Recent Thoughts on "Demand-Responsive Networking"

Zhizhen Zhong

Tsinghua University & UC Davis

zhongzz14@mails.tsinghua.edu.cn , zzzhong@ucdavis.edu

6 Apr. 2018

Networks Lab Group Meeting

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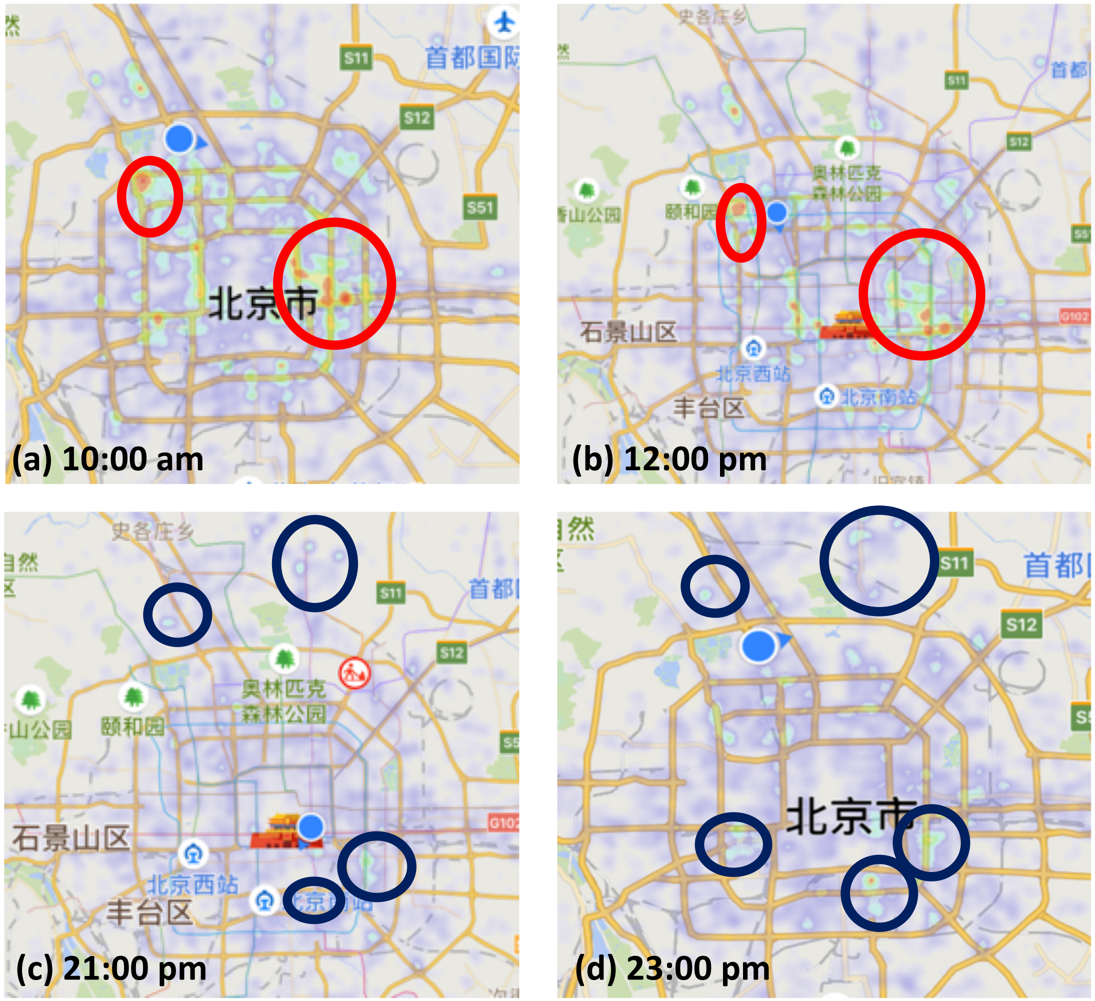
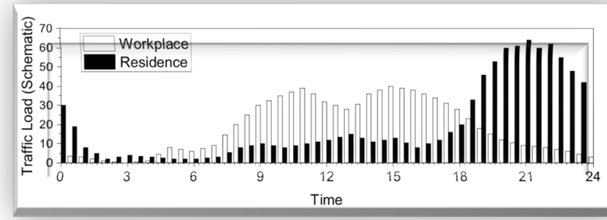
Outline

- **Previous work I: tidal traffic in metro-core networks**
- Previous work II: short-term traffic fluctuations in EON
- Physical-Layer Innovations and Open discussions

Tidal traffic in metro-core networks





Beijing Population HeatMap

Business Areas

Residence Areas

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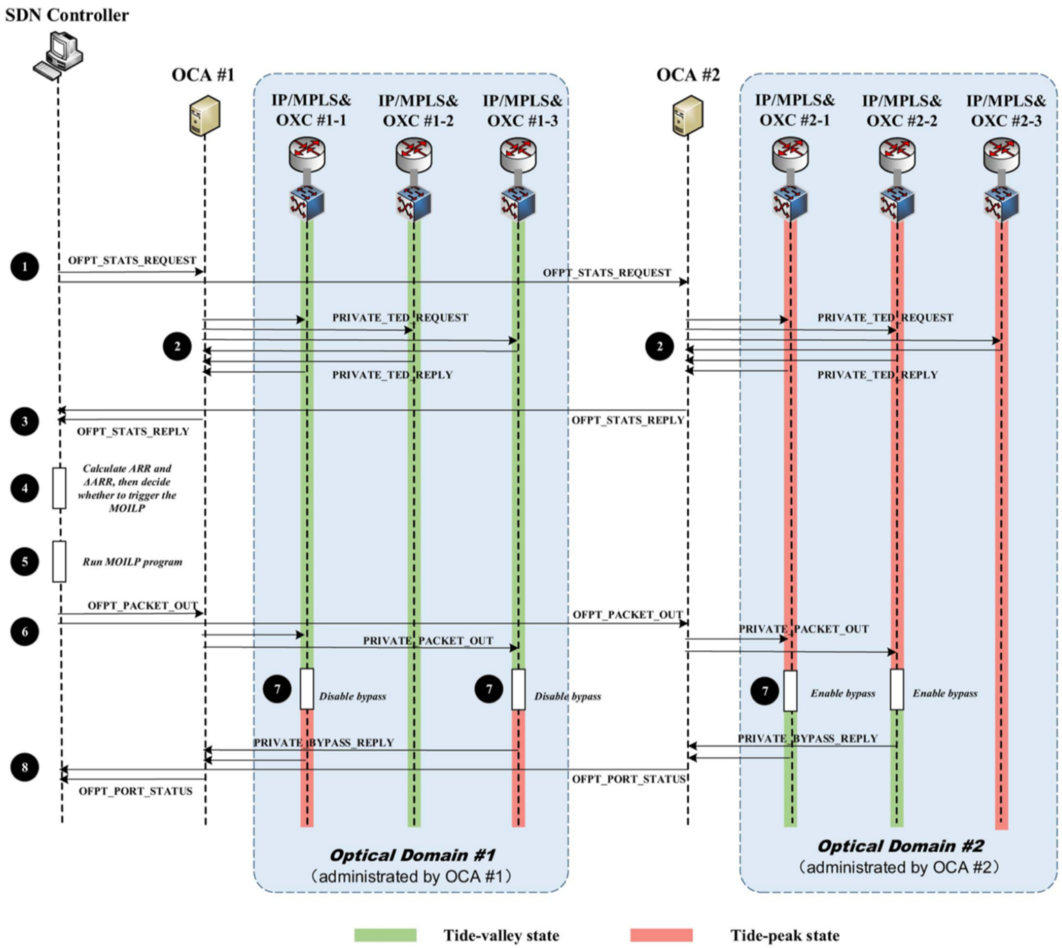
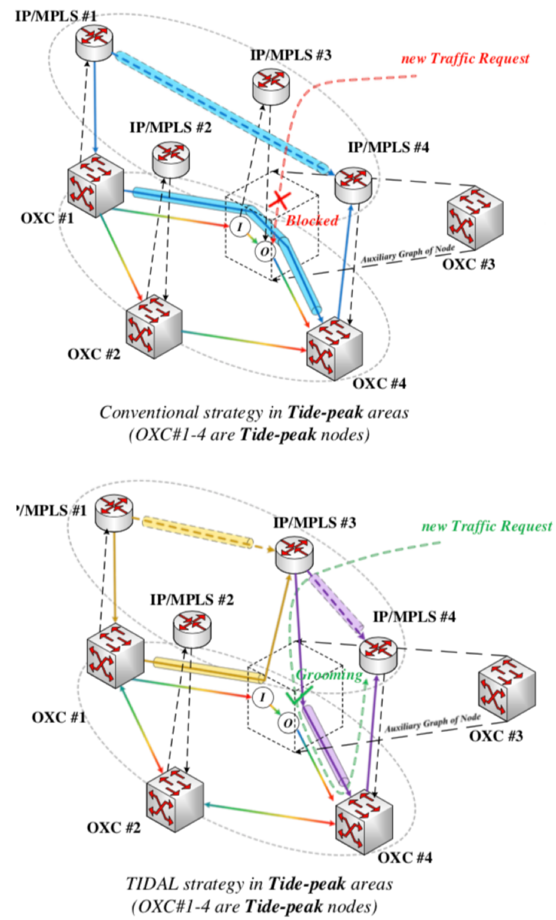
Stateful Grooming for Tidal traffic





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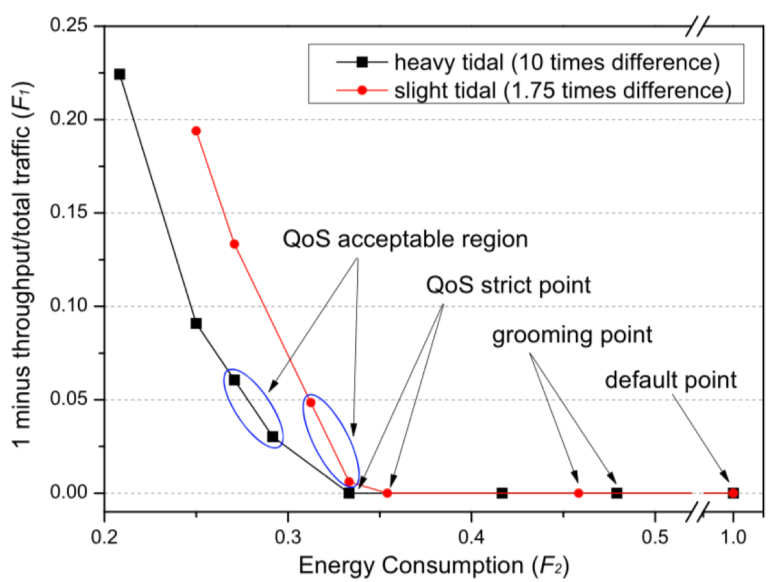
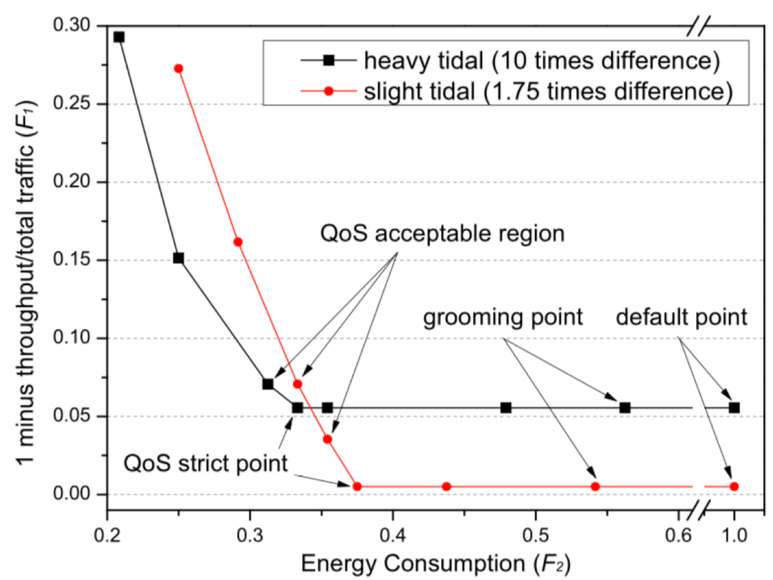
Numerical evaluations

- Not all nodes in tide-peak area have to be in tide-peak state!
  - A proper selection of tide-peak state nodes under a given traffic is needed.
  - ILP applied



(a)



(b)

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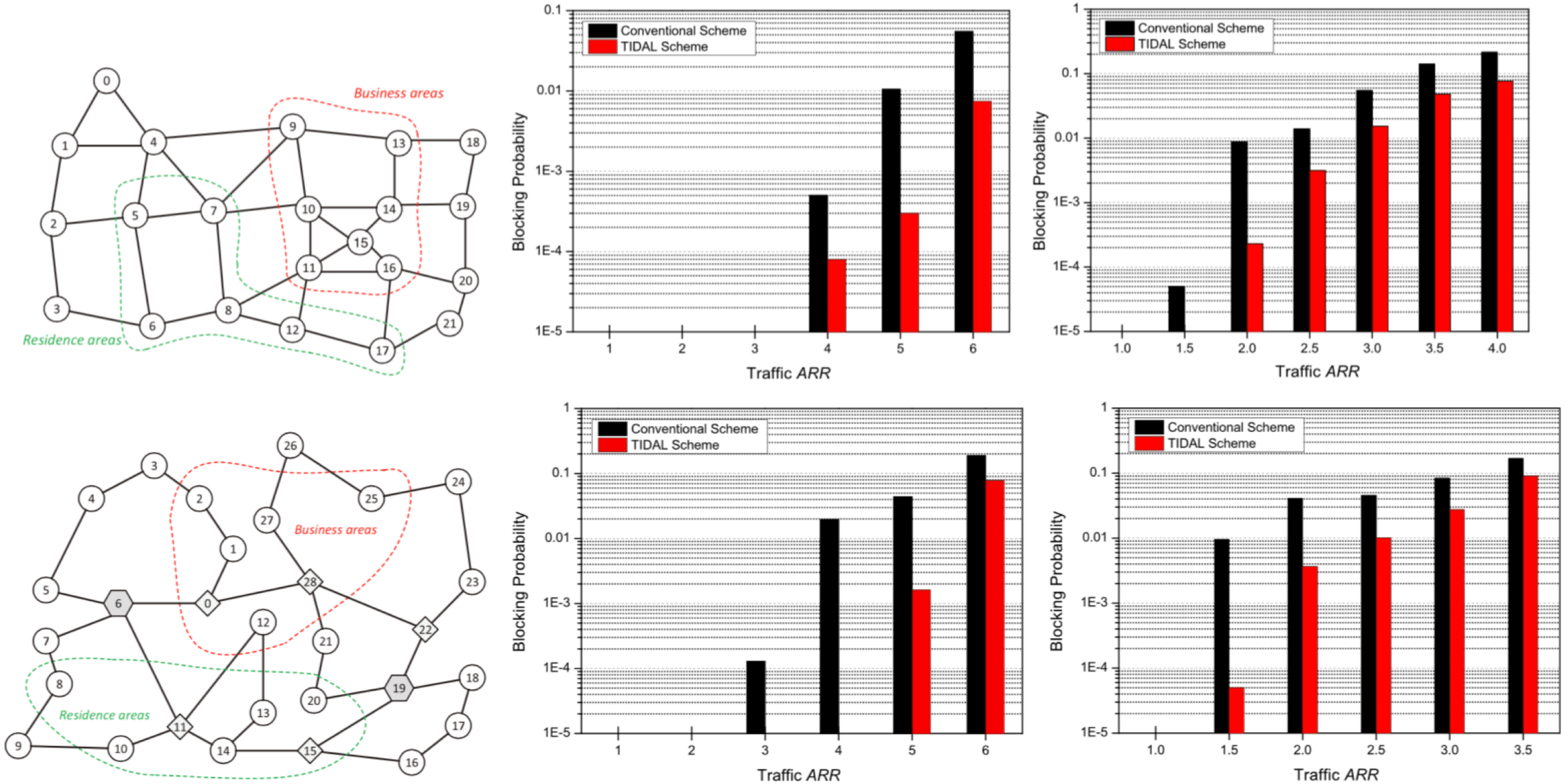
Numerical evaluations



Zhizhen Zhong, Nan Hua, Massimo Tornatore, Yao Li, Haijiao Liu, Chen Ma, Yanhe Li, Xiaoping Zheng, Biswanath Mukherjee, "**Energy Efficiency and Blocking Reduction for Tidal Traffic via Stateful Grooming in IP-over-Optical Networks**," IEEE/OSA JOCN, 2016.

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- **Previous work II: short-term traffic fluctuations in EON**
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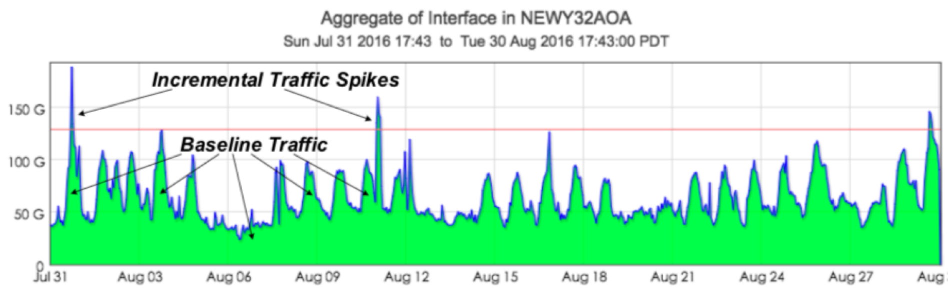
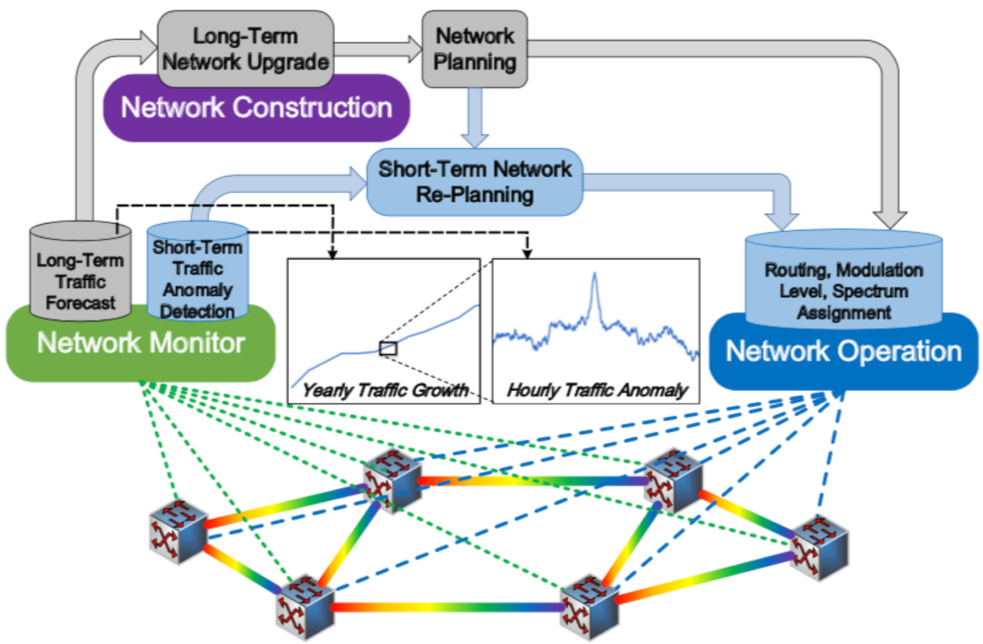
Short-term traffic fluctuations in EON





- Short-term traffic spikes
  - Black friday
  - Olympic games, FIFA world cups

[1] The Akamai Blog, “2015 Black Friday traffic spikes 109 percent over average, pre-holiday activity,” https://blogs.akamai.com/2015/12/2015- black- friday- traffic- spikes- 109- percent- over- average- pre- holiday- activ ity.html, 2015.
[2] J. Ryburn, “Black Friday vs. Cyber Monday: Traffic Insights from Kentik,” https://www.kentik.com/black- friday- vs- cyber- monday- traffic -insights-from-kentik/, 2017.
[3] Huawei, “Will the Internet crash,” https://www1.huawei.com/enapp/19 8/hw-082173.htm.

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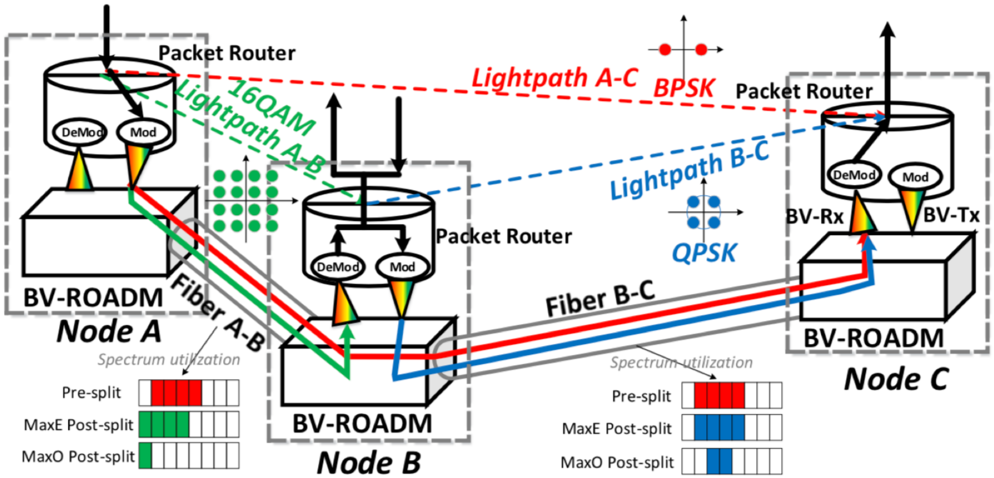
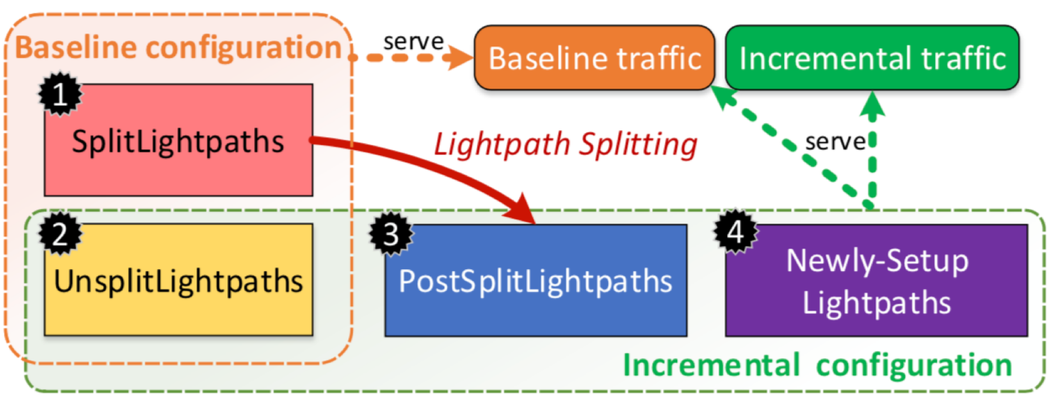
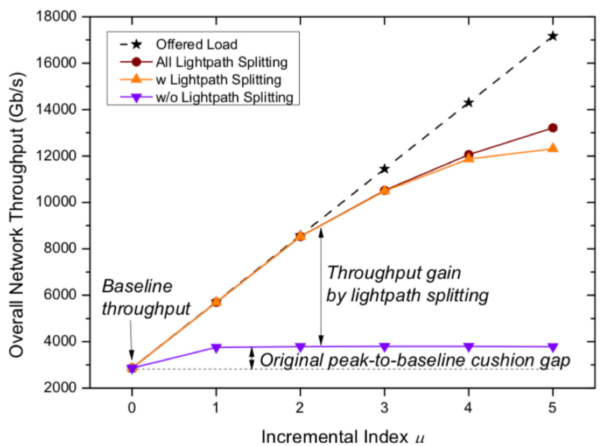
Short-term traffic fluctuations in EON





- Basic idea: split long lightpath into shorter ones to raise the modulation format, thus capacity.

Optimization Results



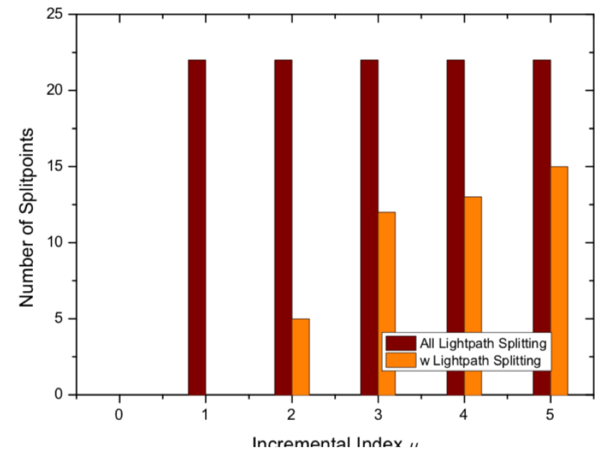


TABLE III

OPTIMIZATION RESULTS: UNSPLITLIGHTPATHS, SPLITLIGHTPATHS, POSTSPLITLIGHTPATHS AND LIGHTPATH LOAD.

UnsplitLightpaths*	Load (Gb/s)	Possible SplitLightpaths	Load (Gb/s)	PostSpliLightpaths**				
				$\mu = 1$	$\mu = 2$	$\mu = 3$	$\mu = 4$	$\mu = 5$
(5,3,6)	45	(1,2,3,6)	195	(1,2,3,6)	**(1,2), (2,3,6)**	**(1,2), (2,3,6)**	**(1,2), (2,3), (3,6)**	**(1,2), (2,3), (3,6)**
(3,2,6)	39	(4,5,6,1)	192	(4,5,6,1)	**(4,5), (5,6,1)**	**(4,5), (5,6,1)**	**(4,5), (5,6), (6,1)**	**(4,5), (5,6), (6,1)**
(2,3,4)	37	(4,5,3,6)	114	(4,5,3,6)	**(4,5,3), (3,6)**	**(4,5), (5,3), (3,6)**	**(4,5), (5,3), (3,6)**	**(4,5), (5,3), (3,6)**
(2,6,5)	24	(1,6,3)	103	(1,6,3)	**(1,6), (6,3)**	**(1,6), (6,3)**	**(1,6), (6,3)**	**(1,6), (6,3)**
		(5,6,2)	98	(5,6,2)	(5,6,2)	**(5,6), (6,2)**	(5,6,2)	(5,6,2)
		(1,6,5)	71	(1,6,5)	(1,6,5)	**(1,6), (6,5)**	**(1,6), (6,5)**	**(1,6), (6,5)**
		(1,6,3,5,4)	47	(1,6,3,5,4)	(1,6,3,5,4)	**(1,6), (6,3,5,4)**	**(1,6), (6,3), (3,5), (5,4)**	**(1,6), (6,3,5), (5,4)**
		(4,3,2)	45	(4,3,2)	(4,3,2)	**(4,3), (3,2)**	**(4,3), (3,2)**	**(4,3), (3,2)**
		(3,2,1)	33	(3,2,1)	(3,2,1)	(3,2,1)	(3,2,1)	**(3,2), (2,1)**
		(5,6,2,1)	32	(5,6,2,1)	**(5,6,2), (2,1)**	**(5,6), (6,2,1)**	**(5,6), (6,2,1)**	**(5,6,2), (2,1)**
		(6,5,3,4)	12.5	(6,5,3,4)	(6,5,3,4)	**(6,5), (5,3), (3,4)**	(6,5,3,4)	**(6,5), (5,3), (3,4)**

* One-hop lightpaths that traverse no intermediate nodes on optical layer are not shown here. They also belong to the category of UnsplitLightpaths.

** For each μ, only bolder ones refer to PostSplitLightpaths, while normal ones are UnsplitLightpaths.

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ILP-guided heuristic design

Problem decomposition:

1) Decide the Number of SplitPoints on Baseline Lightpaths:

determine the number (K) of SplitPoints on baseline network configurations.

2) Which Lighpath and How to Split the Lightpath:

determine which baseline lightpaths to be split, and how to split each lightpath.

3) PostSplitLightpaths Resource Allocation:

allocate available spectrum slots to transform SplitLightpaths into PostSplitLightpaths.

4) Incremental Traffic Routing after Lightpath Splitting:

setup new lightpaths if necessary, and route incremental traffic on the network consisting of un-split baseline lightpaths, PostSplitLightpaths, and newly-setup lightpaths.

which	how
Breath First	Max Optical layer
Depth First	Max Electrical layer

Heuristic Results: throughput increase

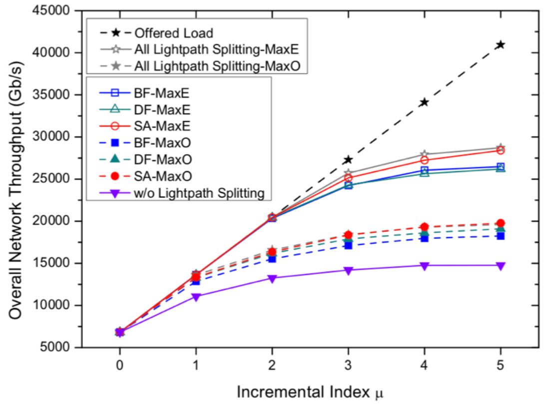


Fig. 10. Overall network throughput vs. μ, when $K = 150$.

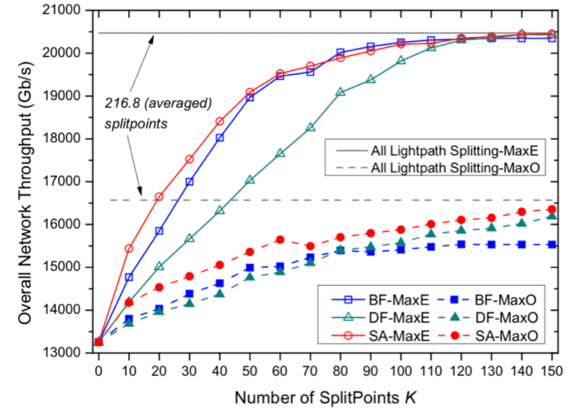
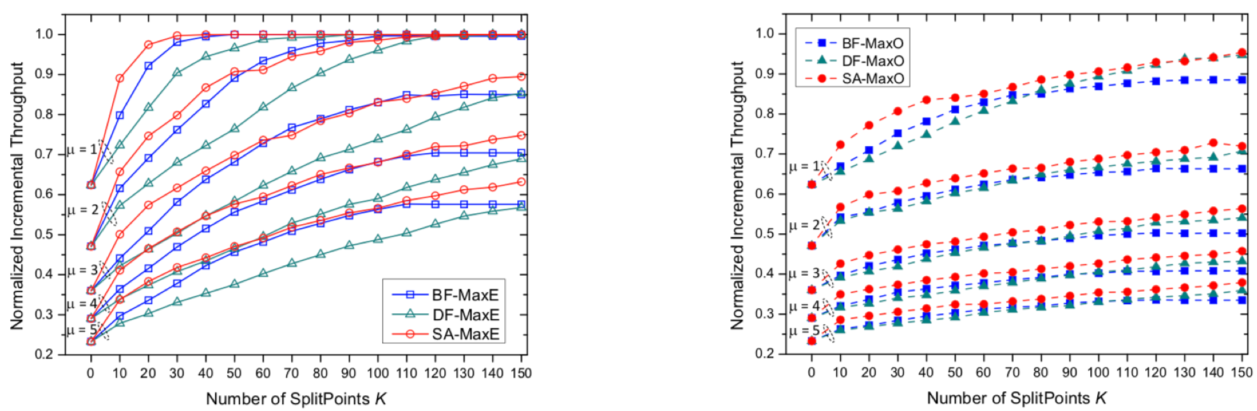


Fig. 11. Overall network throughput vs. K, when $\mu = 2$.



(a) MaxE polocies. (b) MaxO policies.

Fig. 12. Normalized incremental throughput (with respect to the amount of incremental traffic) vs. number of SplitPoints vs. incremental index μ.

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Heuristic Results: affected traffic

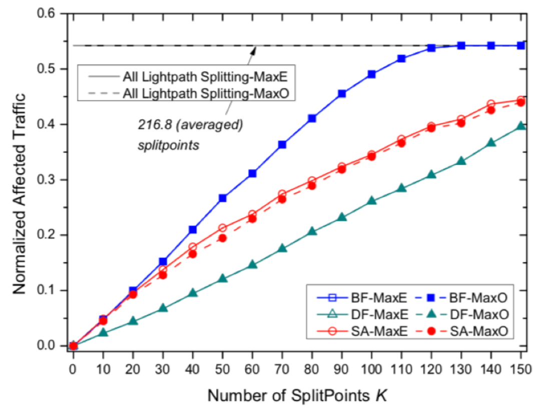

Fig. 13. Normalized affected traffic (with respect to the amount of supporting traffic after Algorithm 1) vs. K, when $\mu = 2$.

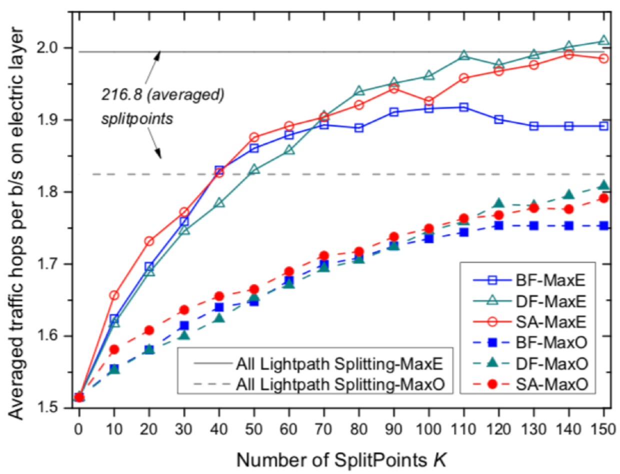

Fig. 15. Average traffic hops per b/s on electrical layer vs. K, when $\mu = 2$.

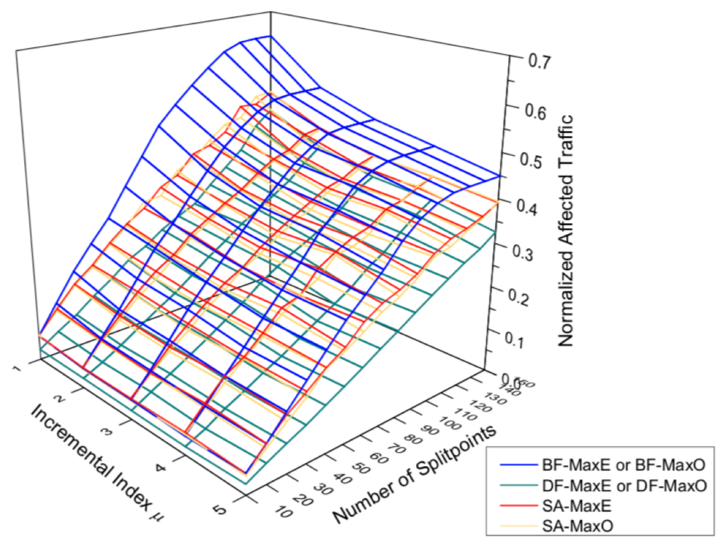

Fig. 14. Normalized affected traffic (with respect to the amount of supporting traffic after Algorithm 1) vs. K vs. μ.

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Heuristic Results: trade-off analysis

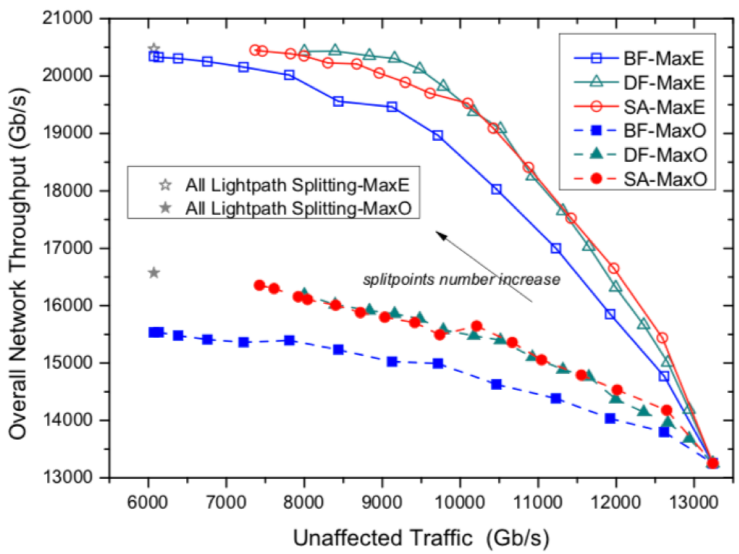

Fig. 16. Pareto front of throughput vs. unaffected traffic, when $\mu = 2$.

- Pareto front analysis: throughput vs. unaffected traffic
- As expected, higher throughput is achieved at the cost of less unaffected traffic
- *all lightpath splitting* is not an economical choice
- the first few SplitPoints with careful selection can gain more throughput increase than affected traffic; however, as the number of SplitPoints grows, the marginal utility of throughput increase diminishes.

Zhizhen Zhong, Nan Hua, Massimo Tornatore, Jialong Li, Yanhe Li, Xiaoping Zheng, Biswanath Mukherjee, "**Provisioning short-term traffic fluctuations in elastic optical networks**," submitted to IEEE/ACM Transactions on Networking, 2018.

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Half-distance law

- The basic assumption of lightpath splitting lies in half-distance law [4].
- What if this law changes?

TABLE I
MODULATION FORMAT VS. DATA RATE VS. TRANSMISSION REACH

Modulation format	BPSK	QPSK	8QAM	16QAM
Modulation level	2	4	8	16
Bits per symbol	1	2	3	4
Slot bandwidth (GHz)	12.5	12.5	12.5	12.5
Data rate (Gbps)	12.5	25	37.5	50
Transmission reach (km)	9600	4800	2400	1200

[4] A. Bocoi, *et al.*, "Reach-dependent capacity in optical networks enabled by OFDM," *OFC*, 2009.

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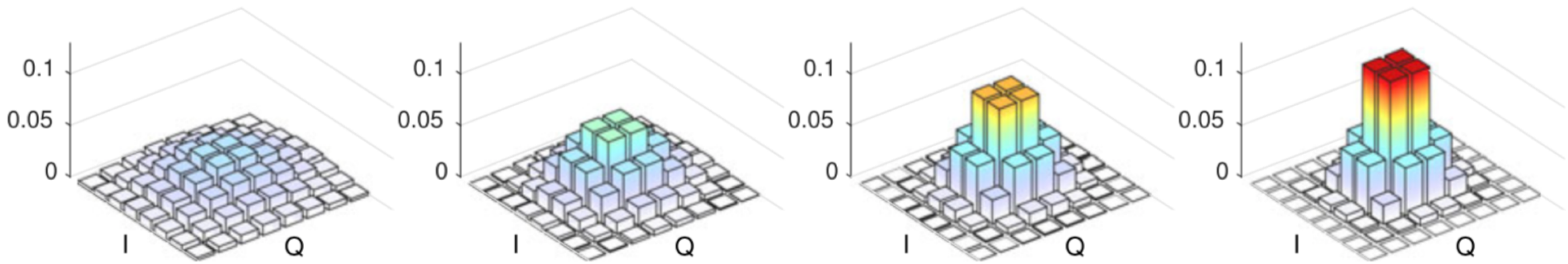
Probabilistic Constellation Shaping （PCS）



(a) (b) (c) (d)

- The standard QAM formats only offer a coarse granularity in spectral efficiency and hence also a coarse granularity in the achievable transmission reach.
- Conventional solutions, like hybrid modulation, require dedicated FEC and baud rate.
- PCS offer arbitrary granularity with respect to transmission distance [5,6].
- PCS use a fixed modulation, FEC, baud rate. What PCS need is only introduceing a distribution matcher (DM) that generates a non-uniform modulation symbol sequence.

[5] Buchali, Fred, Georg Böcherer, Wilfried Idler, Laurent Schmalen, Patrick Schulte, and Fabian Steiner. “Experimental demonstration of capacity increase and rate-adaptation by probabilistically shaped 64-QAM.” *(ECOC), 2015, post-deadline*.
[6] Buchali, Fred, Fabian Steiner, Georg Böcherer, Laurent Schmalen, Patrick Schulte, and Wilfried Idler. "Rate adaptation and reach increase by probabilistically shaped 64-QAM: An experimental demonstration." *Journal of Lightwave Technology* 34, no. 7 (2016): 1599-1609.

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Impacts of Probabilistic Constellation Shaping （PCS）

M3C - Probabilistic Shaping I

- **Probabilistic Constellation Shaping: Challenges and Opportunities for Forward Error Correction**
  Laurent Schmalen
  M3C.1 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Balancing Probabilistic Shaping and Forward Error Correction for Optimal System Performance**
  Junho Cho
  M3C.2 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Combining Probabilistic Shaping and Nonlinear Mitigation: Potential Gains and Challenges**
  F. P. Guiomar, L. Bertignono, A. Nespola, P. Poggiolini, F. Forghieri, and A. Carena
  M3C.3 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **A Simple Nonlinearity-Tailored Probabilistic Shaping Distribution for Square QAM**
  Eric Sillekens, Daniel Semrau, Gabriele Liga, Nikita A. Shevchenko, Zhe Li, Alex Alvarado, Polina Bayvel, Robert. I. Killey, and Domaniç Lavery
  M3C.4 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Experimental and Numerical Comparison of Probabilistically-Shaped 4096 QAM and Uniformly-Shaped 1024 QAM in All-Raman Amplified 160 km Transmission**
  Seiji Okamoto, Masaki Terayama, Masato Yoshida, Keisuke Kasai, Toshihiko Hirooka, and Masataka Nakazawa
  M3C.5 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Residual Non-Linear Phase Noise in Probabilistically Shaped 64-QAM Optical Links**
  Dario Pilori, F. Forghieri, and Gabriella Bosco
  M3C.6 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**

M4E - Probabilistic Shaping II

- **On Joint Design of Probabilistic Shaping and Forward Error Correction for Optical Systems**
  Georg Böcherer
  M4E.1 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Low-Complexity Variable-Length Output Distribution Matching with Periodical Distribution Uniformalization**
  Tsuyoshi Yoshida, Magnus Karlsson, and Erik Agrell
  M4E.2 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Experimental Verification of Rate Flexibility and Probabilistic Shaping by 4D Signaling**
  Fabian Steiner, Francesco Da Ros, Metodi Plamenov Yankov, Georg Böcherer, Patrick Schulte, Søren Forchhammer, and Gerhard Kramer
  M4E.3 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Universal Hybrid Probabilistic-geometric Shaping Based on Two-dimensional Distribution Matchers**
  Zhen Qu, Shaoliang Zhang, and Ivan B. Djordjevic
  M4E.4 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**
- **Efficient Offline Evaluation of FEC Codes Based on Captured Data with Probabilistic Shaping**
  Tsuyoshi Yoshida, Magnus Karlsson, and Erik Agrell
  M4E.5 Optical Fiber Communication Conference (OFC) 2018 **View: PDF**

- An arising interest in PCS in this year's OFC.
- Physical-layer innovations should provide networking-layer more flexibility.
- What can PCS bring us in networking?
  - Flexible transponders?
  - Modulation format determination?

Thank you for attention!

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