

Fully-Flexible Virtual Network Embedding in Elastic Optical Networks

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Outline

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Introduction

- Internet traffic is growing at a very fast rate
 - AT&T experienced 100000% increase in traffic between 2008 and 2016¹
- Optical backbone networks are evolving to keep pace
 - Fine-grained spectrum allocation using 12.5GHz slices as opposed to fixed 50 or 100GHz wavelength grids
 - Elasticity in tuning transmission parameters (e.g., data rate, modulation, and forward error correction (FEC))
- Network virtualization improves utilization
 - Virtual network embedding (VNE) is a fundamental problem

1. L. Peterson et al. Central office re-architected as a data center. IEEE Communications Magazine, 54(10):96–101, 2016.

Elastic optical networks (EONs)

Traditional optical networks

Data Rate (Gbps)	Modulation	FEC (%)	Spectrum bandwidth (GHz)	Reach (km)	ID
100	QPSK	25%	50	2000	T1
200	QPSK	25%	100	1000	T2

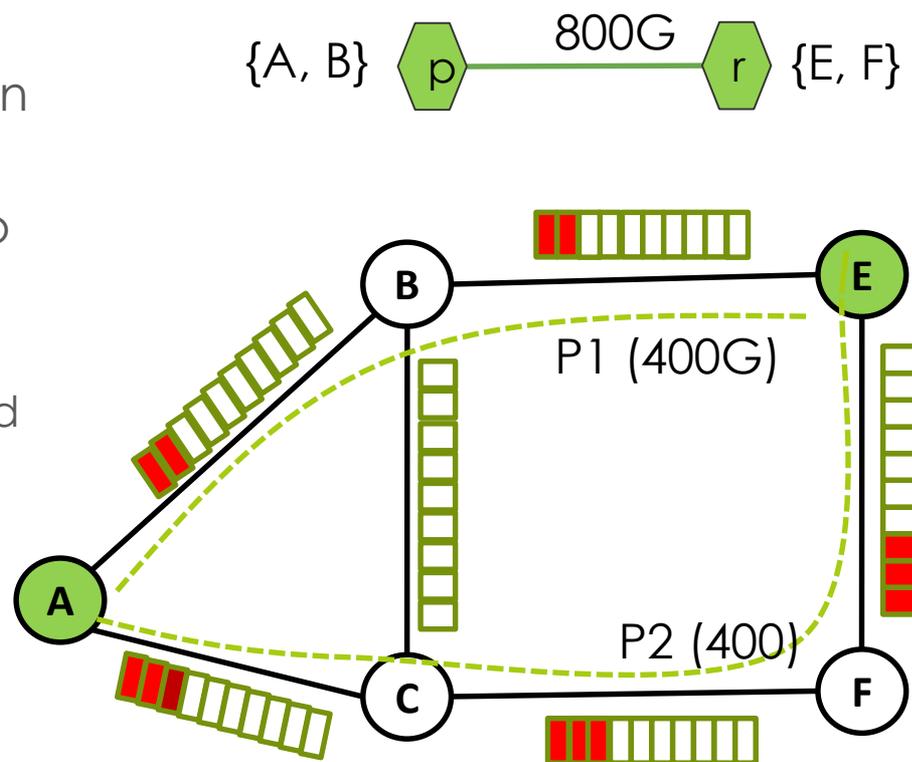
Transmission configuration

Elastic optical networks

Data Rate (Gbps)	Modulation	FEC (%)	Spectrum bandwidth (GHz)	Reach (km)	ID
100	QPSK	25%	50	2000	T1
	16QAM	20%	25	1250	T2
200	QPSK	25%	75	1000	T3
	32QAM	20%	37.5	400	T4

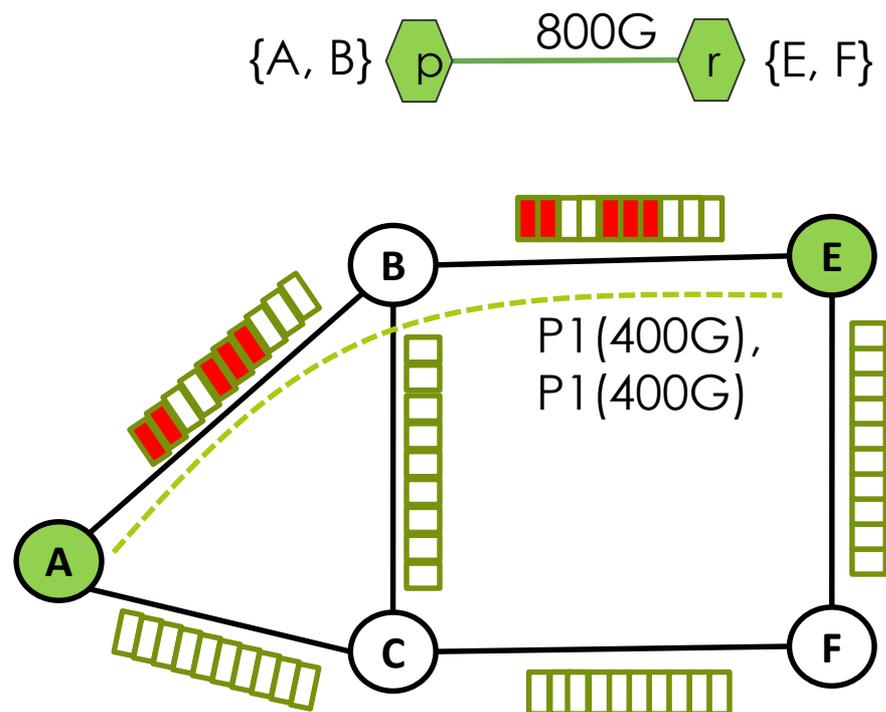
Virtual network embedding (VNE)

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



Related work and contribution

- [1] studied route, spectrum, and modulation level assignment with demand splitting
- We allow virtual link to be mapped over multiple spectrum segments on the same path
- We consider full fledged VN as opposed to demands



1. A. Pages et al., "Optimal route, spectrum, and modulation level assignment in split-spectrum-enabled dynamic elastic optical networks," *Journal of Optical Comm. and Net.*, vol. 6, no. 2, pp. 114–126, 2014.

Proposed solutions

- VNE problem is NP-hard in general
 - Node and link mapping are difficult even when solved independently
- A path based ILP formulation to optimally solve the VNE over EON problem inspired by the formulation of [1]
 - k-shortest paths between pairs of physical nodes are precomputed and given as input
 - ILP formulation can find solutions for small problem instances
- A heuristic algorithm to scale to large problem instances
 - A DP based optimal algorithm to solve for a single virtual link

ILP formulation

- Objectives
 - Minimize total spectrum resource allocation for a VN (Primary)
 - Minimize total number of splits for all the virtual links of a VN (Secondary)

- Link mapping constraints:
 - The number of splits for a virtual link does not exceed an upper limit, q
 - The slices assigned to each split are adjacent to each other
 - One slice on a link can be allocated to only one lightpath
 - Cannot allocate more than the available number of slices on a link

- Node mapping constraints
 - A physical node can host at most one virtual node of a VN
 - A virtual node is mapped to at most one physical node satisfying location constraint

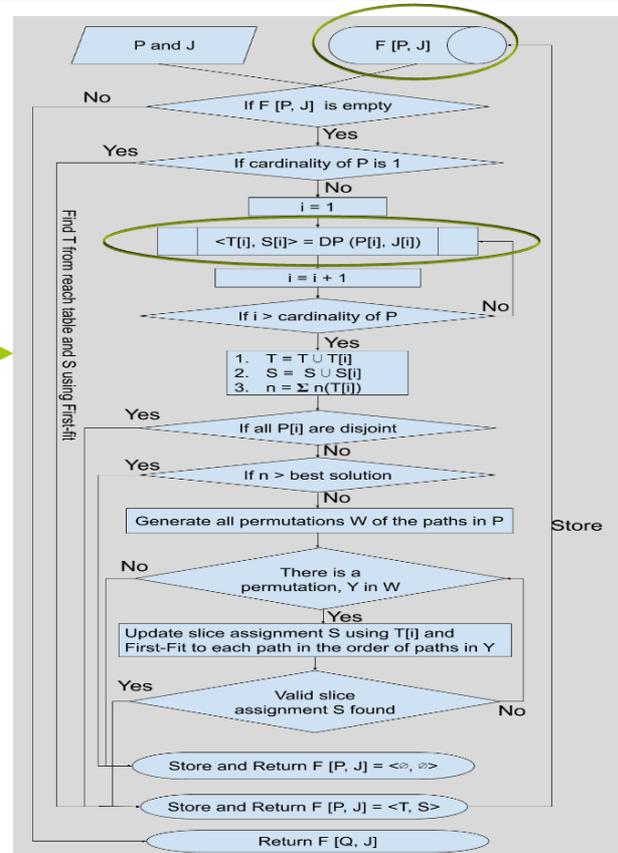
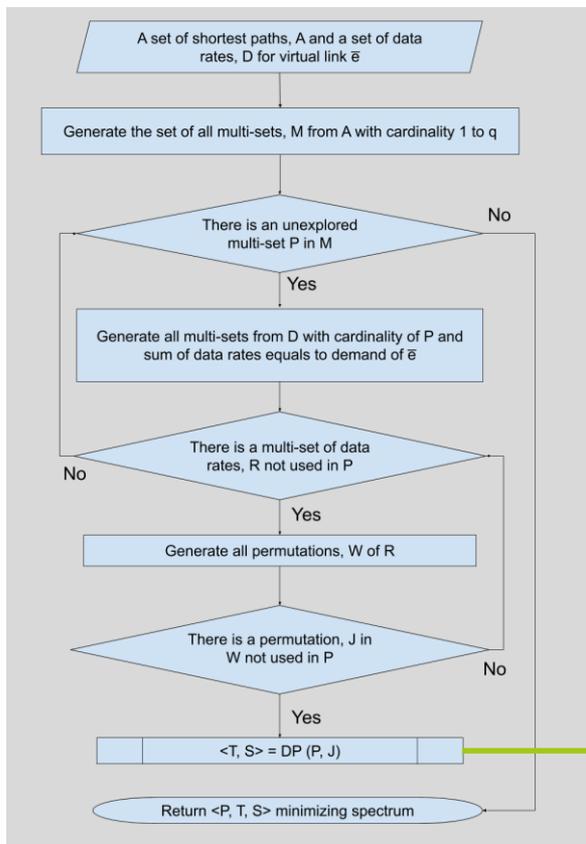
- Coordination between link and node mapping
 - A non-linear constraint that we linearize

DP based optimal algorithm

- Solves the link mapping problem for a single virtual link with given mappings of the two virtual nodes of the link
 - Path selection
 - Transmission configuration selection
 - Spectrum slice allocation

- A path, a transmission configuration, and a slice allocation can appear more than once in a solution
 - ($\langle P1, P1, P3, P3 \rangle, \langle T1, T2, T2, T3 \rangle, \langle S2, S4, S3, S4 \rangle$)
 - Each of them is a multi-set which further increases complexity

Algorithm for single virtual link



Heuristic algorithm for a VN

- The DP based algorithm solves the problem for a virtual link
 - How to extend it for VNs with more than one virtual link?
- Let's assume, a VN has E virtual links
 - An optimal solution requires to explore $E!$ possible ordering
 - Computationally intractable for large VNs
- Our heuristic algorithm explores one of $E!$ orderings chosen according to a criteria (e.g., decreasing order of demand)
 - Apply look-ahead techniques so that selecting a solution for one virtual link does not block the spectrum for remaining links

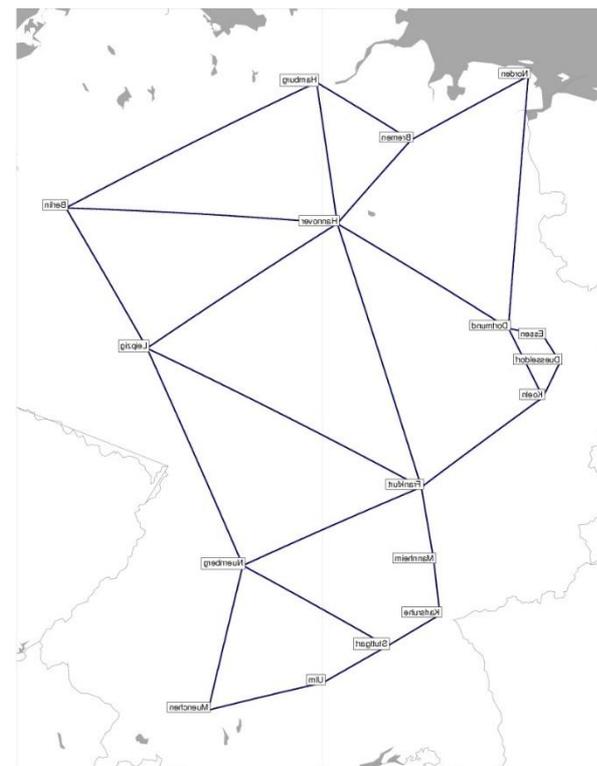
Evaluation – compared approaches

- key questions
 - How jointly considering all the flexible transmission parameters impact VNE?
 - What is the gain of incrementally introducing flexibility?

Degrees of freedom	Fixed FEC		Variable FEC	
	Fixed Modulation	Variable Modulation	Fixed Modulation	Variable Modulation
Fixed grid	Fixed-fixmod-fixfec (FM-FF)	Fixed-varmod-fixfec (VM-FF)	Fixed-fixmod-varfec (FM-VF)	Fixed-varmod-varfec (VM-VF)
Flex grid	Flex-fixmod-fixfec (FM-FF)	Flex-varmod-fixfec (VM-FF)	Flex-fixmod-varfec (FM-VF)	Flex-varmod-varfec (VM-VF)

Evaluation – simulation settings

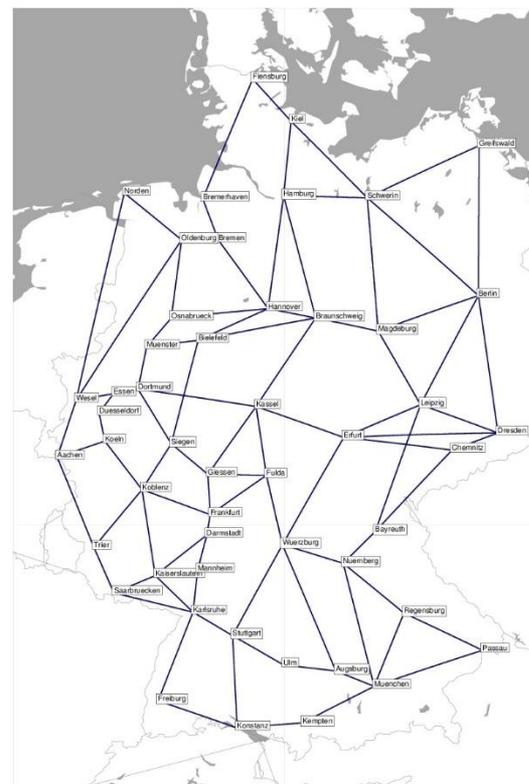
- Small scale
 - EON: Nobel Germany (17 nodes, 26 links)¹
 - Number of spectrum grids/slices per physical link
 - Flex grid: 48 slices of 12.5GHz
 - Fixed grid: 12 grids of 50GHz
 - VNs are generated synthetically
 - 8 virtual nodes with varying number of virtual links
 - Node mapping is given



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

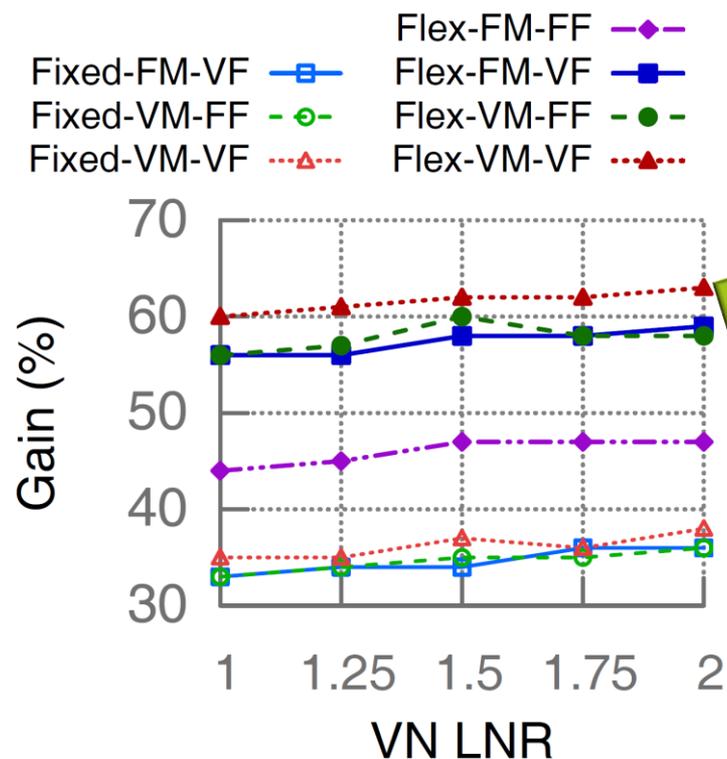
Evaluation – simulation settings

- Large scale
 - EON: Germany50 network (50 nodes, 88 links)¹
 - Number of spectrum grids/slices per physical link
 - Flex grid: 320 slices of 12.5GHz
 - Fixed grid: 80 grids of 50GHz
 - VNs are generated synthetically
 - 50 virtual nodes with varying number of virtual links
 - Node mapping is given



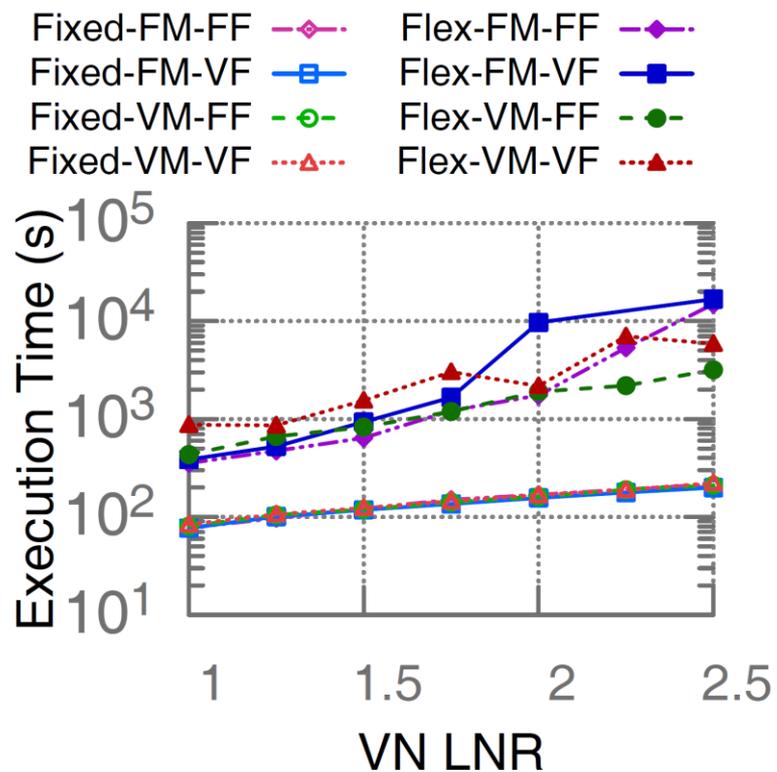
1. <http://sndlib.zib.de/>

Evaluation – spectrum saving gain

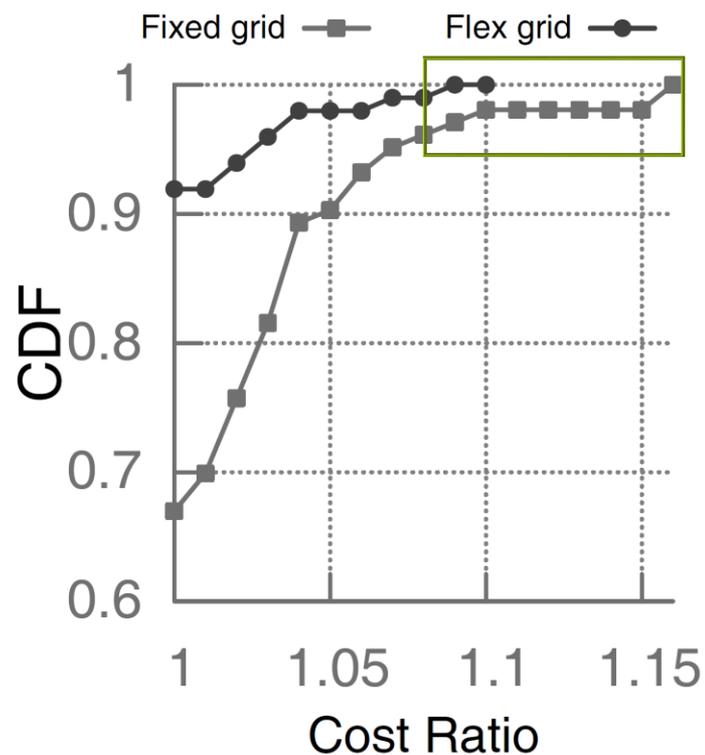


Up to 60%
spectrum
saving

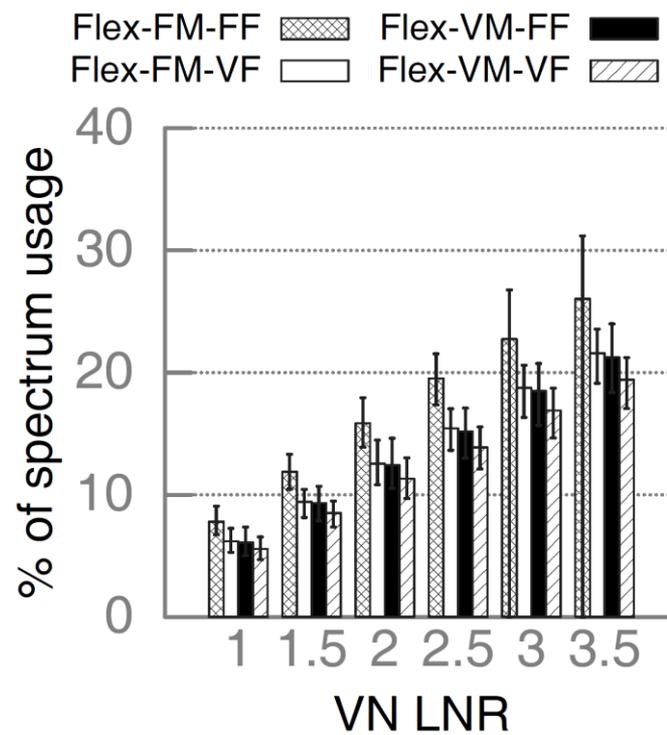
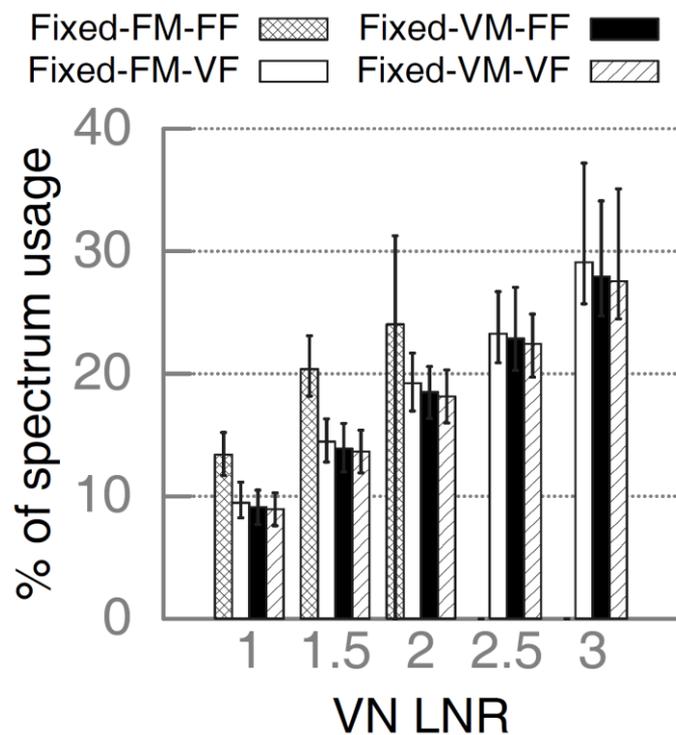
Evaluation – running time



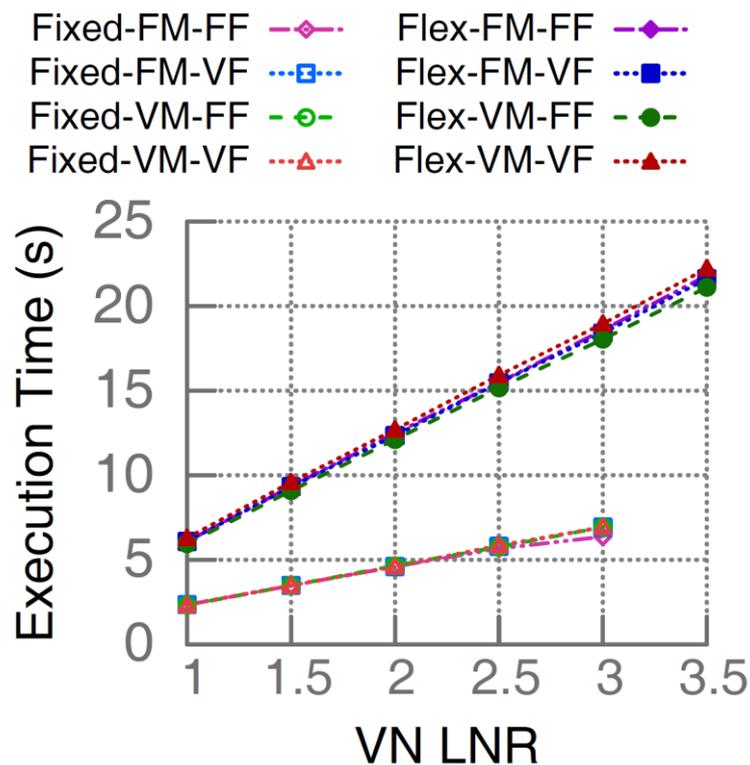
Evaluation – optimality of the heuristic



Evaluation – large scale results



Evaluation – large scale running time



Conclusion and future work

- We study the VNE over EON problem 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
 - Saves up to 60% spectrum compared to VNE with no flexibility

- What's next?
 - Extend the heuristic algorithm to compute node mappings
 - Analyze the performance of the heuristic
 - Explore alternate objective functions (e.g., load balancing)

Thank you