On QoS-Assured Degraded Provisioning in Service-Differentiated Multi-Layer Elastic Optical Networks

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Outline

I. **Introduction**

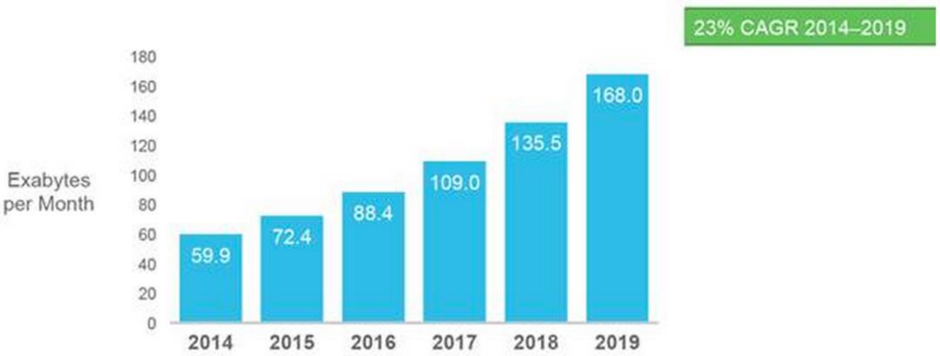
II. **Dynamic degraded provisioning scheme**

III. **Illustrative numerical results**

IV. **Conclusion and future work**

I. Introduction

- Network evolution: large and bursty traffic, heterogeneous requests.



Global IP traffic amount
Source: Cisco VNI Global IP Traffic Forecast, 2014–2019

Global IP Traffic by Application Category
Source: Cisco VNI Global IP Traffic Forecast, 2014–2019

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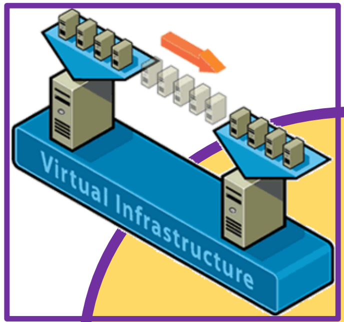
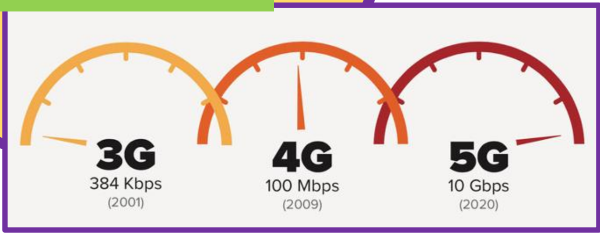
I. Introduction (contd.)



Large and bursty traffic

Heterogeneous requests



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I. Introduction (contd.)

For some of the traffic which is delay-insensitive and can accept some compromise in bandwidth or other aspects, it can be preempted by more "important" requests when the network becomes congested. And different levels of service can charge different prices [1].

1) **QoS-assured**: keeping the total amount of transferred traffic constant by time prolongation or modulation level adjustment with immediate service access.
   (Come and serve & constant amount)

2) **QoS-affected**: directly degrade request bandwidth without time or modulation compensation, or no guarantee for immediate access.
   (Come and wait for serve or reduced amount)

[1] L. He, *et al.*, "Pricing differentiated internet services." in *INFOCOM*, 2005.

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II. Dynamic degraded provisioning scheme

In network resource crunch, how to perform dynamic degraded provisioning?

Inspired by RWA in WDM and RSMA in EON, we decompose the problem into two stages:

1. **Degraded routing:**
   - On which to degrade? Decide a route to degrade.
2. **Degraded resource allocation:**
   - On how to degrade? Decide the sequence of requests the method to degrade.

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II. Dynamic degraded provisioning scheme (contd.)

1. Degraded routing: evaluations

- Two major considerations: **resource occupancy** and **impact on existing traffic.**
- **route hops**: overall amount of resources occupied by the new request.
- **potential degraded requests**: how much the new request will affect existing requests.

The k^{th} link from i to j in any layer of the multi-layer network.

$$V_{ij,k} = (\Theta, C)$$

The available capacity of this link.

A set that contains existing requests routed on this link.

A degraded route for request r_n.

$$\mathcal{P}_{r_n} = \{V_{ij,k} | r_n \in V_{ij,k}.\Theta\}$$

Evaluations:

$$\mathcal{N}_{RH} = |\mathcal{P}_{r_n}|$$

$$\mathcal{N}_{PDR} = |\bigcup_{c=1}^{|\mathcal{P}_{r_n}|} \mathcal{P}_{r_n}[c].\Theta|$$

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II. Dynamic degraded provisioning scheme (contd.)

1. **Degraded routing: computing complexity**

- Given (s,d), **Min N_{RH}**, Dijkstra problem on a graph, easy, O(N^2).
- Given (s,d), **Min N_{PDR}**, list all the supporting requests of all possible routes, not easy, O((n-2)!).

Especially hard for electric layer, because electric layer topo can be partly regarded as fully connected, and a possible degraded route can be any links between (s,d).

New methods for quickly solving **Minimizing-PDR problem** must be proposed!

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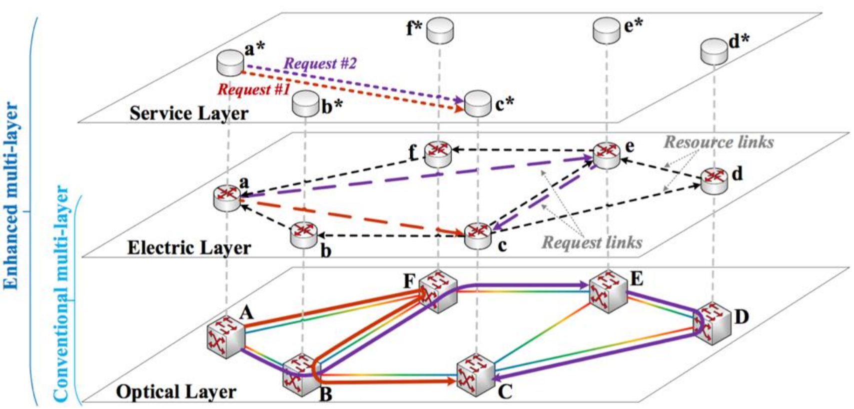
II. Dynamic degraded provisioning scheme (contd.)

1. <u>Degraded routing: enhanced multi-layer network model.</u>



minimizing-PDR problem -> ***weighed shortest-path problem.*** Worst case, complexity $O(N^3)$.

- A multi-layer (optical, electric, service) graph.
- Two kinds of directional links, all nodes included.
- **Request link weight**: a given large number times a binary that indicates whether there are existing requests between the node pairs.
- **Resource link weight**: binary, whether there is available and sufficient resource for this request.
- If the mapped upper layer has **isolated nodes**, while the isolated node turns out to be the source or destination of the request, then we replace the isolated node with the originating or terminating nodes of lightpaths (or request) that running bypass the isolated node.

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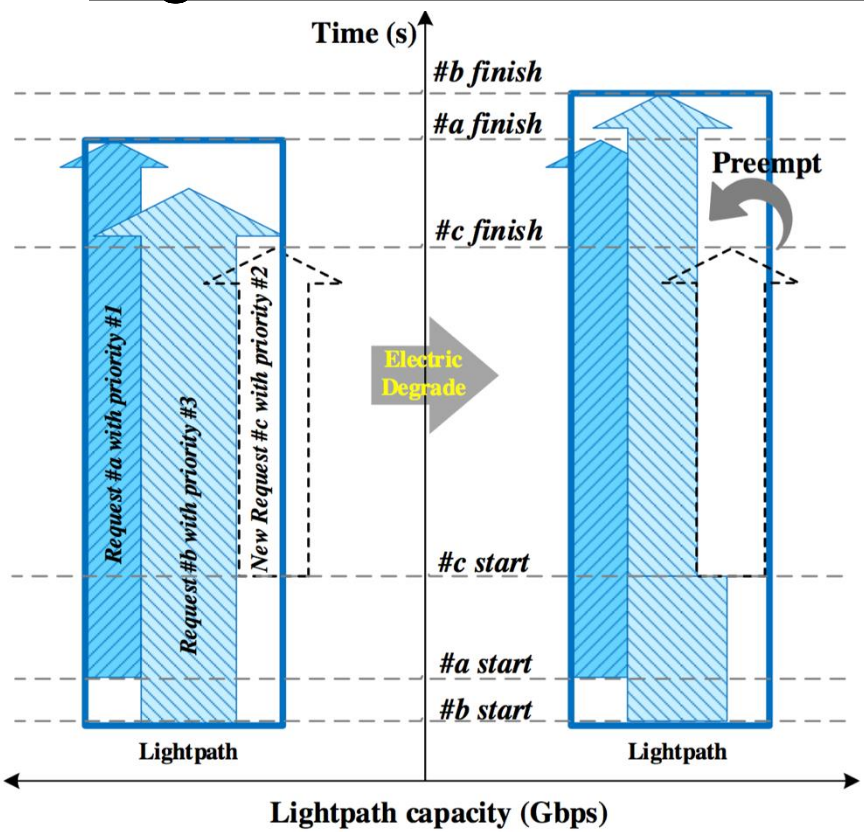
II. Dynamic degraded provisioning scheme (contd.)

2. Degraded resource allocation: electric layer.



- **QoS-assured**: request amount constant, reduce request-transmission rate and extend the holding time accordingly, but no exceed the request deadline.
- **Priority-based**: high priority requests preempt lower ones, and start from the lowest-priority one.
- **Least-affected**: we manage to degrade the minimal number of requests to provide just-enough bandwidth for the new arriving one.

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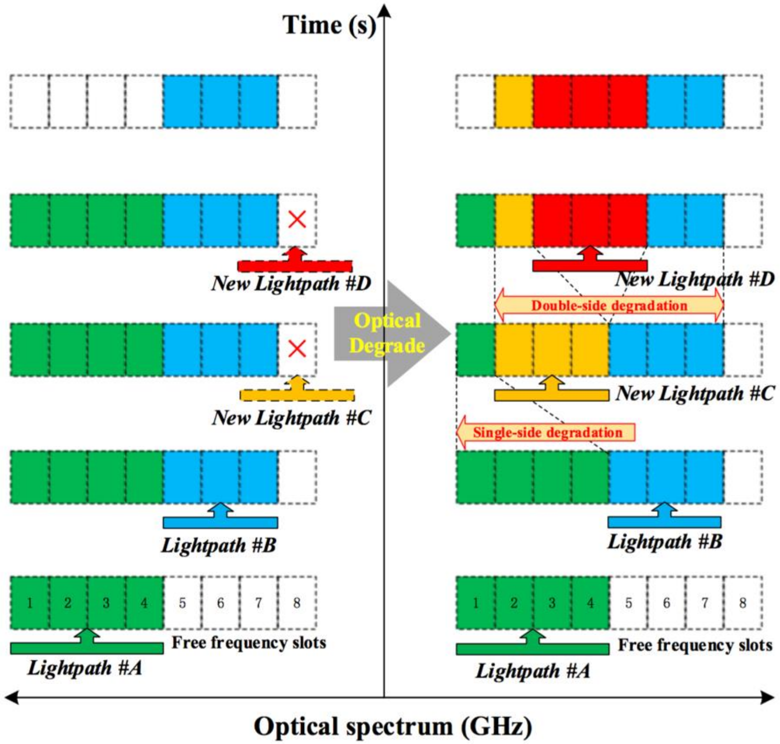
II. Dynamic degraded provisioning scheme (contd.)

2. Degraded resource allocation: optical layer.



Dynamic optical degradation: on one fiber.

- **QoS-assured**: lightpath capacity constant, raise modulation level and save occupied slots, modulation level do not exceed the distance constraints.
- **First-fit**: slot with smaller index number first.
- **Least-affected**: single-side degradation first, if not enough capacity, then double-side degradation.
- **Threshold-based** grooming: if the request is lower than threshold, then setup a lightpath with capacity of threshold, others, setup the lightpath with request capacity. Better blocking performance than WDM and non-grooming EON [2].

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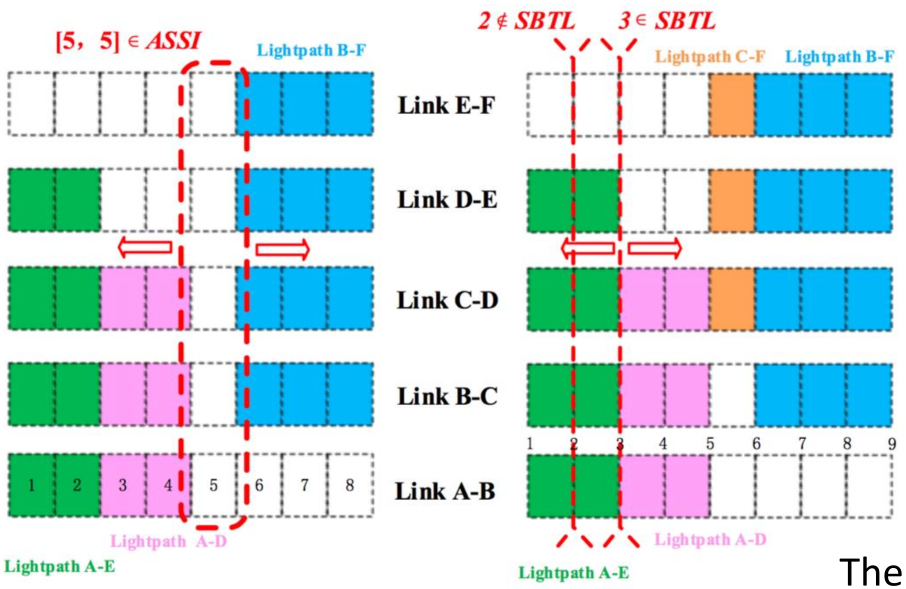
[2] X. Wan, *et al.*, "Dynamic Traffic Grooming in Flexible Multi-Layer IP/Optical Networks," *IEEE Commun. Lett.*, vol. 16, no. 12, 2012.

II. Dynamic degraded provisioning scheme (contd.)

2. Degraded resource allocation: optical layer.



(a) ASSI > 0 (b) ASSI = 0

Dynamic optical degradation: along a route,

Available Spectrum Slots Intersection (ASSI).

$S_f[p]$, binary, whether p^{th} slot is utilized on fiber f.

$$ASSI = \{S_f[p] | \sum_{f=1}^{|\mathcal{P}^o|-1} S_f[p] \vee S_{f+1}[p] = 0\}$$

Slot Border Through Lightpaths (SBTL).

$$L = (f, \xi_l, \xi_r, \eta, \delta)$$

The lightpath request, the fiber, left and right indices of occupied spectrum slot, modulation level, lightpath distance.

w denotes index of spectrum slot borders, $w \in [1, B+1]$

D(x) decision function, if x>0, D(x)=0; x<0, D(x)=1.

$$SBTL = \{w | \sum_{L:L.f \in \mathcal{P}^o} D((w - \frac{1}{2} - L.\xi_l)(w - \frac{1}{2} - L.\xi_r)) = 0\}$$

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II. Dynamic degraded provisioning scheme (contd.)

2. **Degraded resource allocation: complexity analysis.**

- Consider the worst case, that degraded route go through every node, hops is $O(N)$.
- In electric layer, the maximum number of existing requests on each link is R, which is related to traffic load, and the complexity is $O(NR)$.
- In optical layer, the number of spectrum slots is B, and the complexity is $O(NB^2)$.

III. Illustrative numerical results

Simulations setup.

- Fibers: **unidirectional** with **300 spectrum slots**, the spectrum width is **12.5 GHz**.
- Traffic requests: generated **between all node pairs**, and characterized by **Poisson arrivals** with **negative exponential holding times**. The granularities of requests distributed **independently** and **uniformly** from **5 Gbps to 150 Gbps**. The maximum acceptable value of degraded transmission rate is uniformly distributed between **100 and 25 percent** of their original bandwidth.
- Priorities: 5 levels, equal amount each.
- Lightpath threshold: **150 Gbps**, which is equal to the largest request bandwidth, and has been demonstrated to perform the best of blocking performance [1].

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

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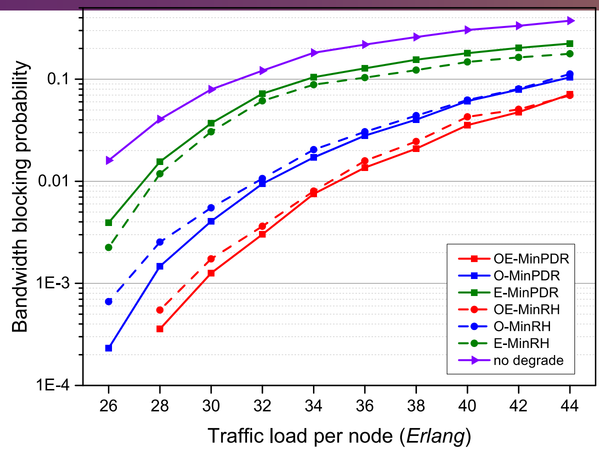
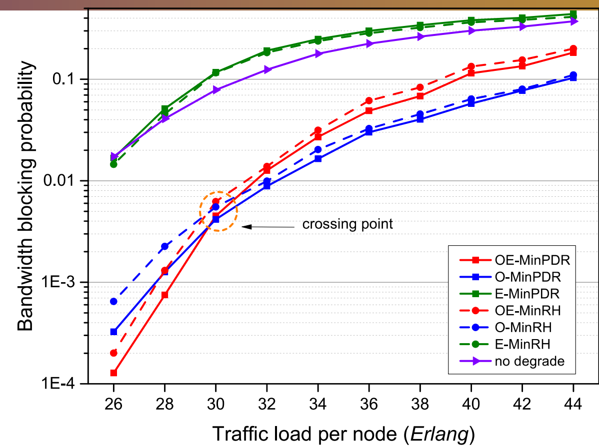
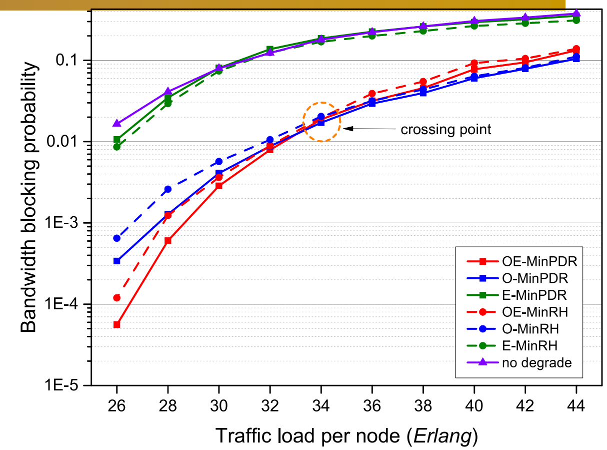
Dynamic analysis results



(a) requests with all priorities.



(b) requests with highest priority.



(c) requests with lowest priority

- Optical degradation performs almost the same regardless of priorities, because optical degradation does not involve service priorities as electric degradation does.
- MinPDR performs better in optical-related degradations (both-layer degradation and optical degradation), while MinRH performs better only in electric degradation.
- Optical degradation has stronger influence on blocking reduction because it can enlarge the network capacity, while electric degradation just deals with the bandwidth-time exchange to trade time for space.

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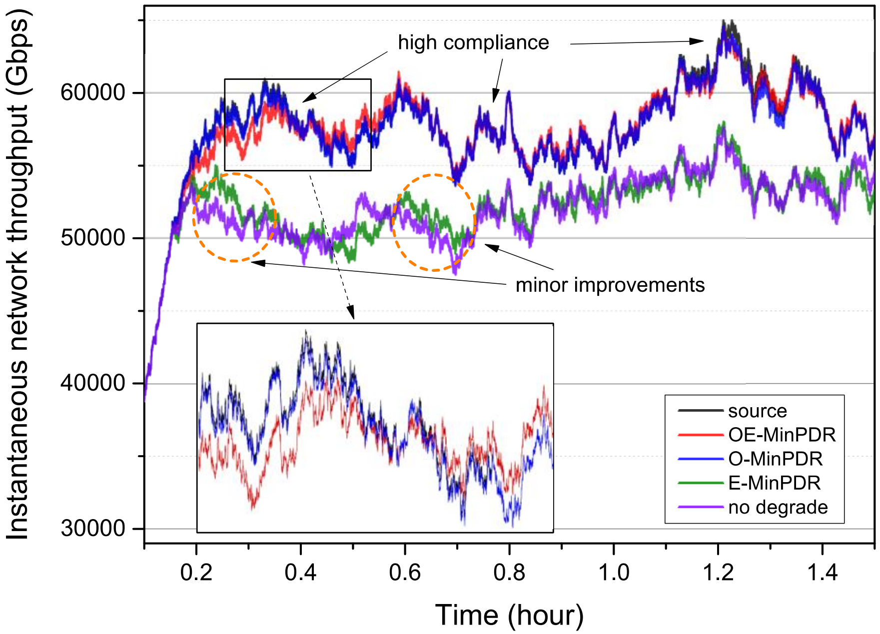
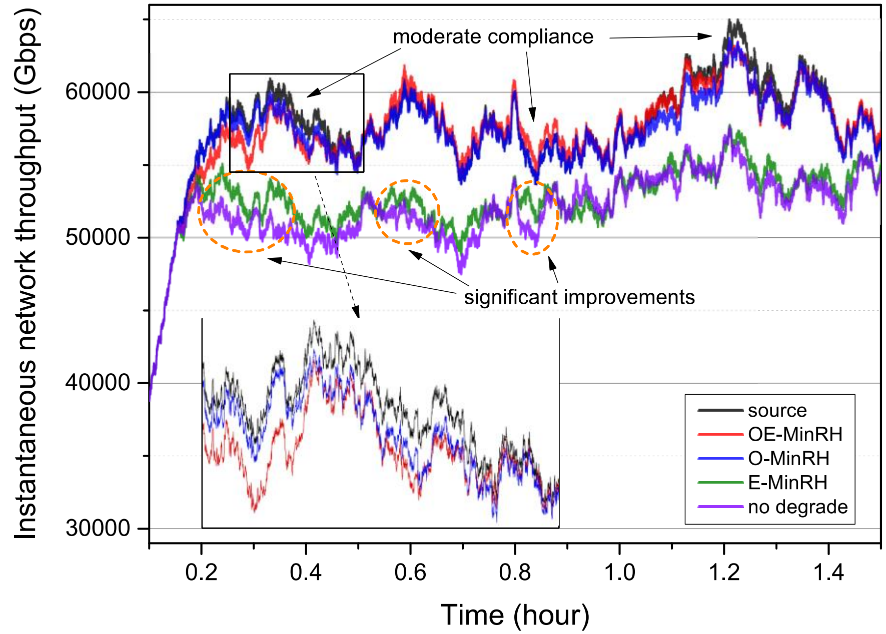
Transient analysis results: part I



(a) Instantaneous network throughput (MinPDR).



(b) Instantaneous network throughput (MinRH).

- Optical-related degradation achieves better compliance with the offered load in MinPDR, while electric degradation accomplishes better improvements in MinRH (another aspect to support the observations before).

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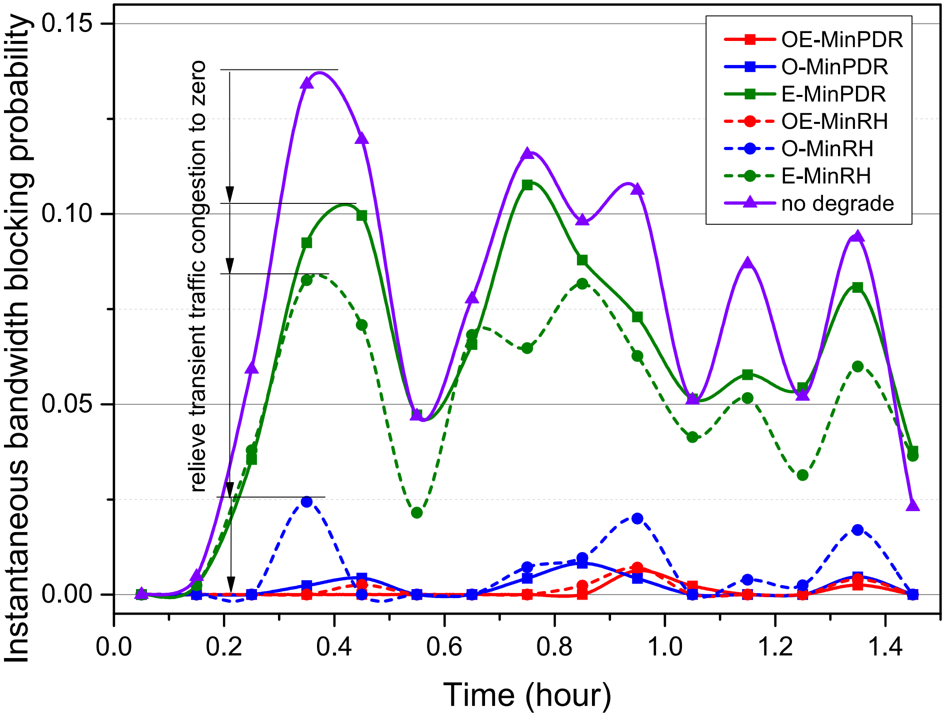
Transient analysis results: part II

- Evaluate the transient performance of network blocking.
- Relieve transient traffic congestion, even down to zero.
- Both-layer degradation policies have the largest blocking reduction, and OE-MinPDR performs even better (almost zero blocking).



Instantaneous bandwidth blocking probability.

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Conclusions

- In this work, we investigated dynamic QoS-assured degraded provisioning problem in service-differentiated multi-layer networks with optical elasticity.
- We proposed and leveraged the enhanced multi-layer architecture to design effective algorithms for network performance improvements.
- Numerical evaluations showed that we can achieve significant blocking reduction, up to two orders of magnitude via the new degraded provisioning policies.
- We also conclude that optical-related degradation achieves better performance with MinPDR, while electric degradation has lower blocking with MinRH due to different mechanisms of multi-layer degradation.

Future research goals

1. Degraded provisioning in network planning stage.

Optimize: comprehensive **revenue loss** of network operator. (revenue loss by bandwidth request failures (large weight), revenue loss by degraded requests (medium weight), and future impact by holding-time prolongation (small weight)).

Constraints:

- spectrum and modulation continuity,
- spectrum consecutive,
- physical and virtual layers flow conservation,
- lightpath capacity,
- degradation constraints (electric layer with request amount constant, and optical layer with lightpath capacity constant),
- priority-based degradation sequence.

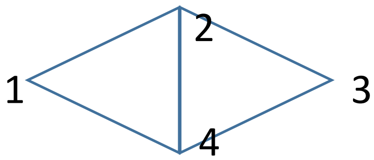
Future research goals (contd.)

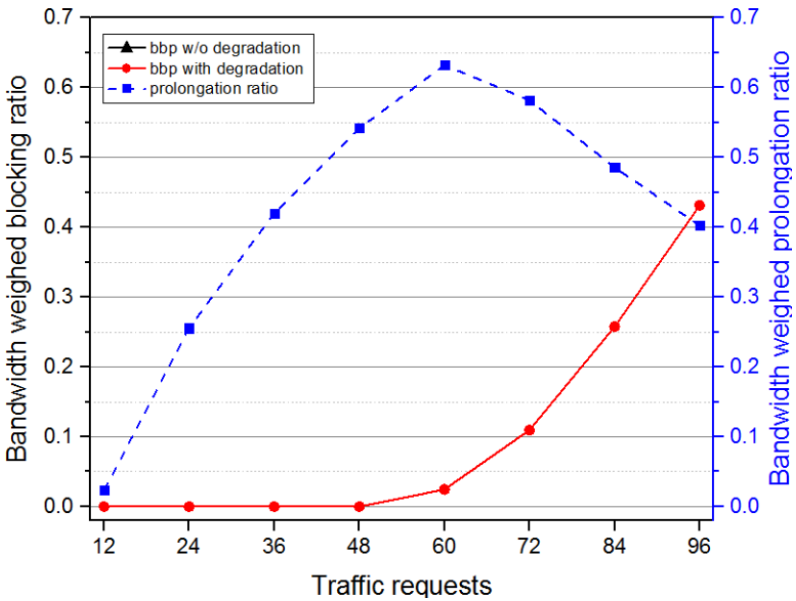
TABLE II
CP OPTIMIZATION PARAMETERS

Parameters	Value
η_1, η_2, η_3	$(1, 4, 10) \times 10^8$
$\alpha_1, \alpha_2, \alpha_3$	$(1, 4, 10) \times 10^4$
Number of spectrum slots per fiber	4
Bandwidth of a spectrum slot	12.5Gbps
Request bandwidth	5Gbps—150Gbps

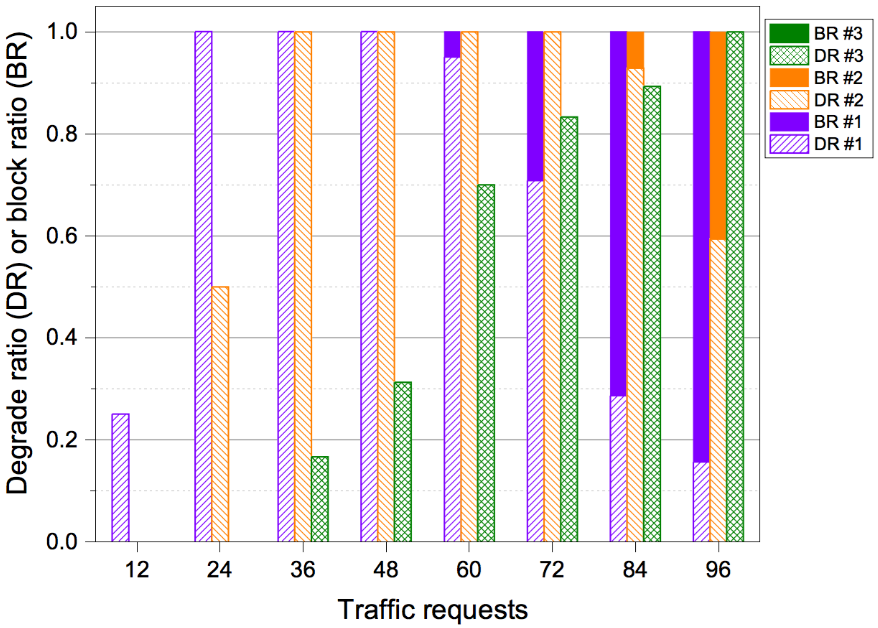
1. Degraded provisioning in network planning stage.

3 priorities, 4 node-topology.





bbp & prolongation vs. traffic requests.



degraded request ratio and blocked request ratio in different priorities.

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Future research goals (contd.)

2. Analyze the impact of degradation.
- How much will the bit rate change or spectrum reallocation cause a temporary service interruption due to physical device reconfiguration (reviewer).

3. A unified network flow degradation model, zero blocking.
- Develop a unified network model (maybe a mathematical model based on network graph theory) for both layers (electric, optical) constraints.
- Realize zero blocking, may compromise large amount of degradation.
- There maybe a counterpart of degradation such as a promotion/upgrade. A connection that has been degraded can then be upgraded when resources become available (reviewer).

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Thank you!
Any questions or comments?

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