Reliable Slicing of 5G Transport Networks with Dedicated Protection

Nashid Shahriar, Sepehr Taeb, Shihabur R. Chowdhury, Mubeen Zulfiqar, Massimo Tornatore, Raouf Boutaba

UNIVERSITY OF WATERLOO
FACULTY OF MATHEMATICS
David R. Cheriton School of Computer Science

Jeebak Mitra, Mahdi Hemmati

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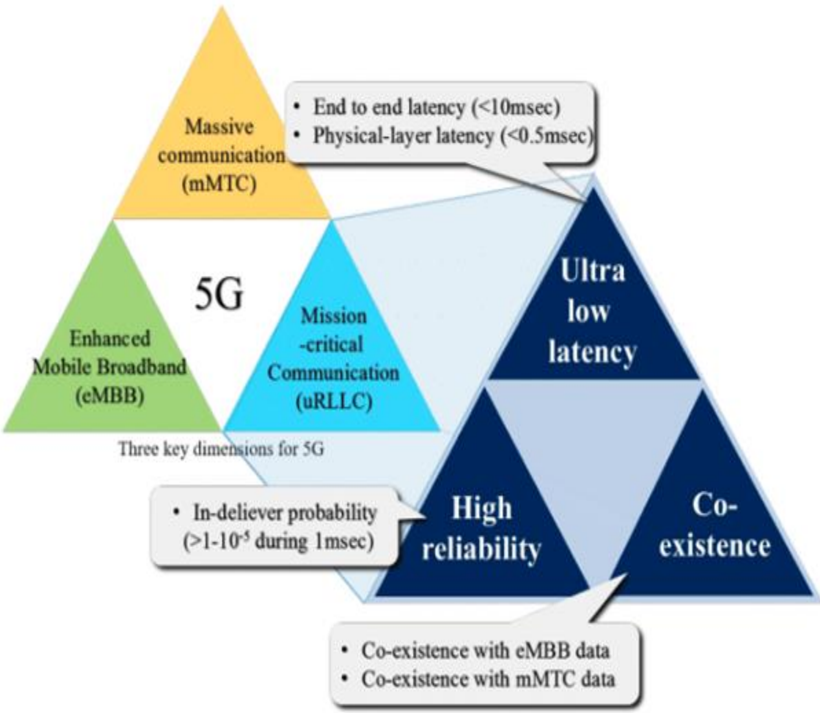
Outline

- Introduction
  - Transport Network technologies
  - Virtual network (VN) embedding
  - Reliable VN embedding
- Proposed solutions
  - Integer Linear Program (ILP) formulation
  - Heuristic algorithm
- Evaluation
- Summary and future work

Introduction

- 5G services rely on slicing
  - Partition network resources
  - Meet stringent QoS requirements
- An enabling technology is *network virtualization*
  - Multiple VNs on same transport network (SN)
  - VNs have different reliability requirements



Transport network technologies

- Transport network connects Point of Presence (PoP) nodes
  - Optical network is the dominant technology
  - Thanks to high-bandwidth and low-latency

- Fixed-grid technology allocates spectrum in coarse-grained fashion
  - Inefficient - supports only 50 or 100 GHz wavelength grids
  - Rigid - allows limited transmission configurations for each data rate

Data Rate (Gbps)	Modulation	FEC (%)	Spectrum bandwidth (GHz)	Reach (km)
100	QPSK	25%	50	2000
200	QPSK	25%	100	1000

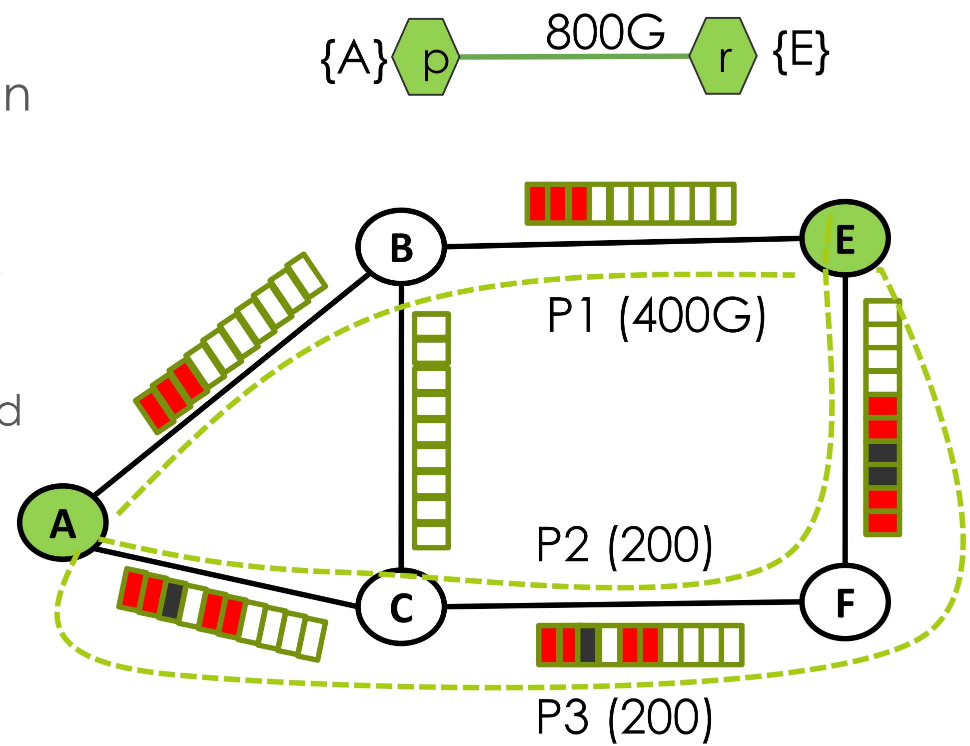
Transport network technologies

- Elastic Optical Networks (EONs) are emerging
  - Enables finer granularity (12.5GHz) with flexible number of spectrum slices based on customer demand
  - Facilitates adaptation of transmission configurations

Data Rate (Gbps)	Modulation	FEC (%)	Spectrum bandwidth (GHz)	Reach (km)
100	QPSK	25%	50	2000
	16QAM	20%	25	1250
200	QPSK	25%	75	1000
	32QAM	20%	37.5	400

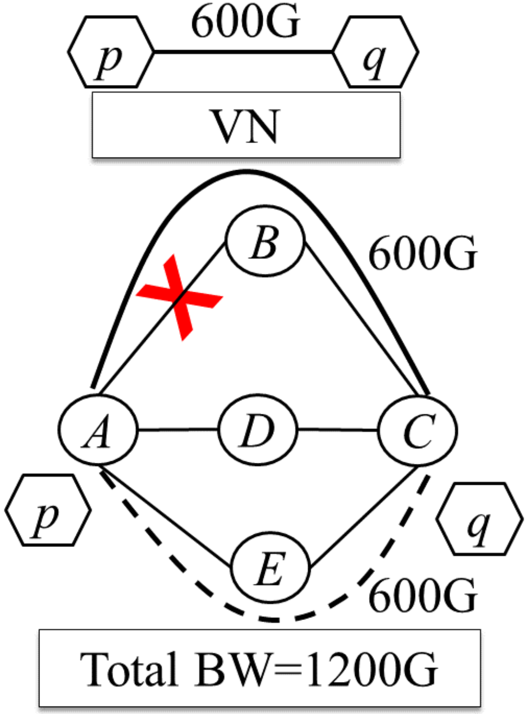
Virtual network embedding (VNE)

- Embed a VN on an EON
  - A virtual node is hosted on a physical node
  - A virtual link (VLink) is mapped to a non-empty set of lightpaths
    - Each lightpath is assigned a transmission configuration and required spectrum slots
    - Spectrum contiguity and continuity constraint

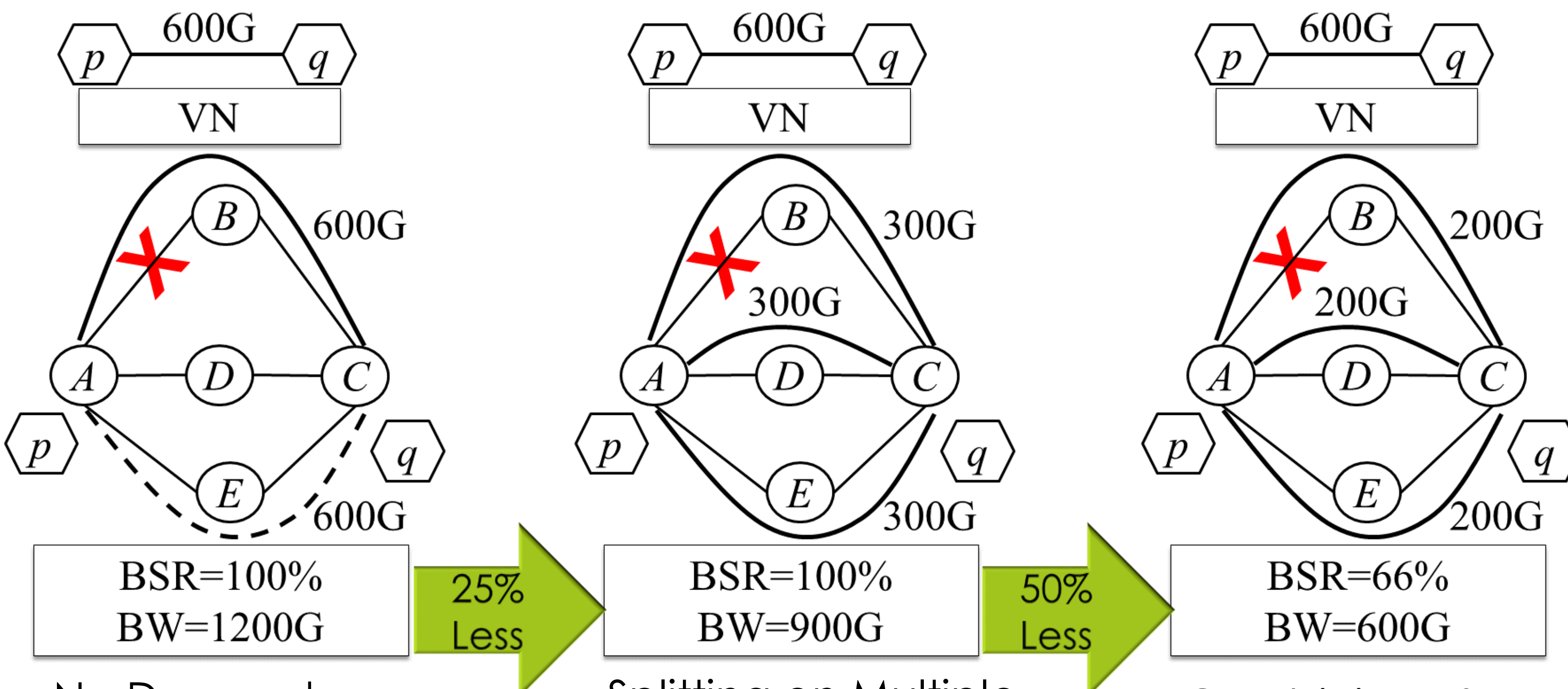


Reliable VNE

- Failures cause significant traffic disruption
  - Single substrate link failure (e.g., fiber-cut)
- Pre-provision dedicated backup paths
  - Facilitates fast fail-over switching to backup
  - Requires a significant redundant resource
- How to reduce wastage of resource?
  - Bandwidth squeezing rate (BSR)
    - Tune the amount of bandwidth guaranteed in case of failures
  - Demand splitting over multiple disjoint paths



Reliable VNE with BSR and splitting

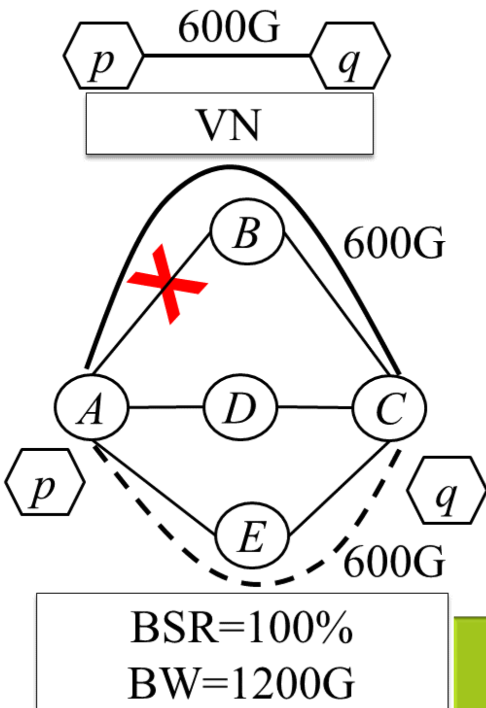


No Demand Splitting

Splitting on Multiple disjoint paths

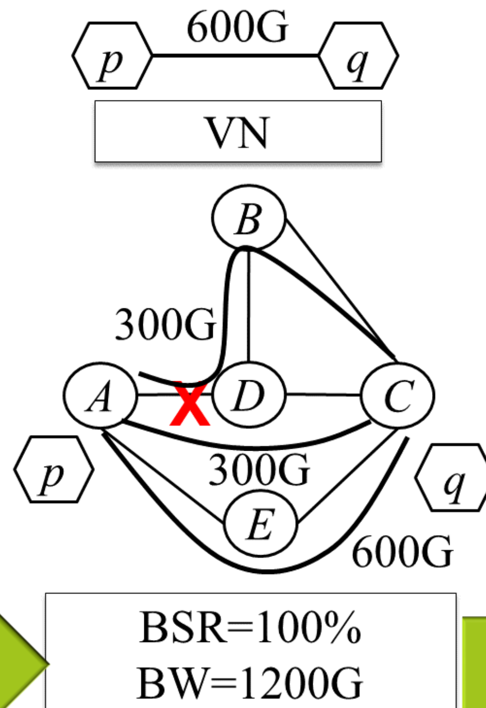
Combining BSR & Splitting

Reliable VNE with BSR and splitting



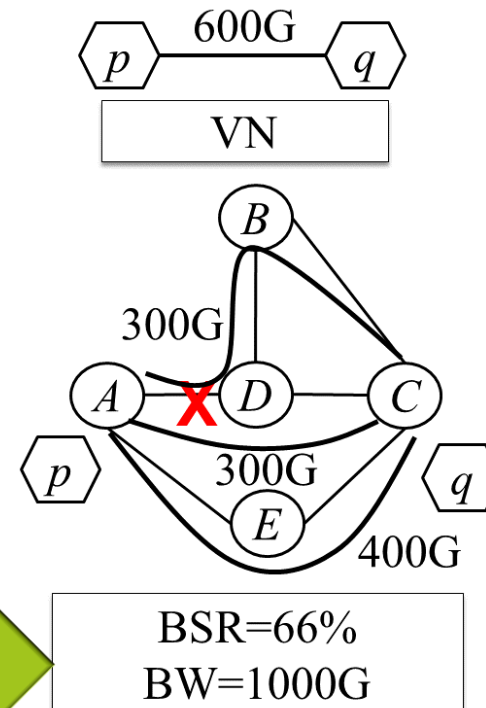
No Demand Splitting

0% Less



Splitting on some non-disjoint paths

16% Less



Combining BSR & non-disjoint paths

Proposed solutions

- Assumptions and inputs
  - Node mapping is given
  - k-shortest paths between pairs of physical nodes are precomputed
- A path based ILP to optimally solve reliable VNE
  - Very slow and scalable to small problem instances
- A heuristic algorithm to scale to large problem instances
  - Fast and scalable to large problem sizes

ILP formulation

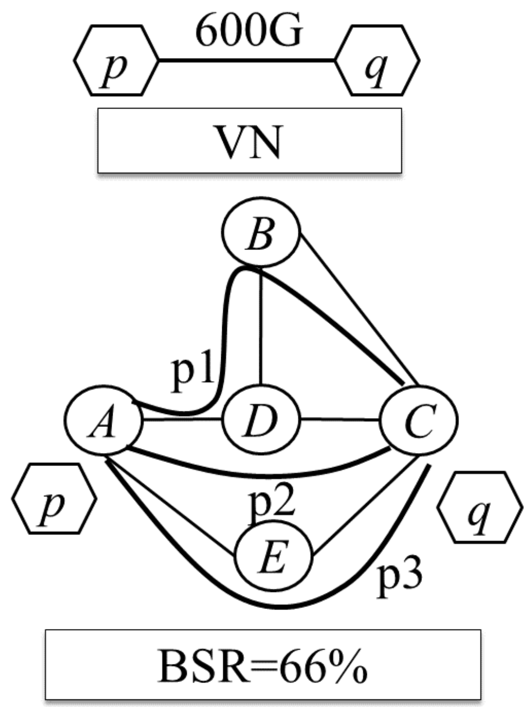
- Objectives
  - Minimize total spectrum resource allocation for a VN (Primary)
  - Minimize total number of splits for all the VLinks of a VN (Secondary)
- Link mapping constraints
  - The number of splits for a VLink does not exceed an upper limit, q
  - The slots assigned to each split are adjacent to each other
  - A slot on a link can be allocated to only one lightpath
  - Cannot allocate more than the available number of slots on a link
- Reliability constraints
  - For each single link failure scenario, the aggregate data rate of the unaffected splits of a VLink is at least BSR percentage of the VLink demand

Heuristic algorithm for reliable VNE

- Let's assume, a VN has *E* virtual links
  - An optimal solution requires to explore *E!* possible orders
  - Computationally intractable for large VNs
- Our algorithm explores one of *E!* orders chosen
  - Find an order that minimizes number of common links among the candidate paths of a VLink and VLinks that precede it
    - By constructing an auxiliary graph for the order
  - Compute reliable embedding of each VLink iteratively
    - Using a per-VLink divide-and-conquer approach

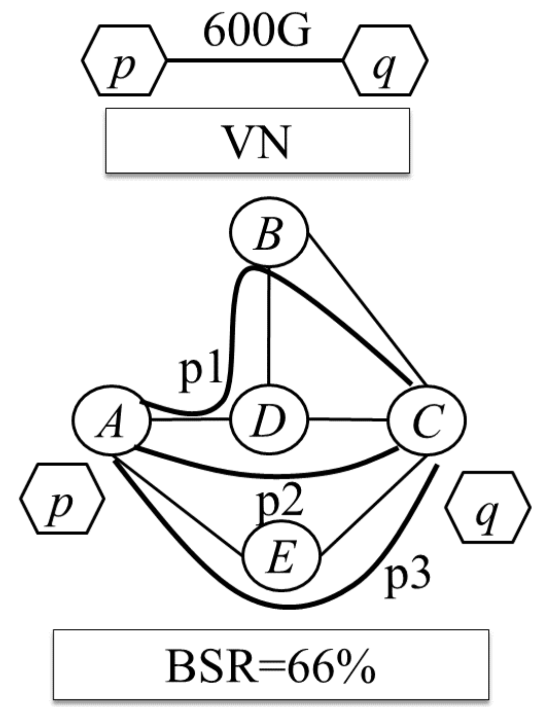
Algorithm for a VLink

- Compute disjoint path groups from the candidate path set of a Vlink e
- Find the set of all disjoint path groups for e, G_e
  - G_e= {{p1, p3}, {p2, p3}}
- Apply heuristic to keep G_e small
- Explore all non-empty subsets of G_e
  - Each subset is a path selection



Algorithm for a VLink

- Lets assume the subset
  - G_e= {{p1, p3}, {p2, p3}}
- Assign all possible datarate combinations to disjoint groups
  - {p1, p3}->200G, {p2, p3}->400G
  - {p1, p3}->400G, {p2, p3}->200G
  - … many more
- Each group $H_e \epsilon G_e$ provides dedicated protection to its assigned rate based on BSR

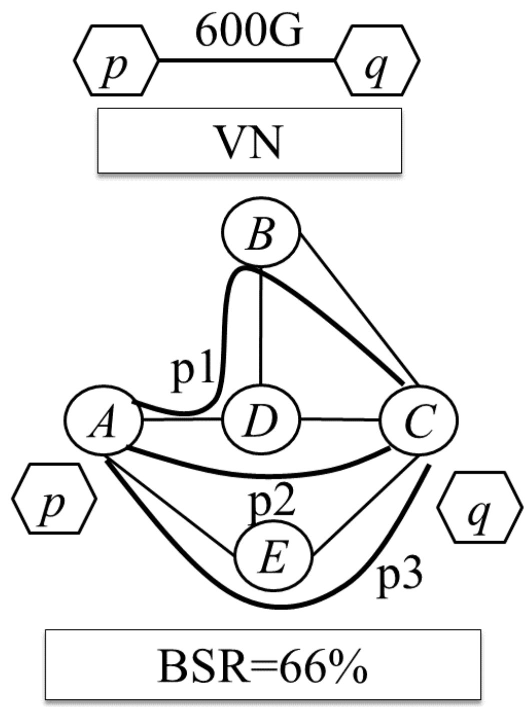


Algorithm for a VLink

- Compute datarate for each path in a group H_e as follows

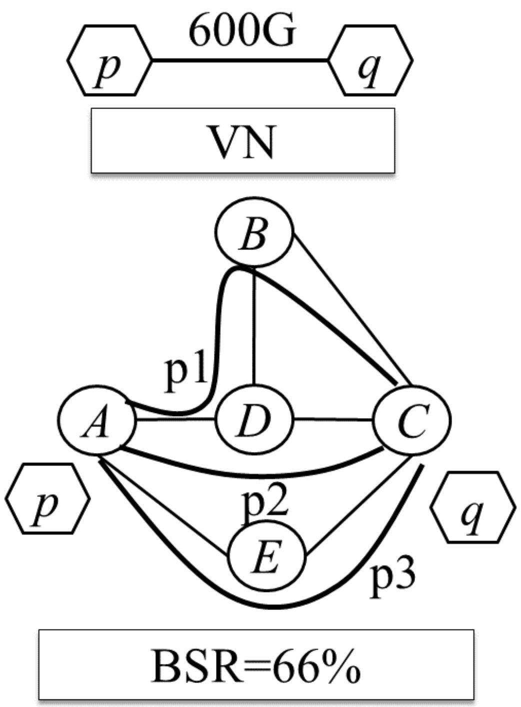
$$d_{p_{H_{\bar{e}}}} = max(\frac{d_{H_{\bar{e}}} \times BSR_{\bar{e}}}{100 \times (|H_{\bar{e}}| - 1)}, \frac{d_{H_{\bar{e}}}}{|H_{\bar{e}}|})$$

- For {p1, p3}->200G
  - p1->132G, p3->132G
- For {p2, p3}->400G
  - p2->264G, p3->264G
- Merge datarates of common path
  - p1->200G, p2->300G, p3-> 400G



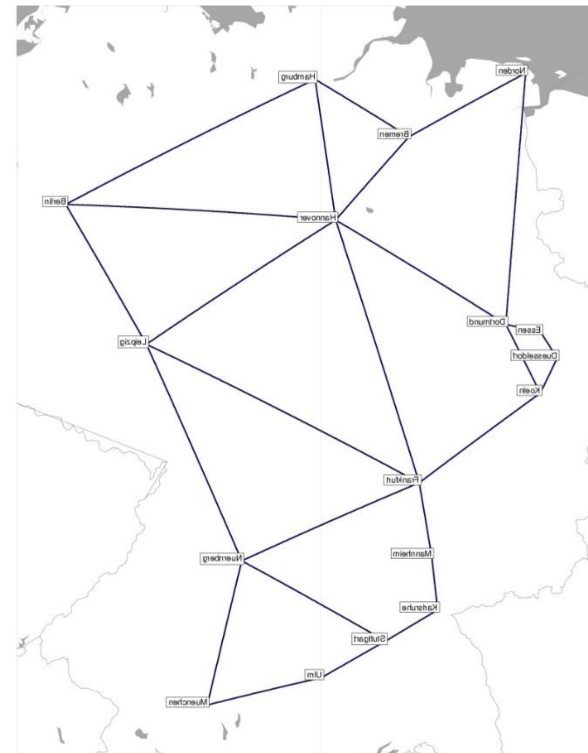
Algorithm for a VLink

- For a path and its corresponding datarate in the subset
  - Find the best transmission configuration
  - First-fit spectrum slot allocation
- Use dynamic programming to prune possible combinations
- Select the subset as per objective
  - Minimize spectrum slot requirement



Evaluation – simulation settings

- Small scale
  - EON: Nobel Germany (17 nodes, 26 links)[1]
  - Number of spectrum grids/slices per link
    - Fixed grid: 12 grids of 50GHz
    - Flex grid: 48 slices of 12.5GHz
  - VNs are generated synthetically
    - 4 virtual nodes and 5 VLinks
    - VLink demand randomly chosen between 100G to 1T
    - BSR vary from 0% to 100%
  - Max number of splits is 8



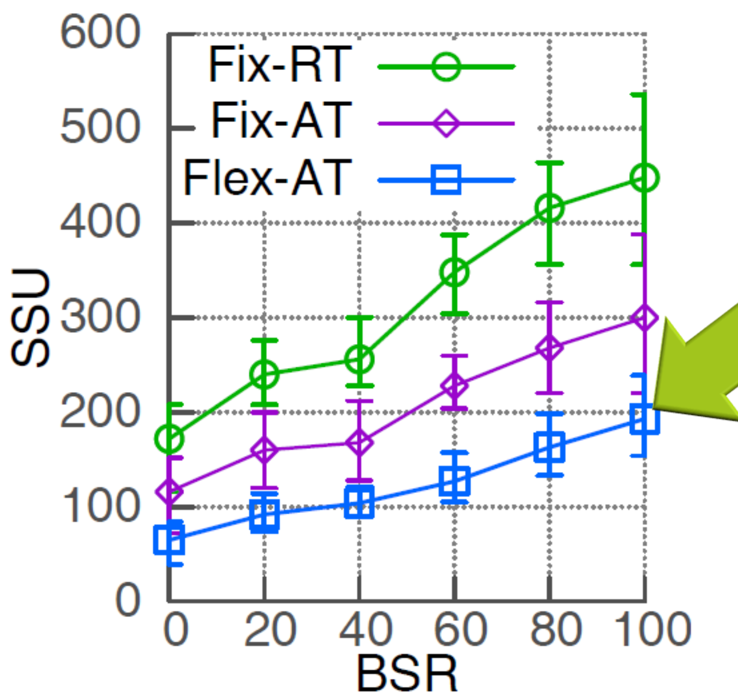
1. http://sndlib.zib.de/

Evaluation – compared variants

Variant Name	**Feature**
Fix-RT	Fixed grid allocation with rigid transmission configuration
Fix-AT	Fixed grid allocation with adaptive transmission configuration
Flex-AT	Flexible grid allocation with adaptive transmission configuration
Flex-AT-NoSplit-onSamePath	Similar to Flex-AT but using splitting model of [1]

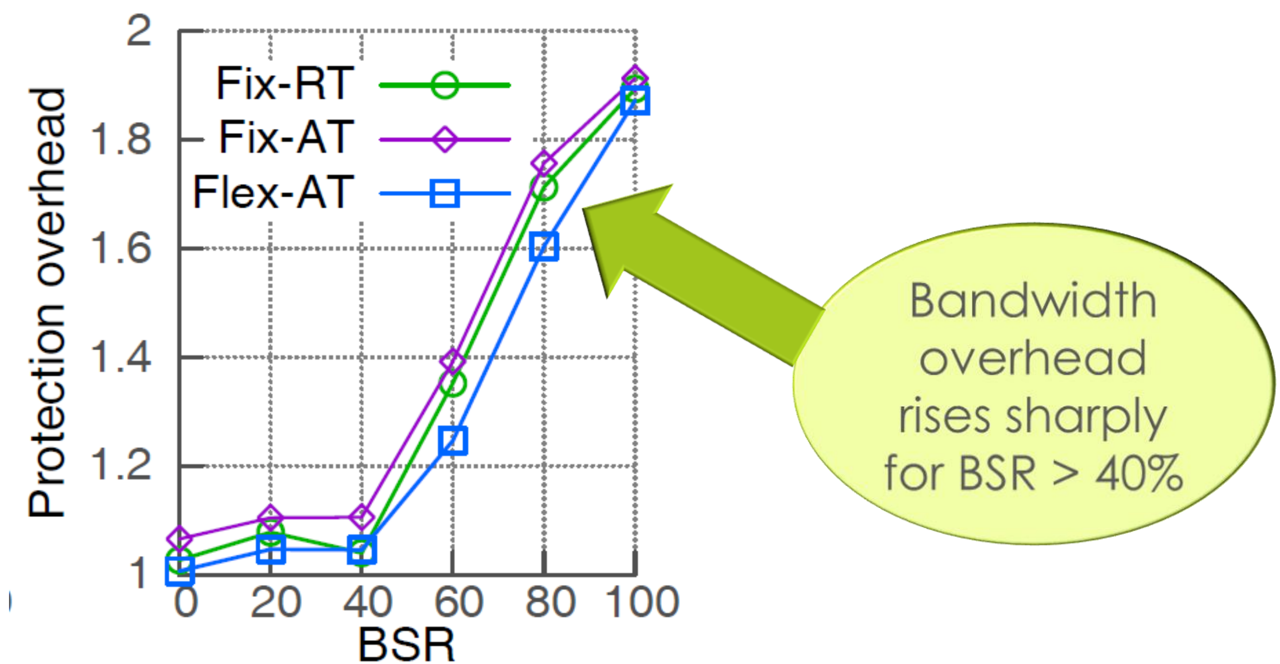
1. R. Goscien, et al, “Survivable multipath routing of anycast and unicast traffic in elastic optical networks,” *IEEE/OSA Journal of Optical Communications and Networking*, vol. 8, no. 6, pp. 343–355, 2016.

Evaluation – spectrum saving

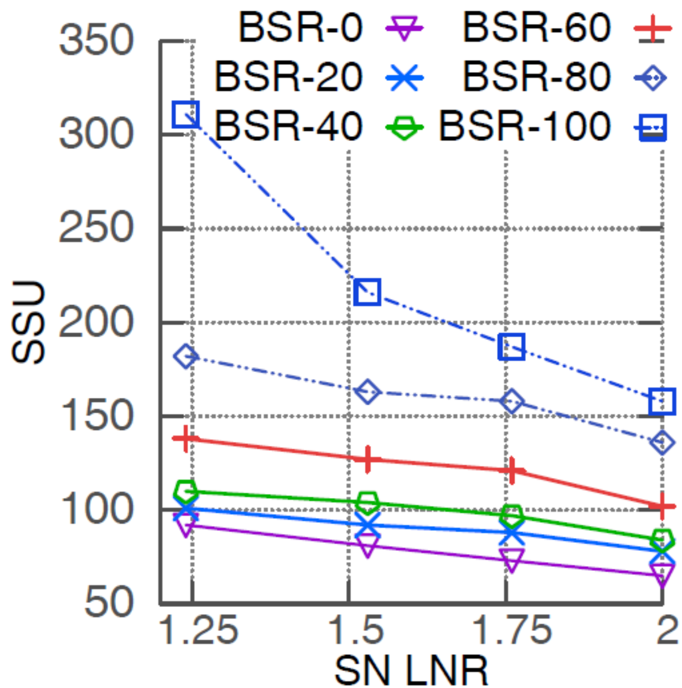


Up to 57% spectrum slot (SSU) saving compared to traditional technology

Evaluation – protection overhead

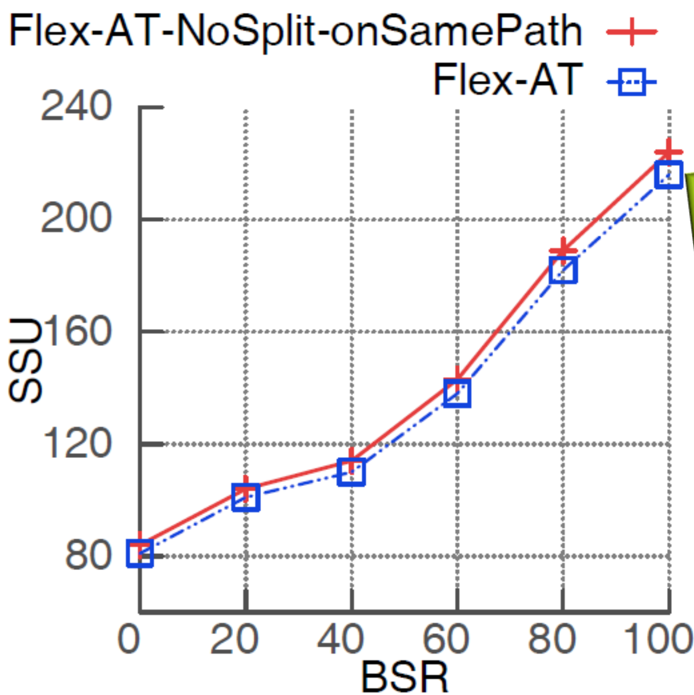


Evaluation – SN connectivity



Spectrum slot (SSU) saving is higher for high BSR

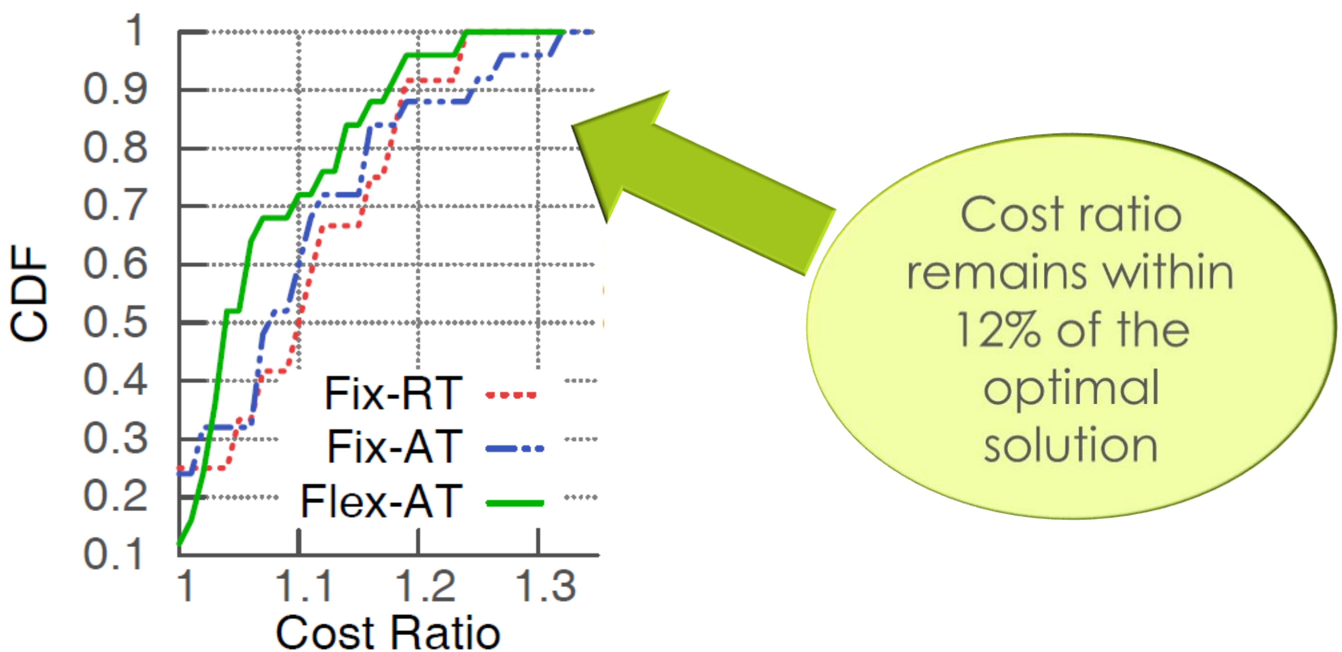
Evaluation – splitting model



Our model saves additional 4% spectrum slots (SSU) compared to [1]

1. R. Goscien, et al, “Survivable multipath routing of anycast and unicast traffic in elastic optical networks,” *IEEE/OSA Journal of Optical Communications and Networking*, vol. 8, no. 6, pp. 343–355, 2016.

Evaluation – optimality of heuristic



Conclusion and future work

- Reliable transport network slicing with full flexibility of all transmission parameters of an EON
  - An ILP based optimization model
  - A heuristic algorithm that obtains near optimal solutions while executing several orders of magnitude faster than ILP
  - BSR and demand splitting significantly reduce spectrum
- Future directions
  - Extend the heuristic algorithm to compute node mappings
  - Explore alternate objective functions (e.g., load balancing)

Thank you!