Multicast Routing and Distance-Adaptive Spectrum Allocation in Elastic Optical Networks With Shared Protection

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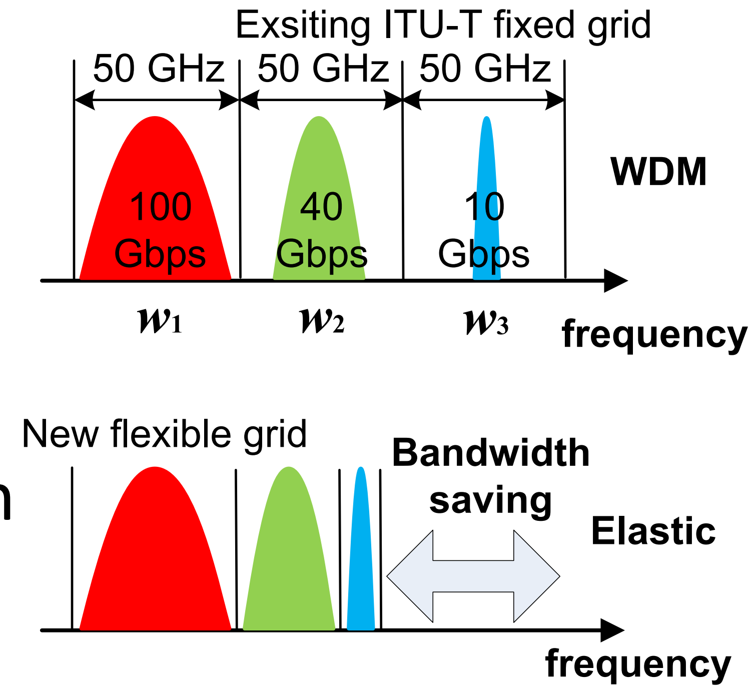
A. Cai, J. Guo, R. Lin, G. Shen, and M. Zukerman, "Multicast routing and distance-adaptive spectrum allocation in elastic optical networks with shared protection," *J. Lightw. Technol.,* vol. 34, no. 17, pp. 4076–4088, Sep. 2016.

Outline

- Introduction & motivation
- Problem statement
- Heuristic algorithm
- Numerical results
- Conclusions

Introduction

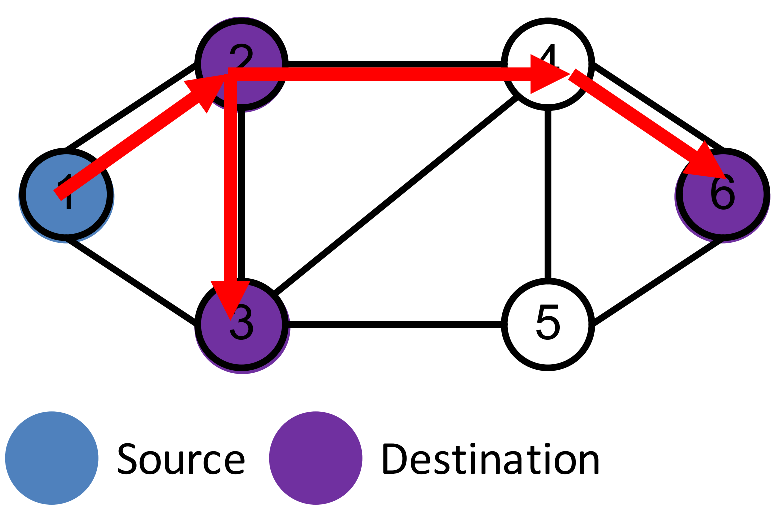
- Rapid growth in Internet traffic: Nearly threefold increase over the next 5 years
- Elastic optical networks
  - Flexible frequency grid
  - Better spectrum utilization
  - Support of super channels
  - Distance-adaptive transmission
  - ……



Cisco, "Cisco Visual Networking Index: Forecast and Methodology, 2015–2020," Jun. 2016.
O. Gerstel, M. Jinno, A. Lord, and S. J. B. Yoo, "Elastic optical networking: A new dawn for the optical layer?" *IEEE Commun. Mag.*, vol. 50, no. 2, pp. s12-s20, Feb. 2012.

Introduction (Cont.)

- Multicast traffic: Data transmitted from one source to multiple destinations
- Bandwidth-intensive multicast services
  - Ultra-high-definition TV delivery, video conferencing, inter-datacenter synchronization, etc.

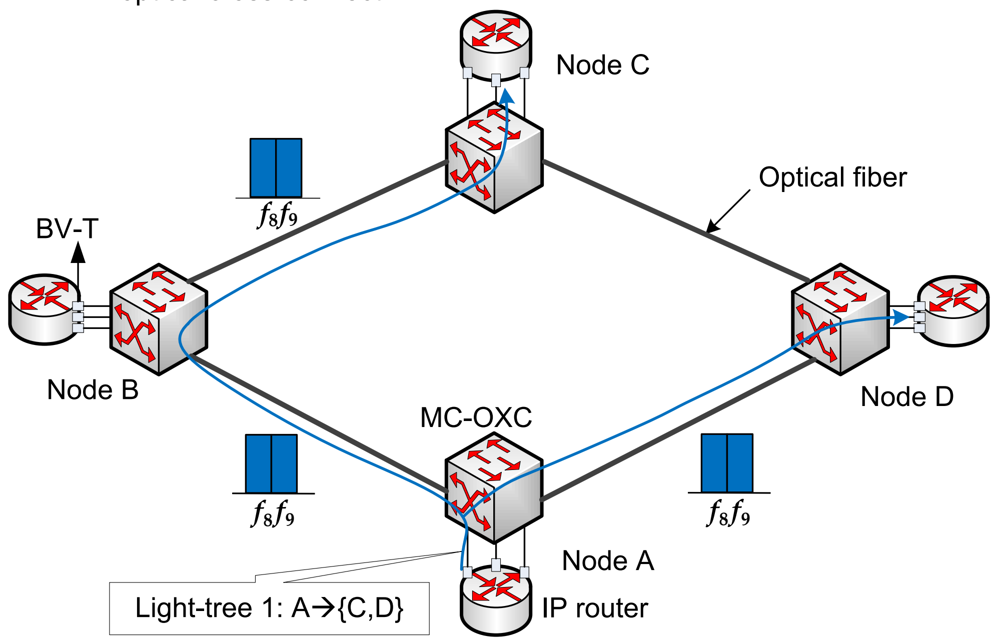


(Source: http://www.imcca.org/)

A Light-Tree-Based Elastic Optical Network

Light-tree: Optical channel from a source to multiple destinations

BV-T: Bandwidth-variable transponder
MC-OXC: Multicast-capable optical cross-connect

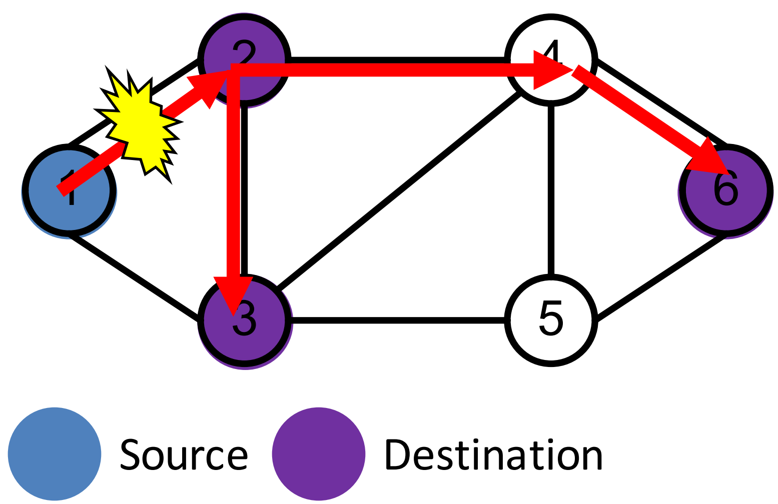


Frequency slot (FS): A unit to quantize the spectral resources

L. H. Sahasrabuddhe and B. Mukherjee, "Light-trees: optical multicasting for improved performance in wavelength routed networks," *IEEE Commun. Mag.*, vol. 37, no. 2, pp. 67-73, 1999.
M. Jinno *et al.*, "Distance-adaptive spectrum resource allocation in spectrum-sliced elastic optical path network," *IEEE Commun. Mag.*, vol. 48, no. 8, pp. 138-145, 2010.

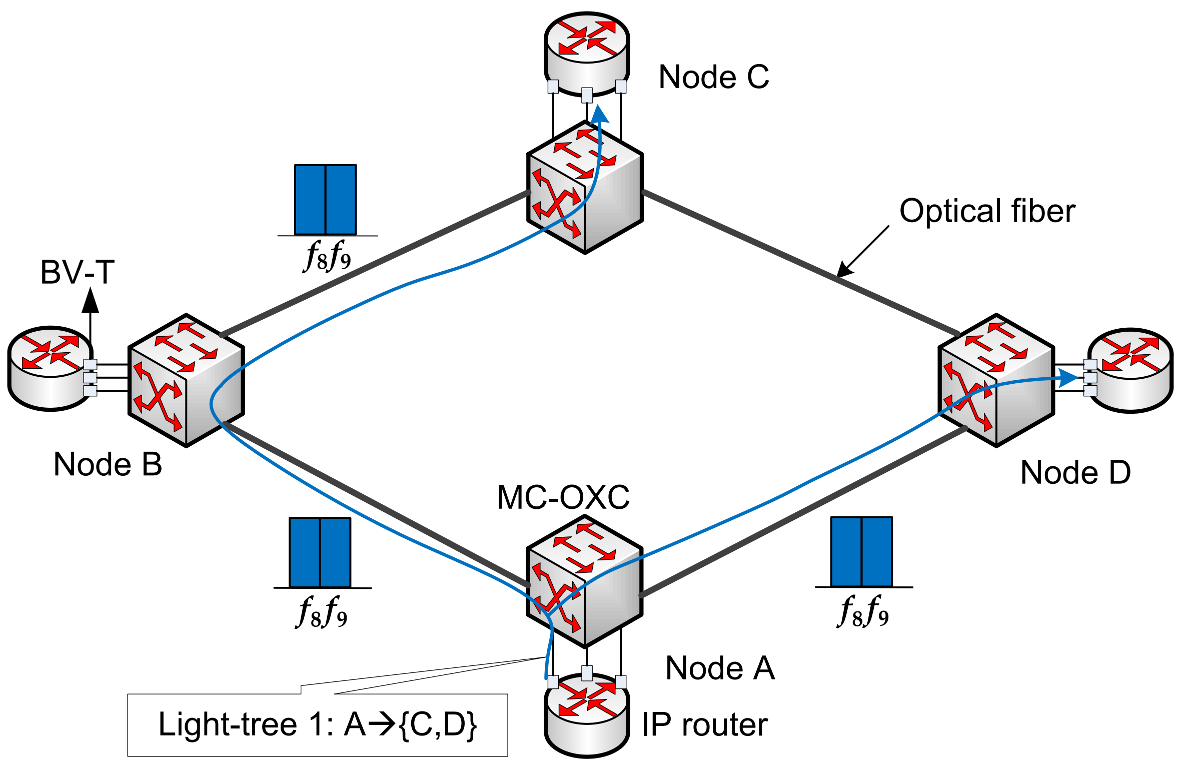
Motivation

- A failure in a link (esp., a trunk of a light-tree) could result in severe service disruption
- Protection: Enable network to continue to operate under a failure
- We focus on multicast protection for the case of a single-link failure in EONs



Multicast Routing, Modulation and Spectrum Assignment (MC-RMSA)

- Multicast routing: Find a routing tree
- Modulation and spectrum assignment: Assign modulation and thus bandwidth

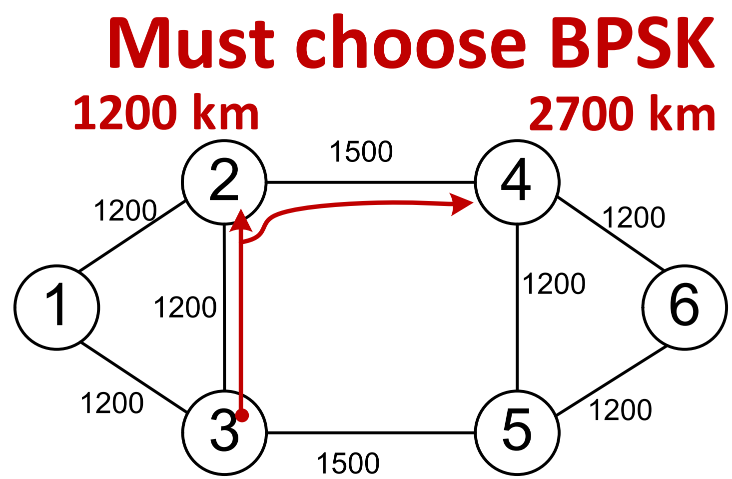


Distance-Adaptive Resource Allocation

- Minimum spectrum resources are adaptively allocated to an all-optical channel according to its physical condition
- To meet required optical signal noise ratio (OSNR), the use of a modulation scheme (MS) for a connection dictates a transparent reach (TsR) or maximal transmission distance
- Modulation and spectrum assignment is subject to the longest distance among the paths to all destinations

TR and Capacity per FS for Each MS*

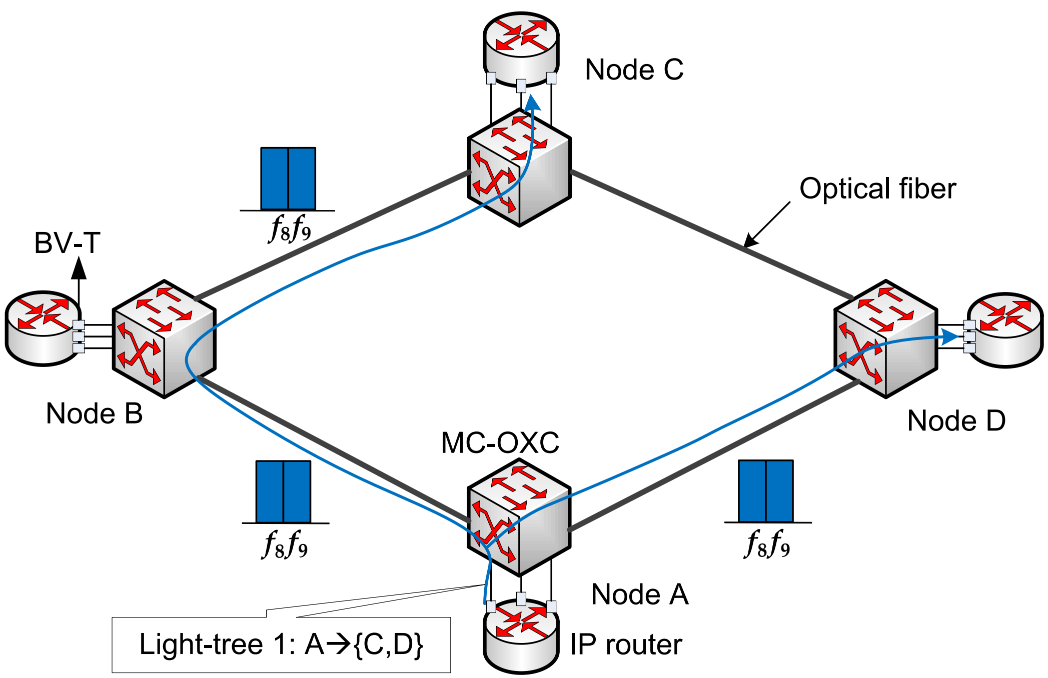
MS	TsR (km)	Capacity per FS (Gbps)
BPSK	4000	12.5
QPSK	2000	25



* C. Wang, G. Shen, and S. K. Bose, "Distance adaptive dynamic routing and spectrum allocation in elastic optical networks with shared backup path protection," *J. Lightw. Technol.*, vol. 33, no. 14, pp. 2955-64, Jul. 2015.

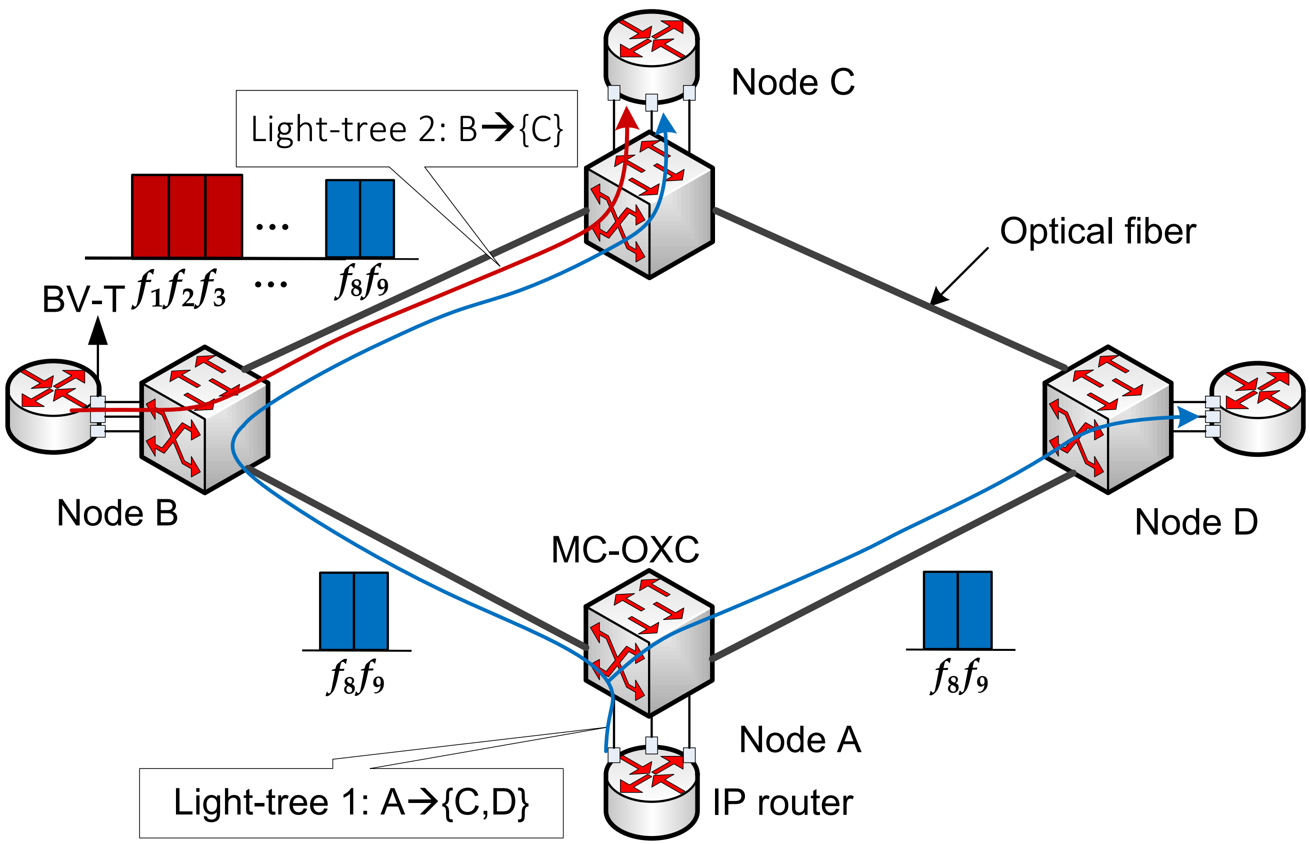
Major Constraints in Spectrum Assignment

- Spectrum continuity (no spectrum conversion capability): Assign same FSs in all traversed links
- Spectrum contiguity (f_8, f_9 not f_8, f_{10})



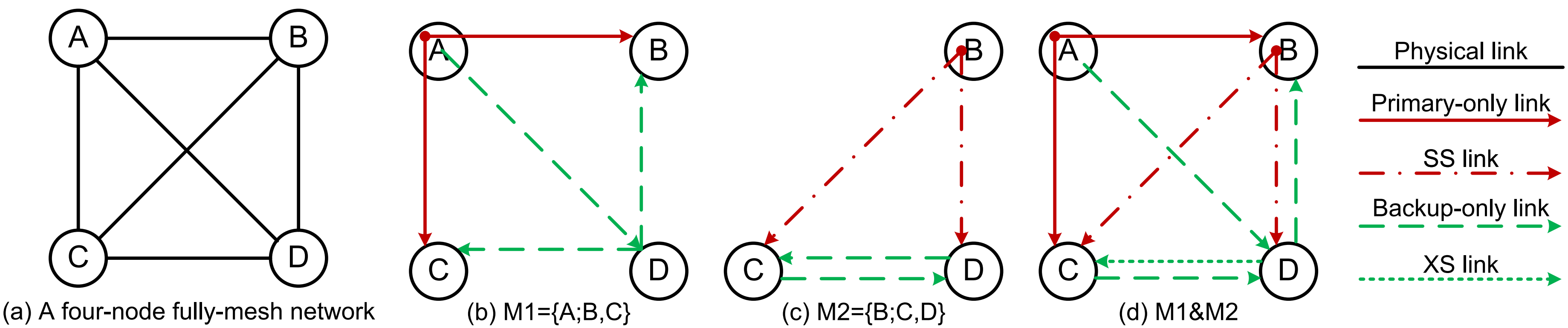
Major Constraints in Spectrum Assignment (Cont.)

- Spectrum non-overlapping: Any FS in a fiber cannot be allocated to two or more connections



Shared Protection Scheme

- Protect a light-tree by having each of its primary paths protected via a link-disjoint backup path
  - Link-disjoint: No backup path shares common link with its primary tree
  - Self-sharing (SS): The resources in a link allocated to a source-destination (SD) pair protect the primary path of another SD pair
- Cross-sharing (XS): Multiple connections can share backup-only resources as long as they do not fail simultaneously



An example for protection schemes: (a) a four-node fully-mesh network; (b) link-disjoint; (c) self-sharing; and (d) cross-sharing.

N. K. Singhal, C. Ou, and B. Mukherjee, "Cross-sharing vs. self-sharing trees for protecting multicast sessions in mesh networks," *Comput. Netw.*, vol. 50, no. 2, pp. 200-206, 2006.

Problem Statement

- Inputs and assumptions
  - A network: Each node is multicast-capable, and each link corresponds to a pair of fibers in opposite directions
  - No spectrum conversion capability
  - A set of multicast demands
  - Each SD pair has at least a pair of link-disjoint paths
  - The same spectrum modulated by the same MS are used in both primary tree and backup paths for self-sharing
- Objective: Minimize the maximum spectrum resource among the spectrum resources required in all links to accommodate the given demands
- Methodology: Mixed integer linear programming (MILP) formulation and heuristic algorithm

Heuristic Algorithms

- MILP is not scalable, but for realistic size problems we still need to minimize the spectrum resources. Accordingly, we aim for
  - A higher-order MS (shorter reach -> shorter path -> smaller trees and fewer FSs)
  - Having smaller trees is an additional benefit (fewer links)
  - But we may need longer path -> lower MS -> current resources can be reused

Demand-Serving Order Matters!

- In our heuristic algorithm, we serve the demands in an order
- Different demand-serving orders yield different results
- Two ordering methods
  - Arrange demands in a decreasing order of their required FSs
  - Randomly shuffle the demands to obtain a randomly ordered demand sequence and to further improve the solution quality, we consider multiple demand sequences for each given set of demands

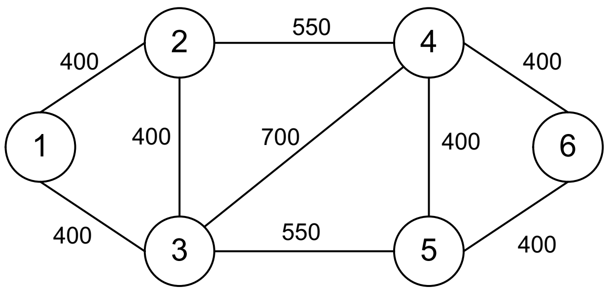
Test Conditions

Transparent reach and capacity per FS for each MS

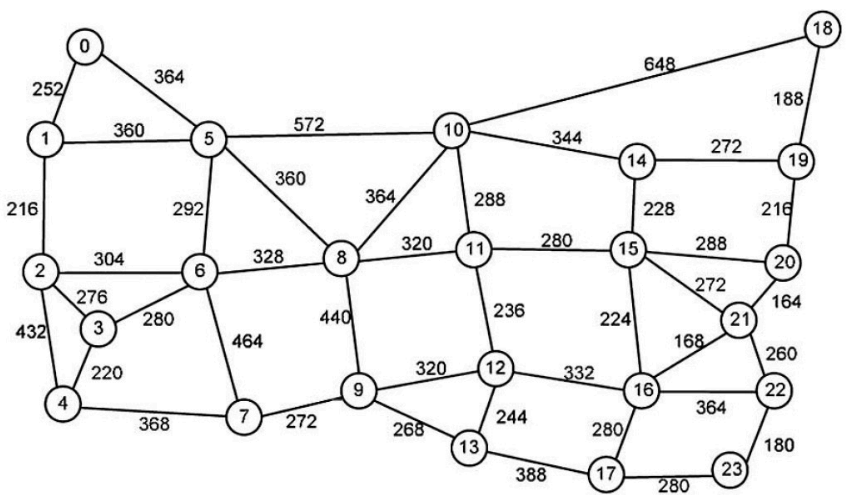
MS	TsR (km)	Capacity per FS (Gbps)
BPSK	4000	12.5
QPSK	2000	25
8QAM	1000	37.5

- FS granularity: 12.5 GHz
- 10 sets of MCC demands: for each set, the multicast demands are randomly generated, where the traffic follows a uniform distribution (100, 200) Gbps and the multicast sessions are obtained randomly

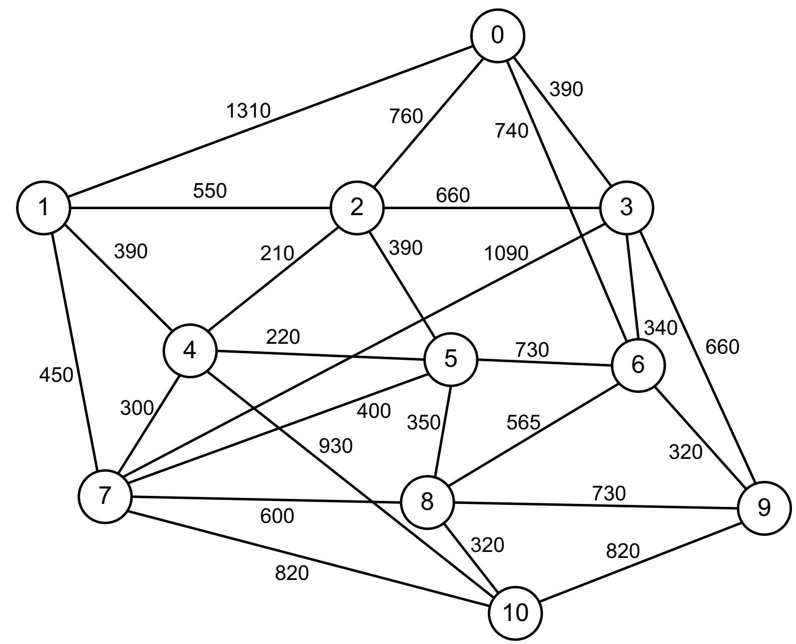
Test Networks



(a) A six-node nine-link (n6s9) network



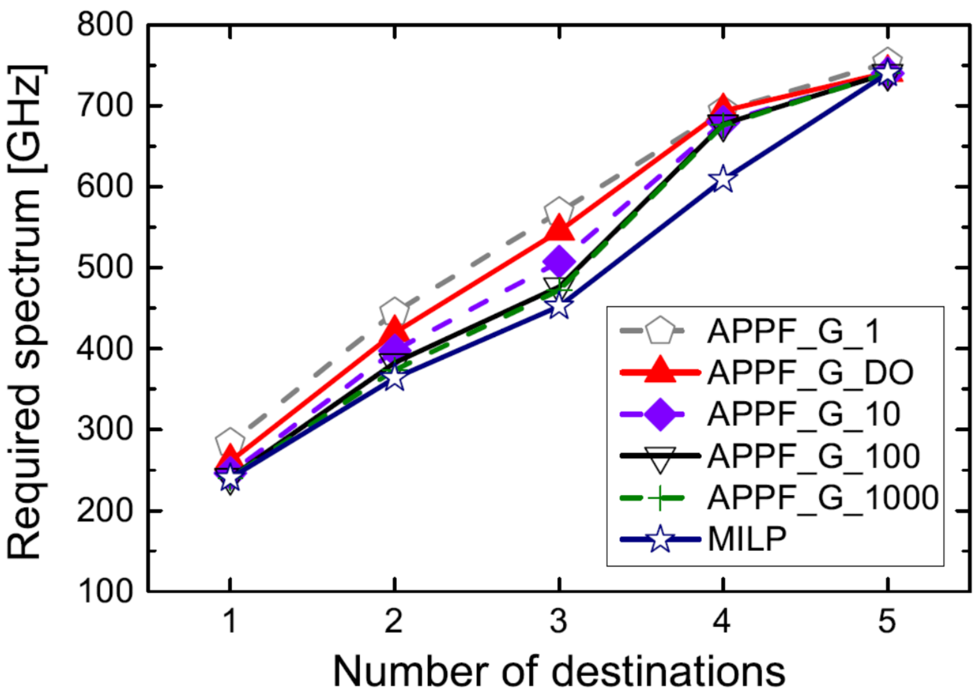
(c) 24-node 43-link USNET network



(b) 11-node 26-link COST239 network

Numerical Results

Method	Routing	Service Order	Method Short Name
MILP	-	-	MILP
Heuristic Algorithm	APPF	Decreasing Order	APPF_G_DO
		n Random Orders	APPF_G_n



Performance comparison for the n6s9 network (10 demands).

Compared to MILP

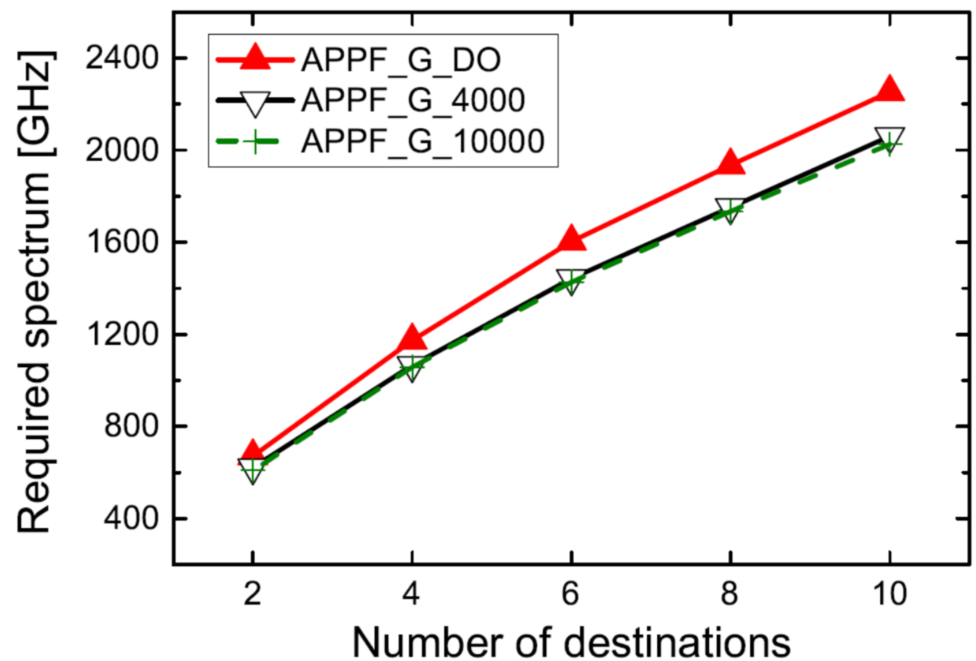
- APPF_G_DO requires 11.8% more spectrum
- APPF_G_100 requires 4.4% more spectrum

100 random sequences are considered sufficient to achieve near optimum

Margin benefit for broadcast: n6s9 average nodal degree is low, i.e., 3

Numerical Results

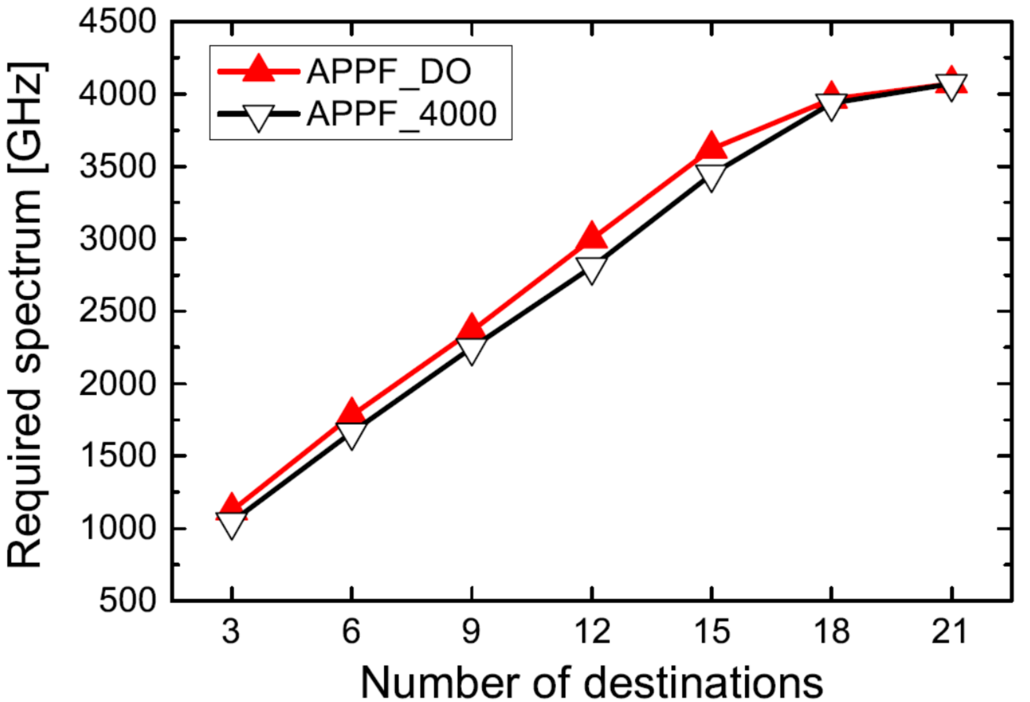
- APPF_G_4000, saves around 9% spectrum compared to APPF_G_DO
- 4000 sequences are considered sufficient
- Significant benefit for broadcast: COST239 average nodal degree 4.7



Performance comparison for the COST239 network (50 demands).

Numerical Results

- APPF_G_4000 saves on average 4.3% spectrum compared to APPF_G_DO
- USNET average nodal degree: 3.6



Performance comparison for the USNET network (50 demands).

Conclusions

- We have considered the MC-RMSA problem in EONs with shared protection
  - A MILP formulation and an efficient heuristic algorithm
  - The proposed heuristic algorithm performs close to the MILP by allowing a longer running time

Thank you
&
questions?