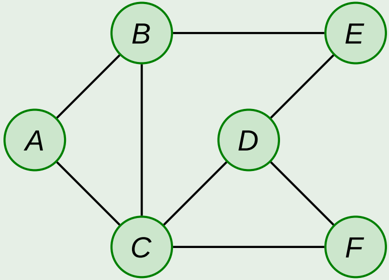


Wavelength Reduction

Wavelength Reduction on Node C = 35-31 = 4

The *k*-maximum *WR* method

Network

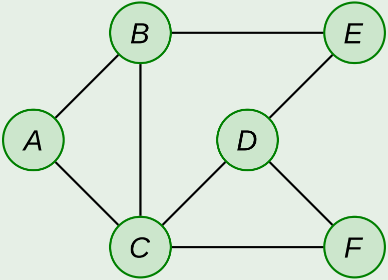


WR Value

- WR(A)=0
- WR(B)=1
- WR(C)=4
- WR(D)=0
- WR(E)=0
- WR(F)=0

The *k*-maximum *WR* method

Network

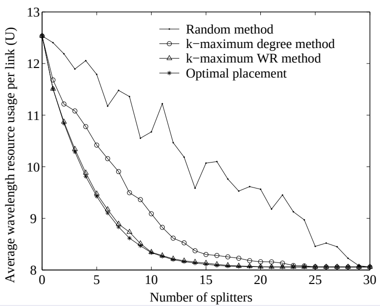


WR Value

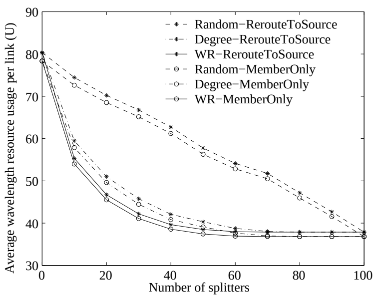
1. WR(C)=4
2. WR(B)=1
3. WR(A)=0
4. WR(D)=0
5. WR(E)=0
6. WR(F)=0

Simulation Results

Performance of placement method



Performance of joint algorithm



Conclusions

- A good splitter placement method is beneficial in efficient utilization of the wavelength resource and improving the performance of the network
- The k-maximum *WR* method proposed is able to yield near optimal per link average wavelength resource usage.
- The k-maximum *WR* method combined with a good algorithm for constructing light forests for the multicast connection can further reduce the average wavelength resource usage

Concluding remarks

- We have proposed the following algorithms for the problems related to routing in all-optical WDM networks:
    - Two alternate routing algorithms: TI-FAR and TI-DAR
    - A method for finding the routing paths for alternate routing
    - A splitter placement method for sparse light splitting multicast routing
- The proposed algorithms yield better performance than the previous algorithms

Future works

We shall further study the problems related to routing in the follwoing networks.

- All-optical WDM networks with wavelength conversion
- All-optical WDM networks with traffic grooming capabilities

Publication List

Journal Papers

1. H.C. Lin, S.W. Wang, and M.L. Hung, “ Finding Routing Paths for Alternate Routing in All-optical WDM Networks,” accepted by *IEEE/OSA Journal of Lightwave Technology*.
2. H.C. Lin, S.W. Wang, C.P. Tsai, and M.L. Hung, “ Traffic Intensity Based Alternate Routing in All-optical WDM Networks,” accepted by *IEEE/OSA Journal of Lightwave Technology*.

Conference Papers

1. H.C. Lin and S.W. Wang, “Splitter Placement in All-optical WDM Networks,” in *Proceedings of IEEE GLOBECOM 2005,* St. Louis, USA, November 28-December 2, 2005.
2. H.C. Lin, S.W. Wang, and C.P. Tsai, “Traffic Intensity Based Fixed-alternate Routing in All-optical WDM Networks,” in *Proceedings of IEEE ICC 2006,* Istanbul, Turkey, June 11-15, 2006.