Reliable Slicing of 5G Transport Networks with Dedicated Protection

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Outline

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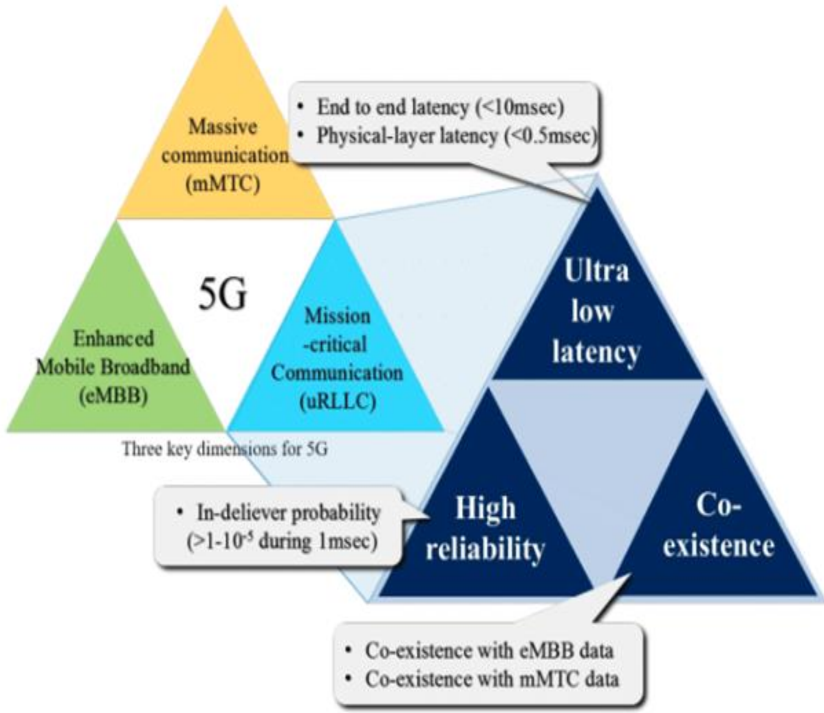
  - Virtual network (VN) embedding
  - Reliable VN embedding
- Proposed solutions
  - Integer Linear Program (ILP) formulation
  - Heuristic algorithm
- Evaluation
- Summary and future work

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

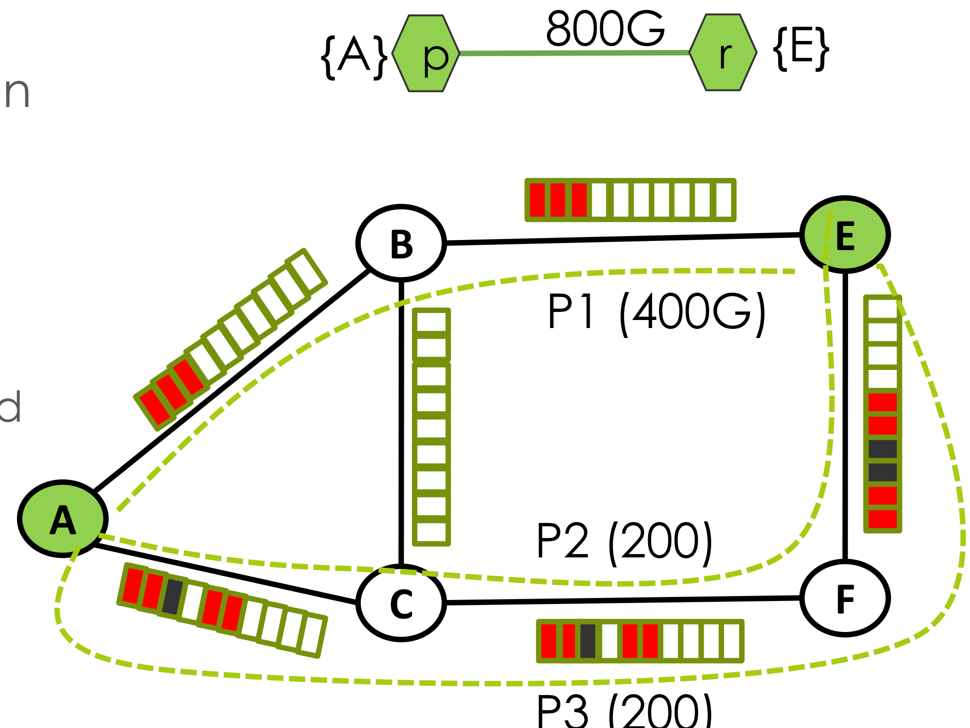
Transport network technologies

- 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

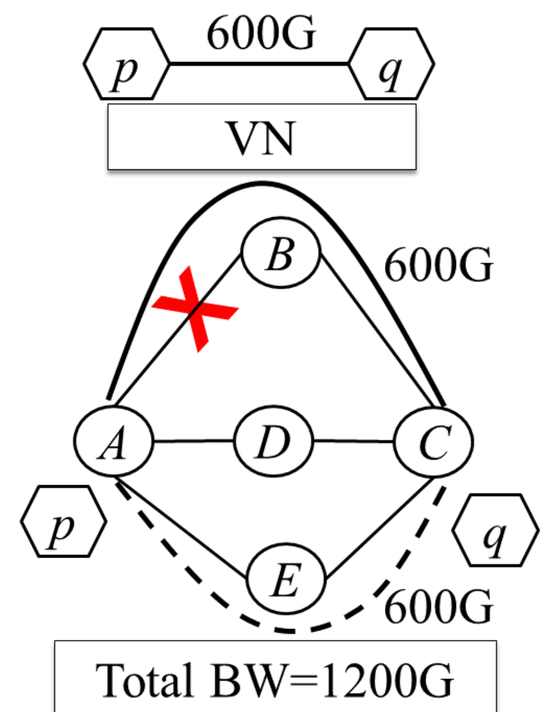
Virtual network embedding (VNE)

- 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

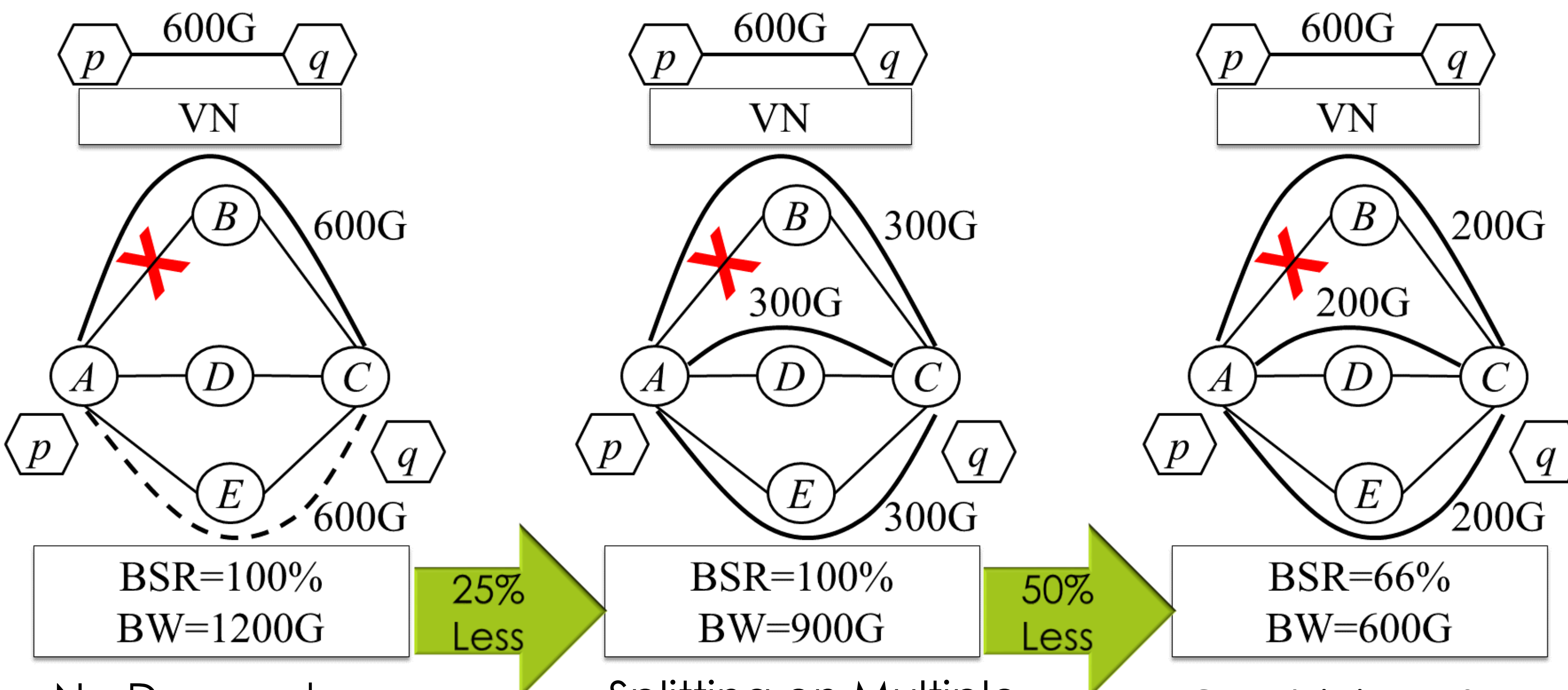


Reliable VNE

- 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

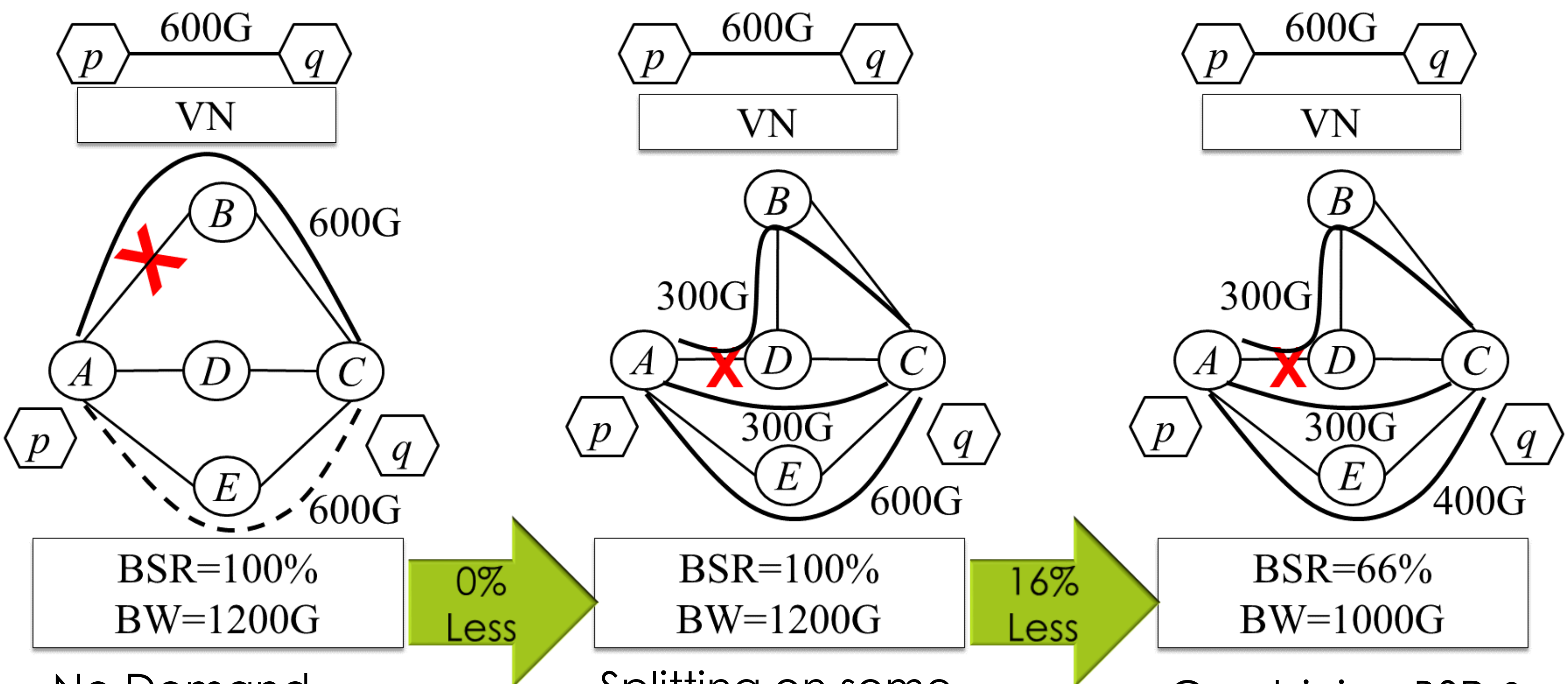


No Demand Splitting

Splitting on Multiple disjoint paths

Combining BSR & Splitting

Reliable VNE with BSR and splitting



No Demand Splitting

Splitting on some non-disjoint paths

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

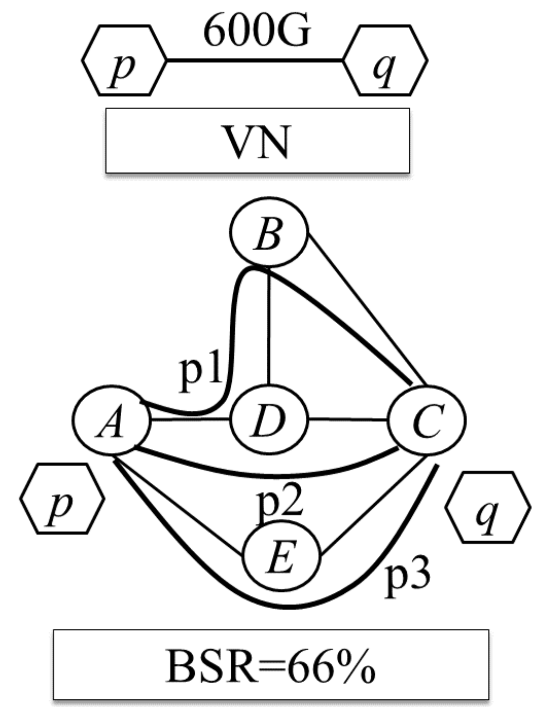
- Objectives
  - Minimize total spectrum resource allocation for a VN (Primary)
  - Minimize total number of splits for all the VLinks of a VN (Secondary)
- Link mapping constraints
  - The number of splits for a VLink does not exceed an upper limit, q
  - The slots assigned to each split are adjacent 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

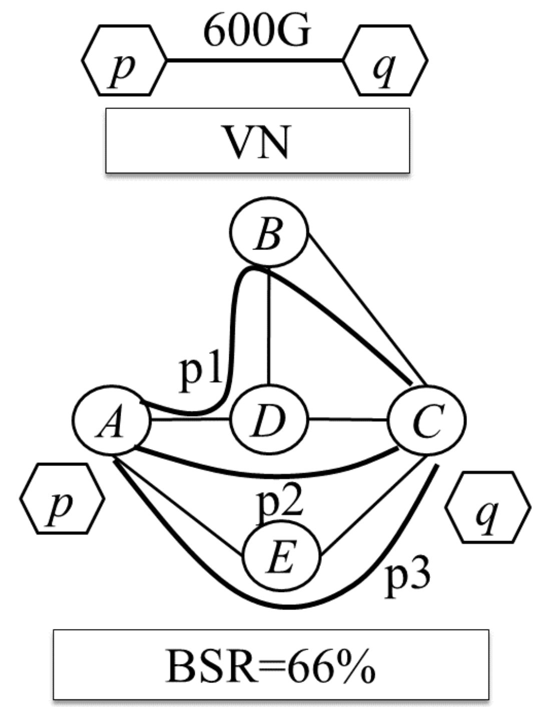
Algorithm for a VLink

- 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

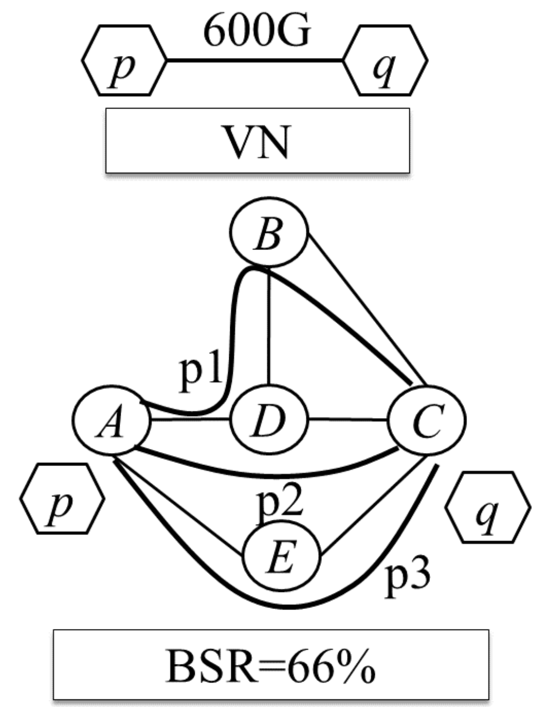


Algorithm for a VLink

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

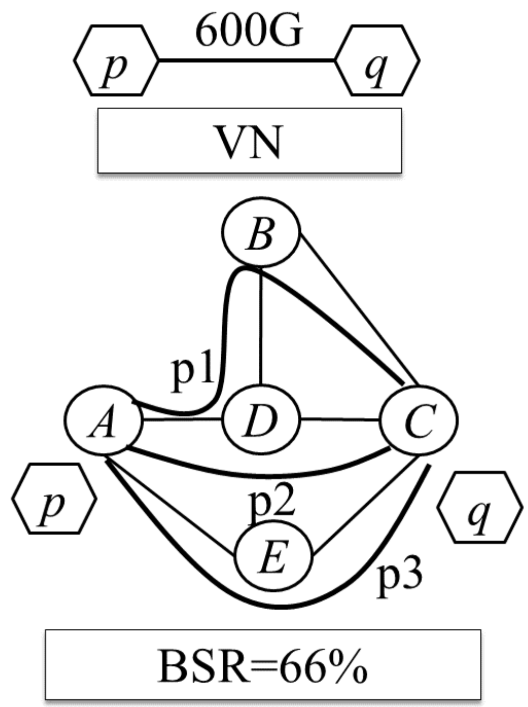
$$d_{pH_{\bar{e}}} = max(\frac{d_{H_{\bar{e}}} \times BSR_{\bar{e}}}{100 \times (|H_{\bar{e}}| - 1)}, \frac{d_{H_{\bar{e}}}}{|H_{\bar{e}}|})$$

- 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



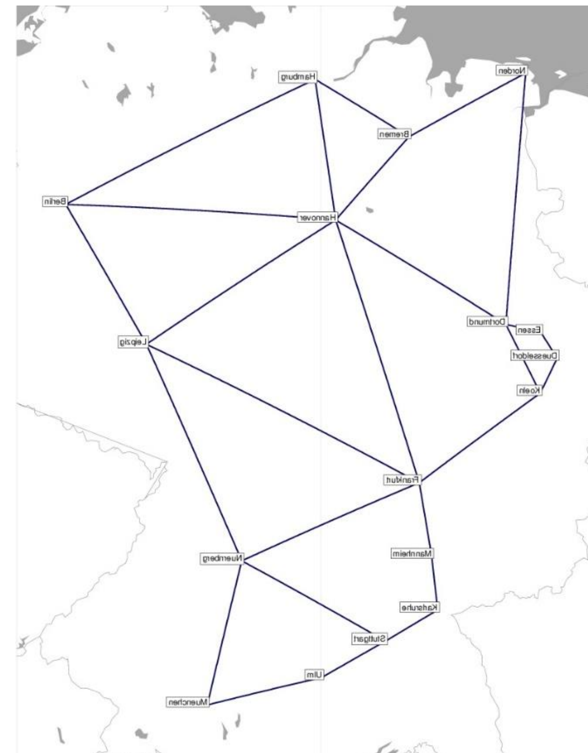
Algorithm for a VLink

- 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

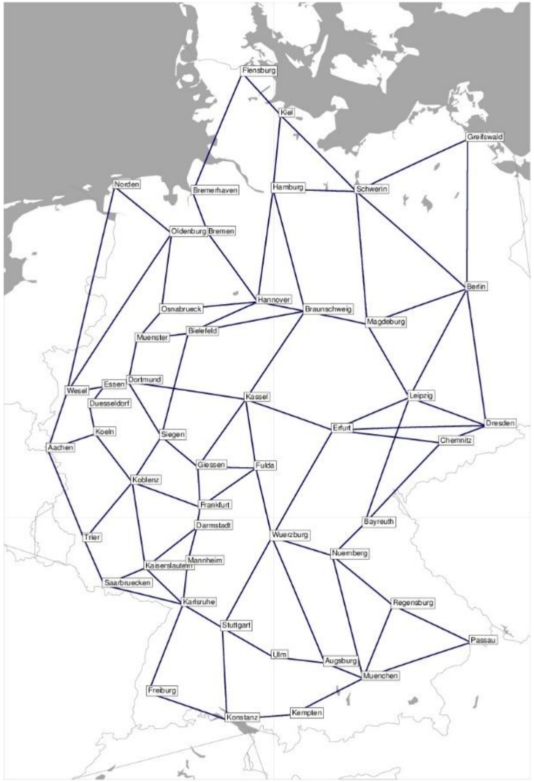
- Small scale
  - EON: Nobel Germany (17 nodes, 26 links)[1]
  - Number of spectrum grids/slices per link
    - Fixed grid: 12 grids of 50GHz
    - Flex grid: 48 slices of 12.5GHz
  - VNs are generated synthetically
    - 4 virtual nodes and 5 VLinks
    - VLink demand randomly chosen between 100G to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



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

Evaluation – simulation settings

- Large scale
  - EON: Germany50 network (50 nodes, 88 links)[1]
  - Number of spectrum grids/slices per physical link
    - Fixed grid: 80 grids of 50GHz
    - Flex grid: 320 slices of 12.5GHz
  - VNs are generated synthetically
    - 50 virtual nodes with varying number of virtual links
    - VLink demand randomly chosen between 100G to 1T
    - BSR vary from 0% to 100%
  - Max number of splits is 8



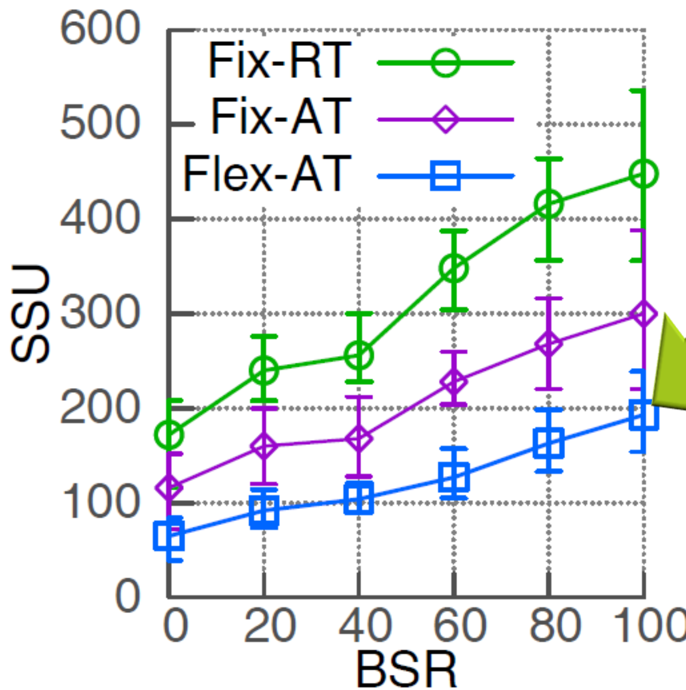
1. http://sndlib.zib.de/

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]

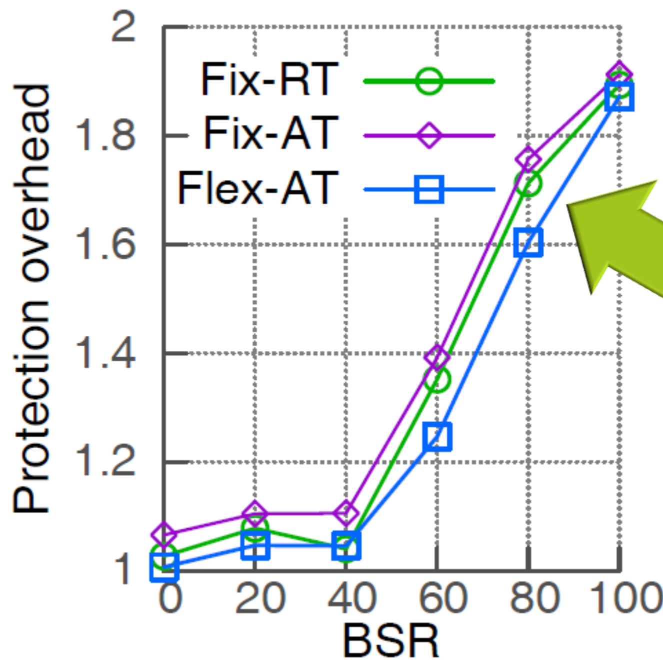
1. R. Goscien, et al, “Survivable multipath routing of anycast and unicast traffic in elastic optical networks,” *IEEE/OSA Journal of Optical Communications and Networking*, vol. 8, no. 6, pp. 343–355, 2016.

Evaluation – spectrum saving



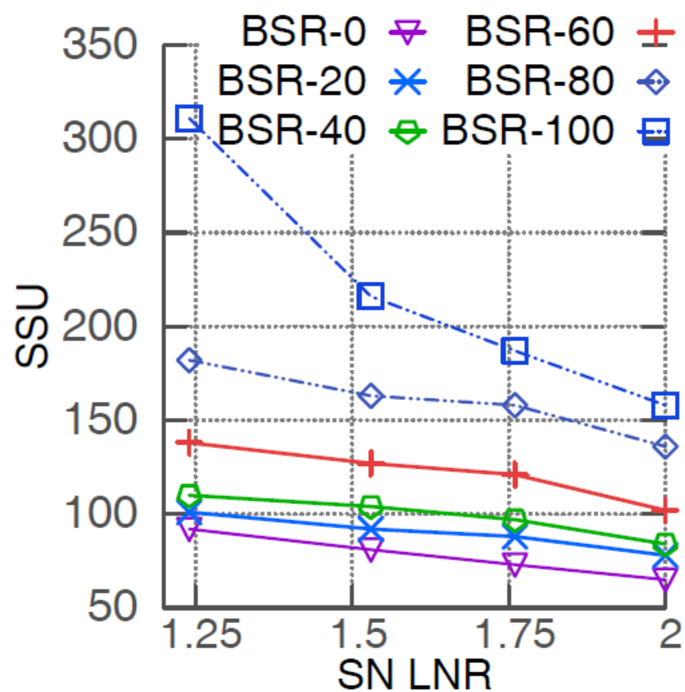
Up to 57% spectrum slot (SSU) saving compared to traditional technology

Evaluation – protection overhead



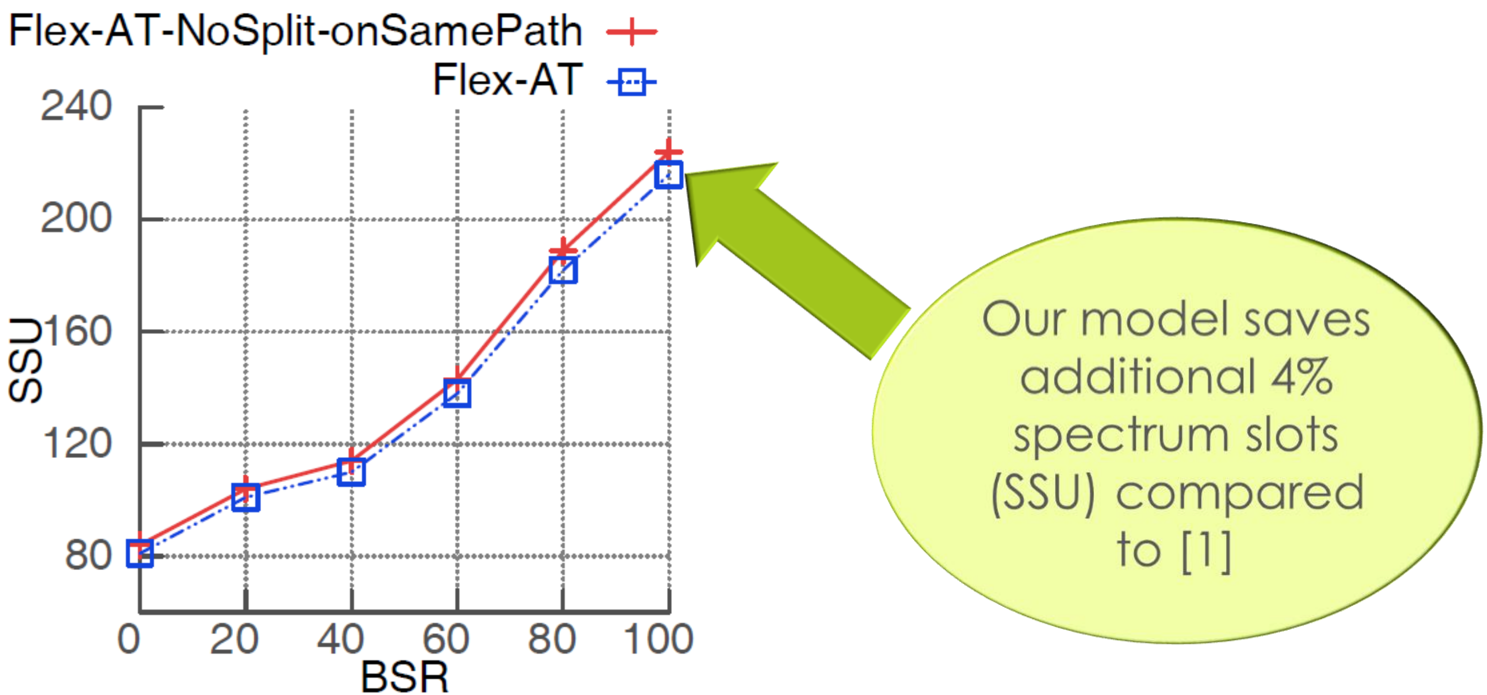
Bandwidth overhead rises sharply for BSR > 40%

Evaluation – SN connectivity



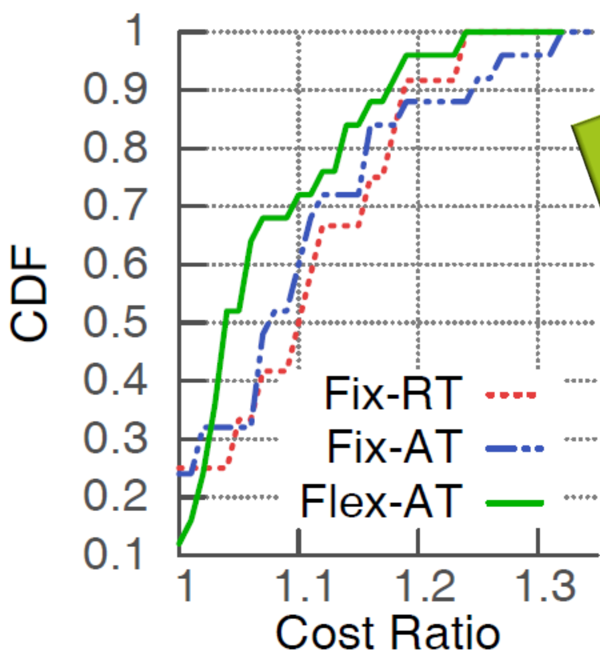
Spectrum slot (SSU) saving is higher for high BSR

Evaluation – splitting model



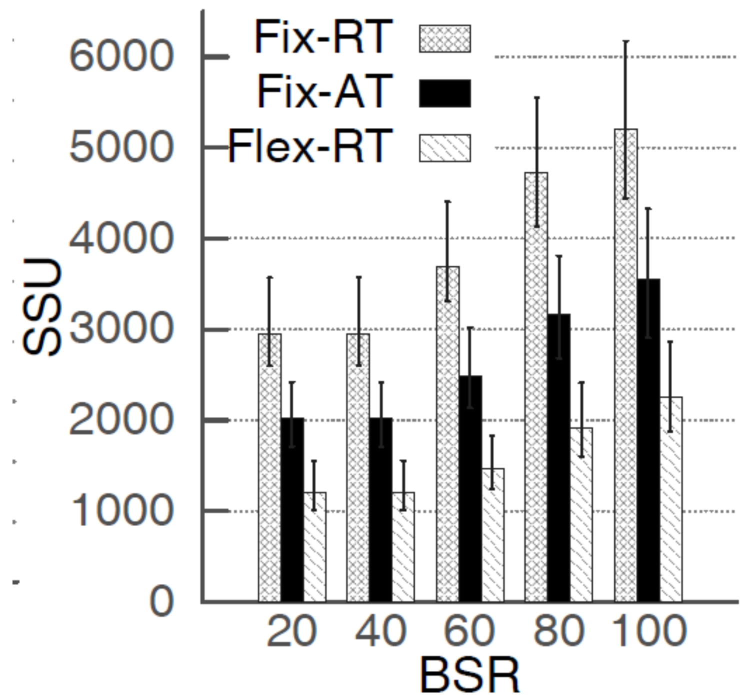
1. R. Goscien, et al, "Survivable multipath routing of anycast and unicast traffic in elastic optical networks," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 8, no. 6, pp. 343–355, 2016.

Evaluation – optimality of heuristic



Cost ratio remains within 12% of the optimal solution

Evaluation – large scale result



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!