Network Convergence for Traffic Disequilibrium

Zhizhen Zhong
Visiting Student, UC Davis
Ph.D. Student, Tsinghua University

清華大學
Tsinghua University

UCDAVIS
UNIVERSITY OF CALIFORNIA

Self Introduction

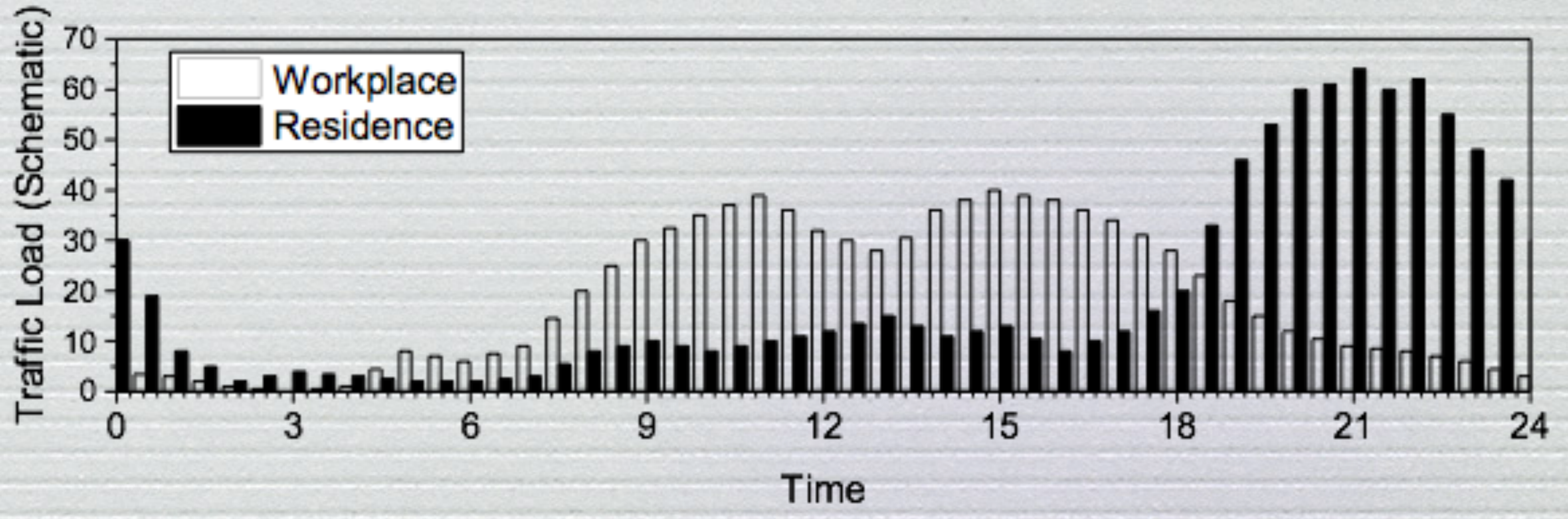
- 2015.07-09, visiting UC Davis, supervised by Prof. Biswanath Mukherjee for two month.
- 2014.09-present, Ph.D. student, Optical Networking Research, Tsinghua University, Beijing, China.
- 2010.09-2014.06, Undergraduate, Electronic Engineering, Tsinghua University, Beijing, China.

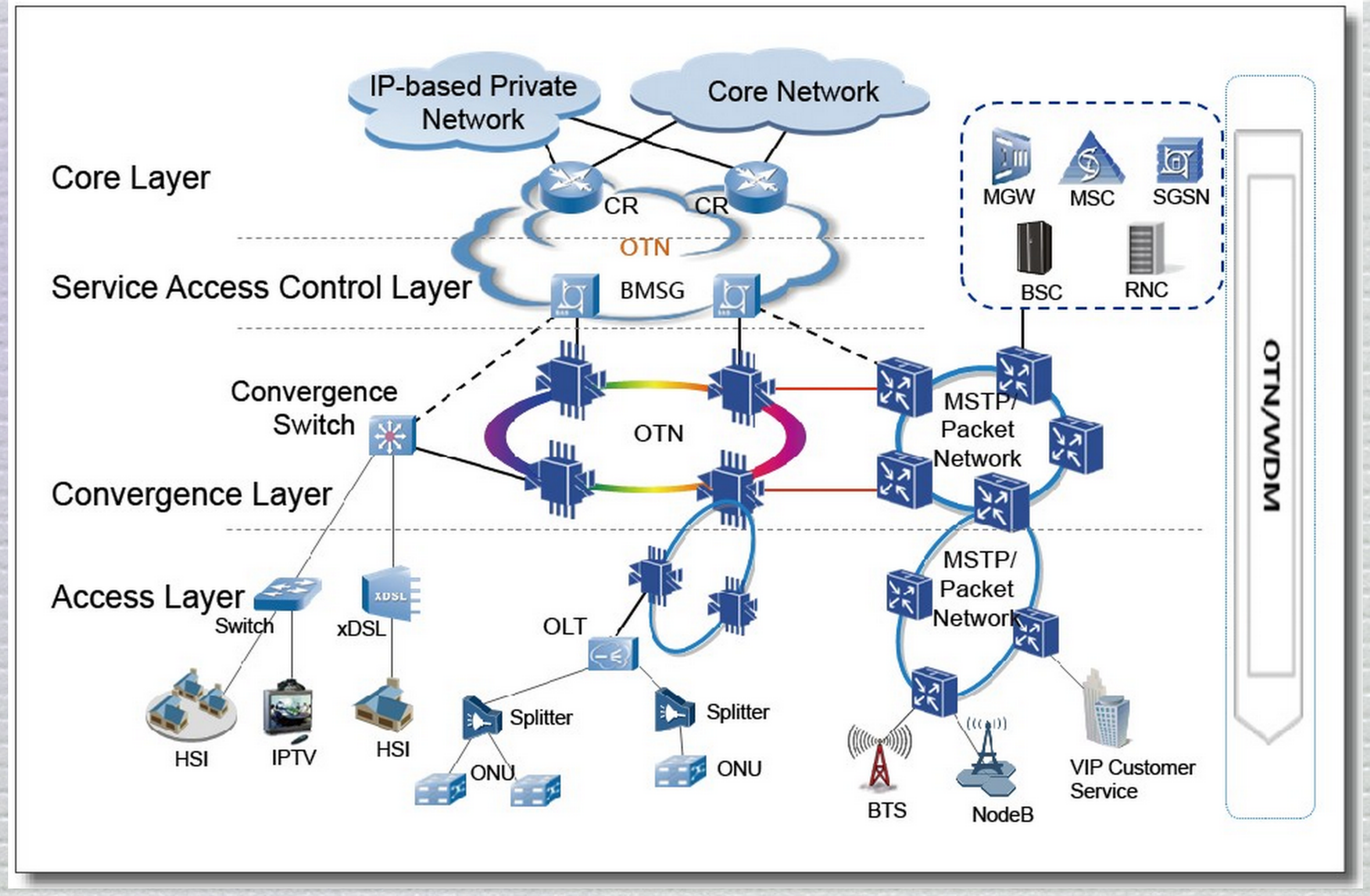
Outline

- Background and Motivation
- Packet/circuit convergence network experiment
- Tidal traffic dispatching through differentiated grooming
- Quasi-static stateful grooming with ILP formulation (Ongoing)
- Future work

Background and Motivation

- Traffic are generated in IP layer and transported in optical layer. The convergence of IP/optical networks will give us more flexibility to improve the network performance.

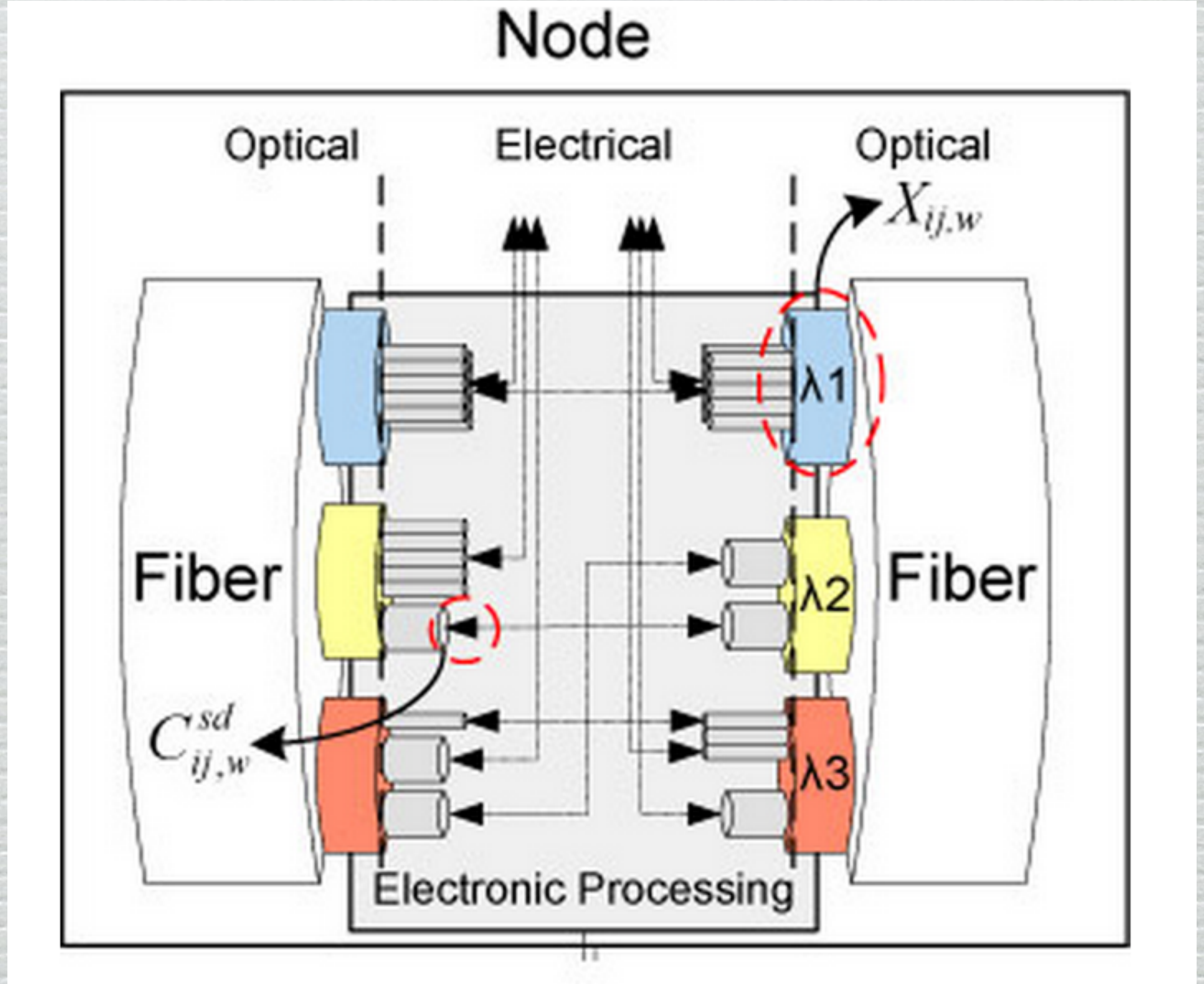




- **Traffic disequilibrium** is an emerging problem as the popularity of high-speed mobile communication, datacenter and cloud computing.
  - *for example, urban citizens use mobile phones to get LTE access to HD video from remote datacenters at workplace during the day while at residence during the night.*

Background and Motivation

- **Traffic grooming** is the bridge between IP networks and optical transport networks, enabling fine-grained IP traffic transported by coarse-grained lightpath, which makes a good solution for traffic disequilibrium.

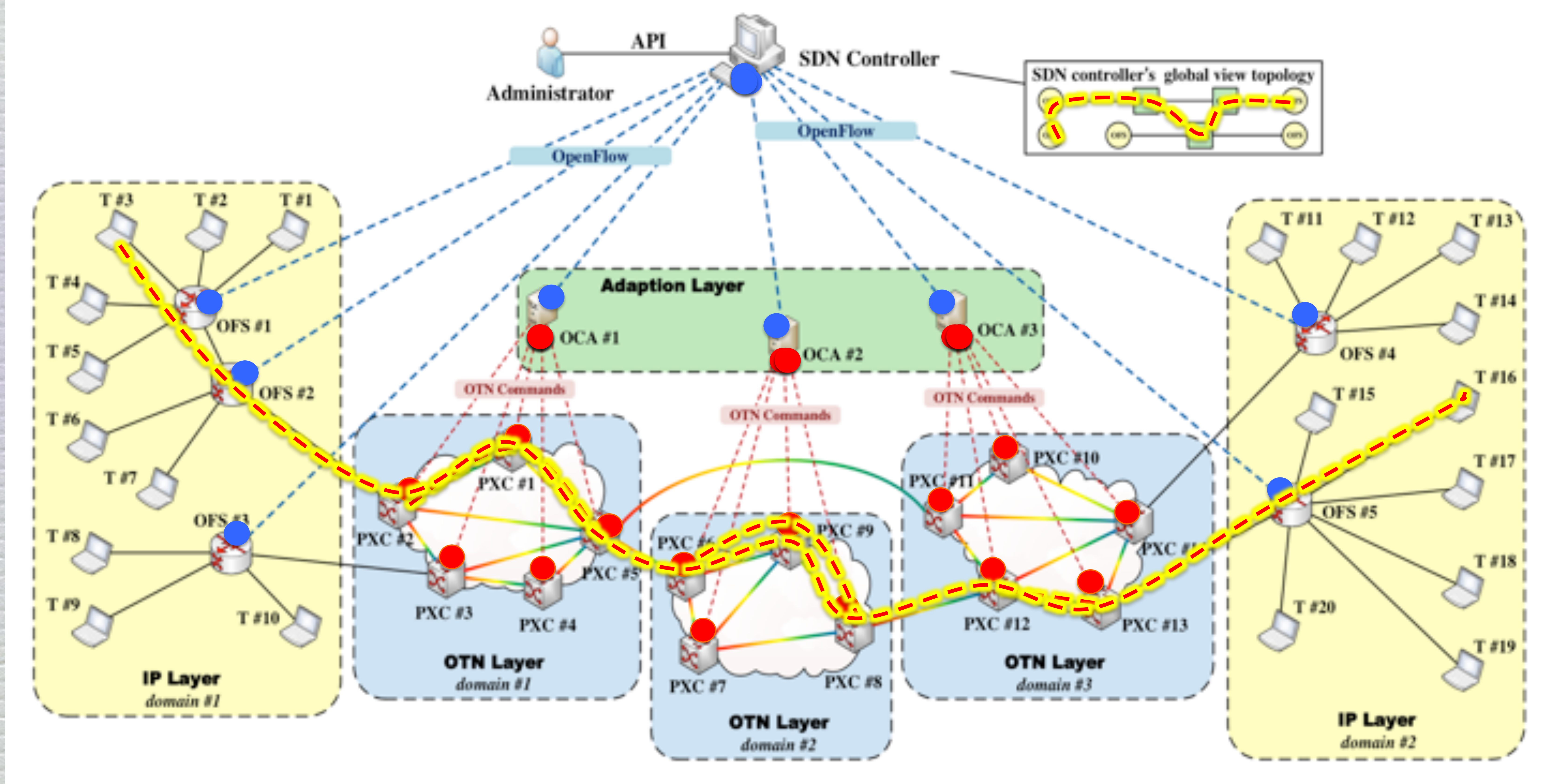


Chapter I:

Packet/circuit convergence network experiment

Proposed architecture

In control layer, the Optical Control Agent (OCA) is introduced. From the view of the SDN controller, one domain of the OTN is virtualized by one OCA. All the intra-domain resources allocation, including light path setup and teardown are controlled only by the OCA of the corresponding OTN domain. Thus the SDN controller only deal with the network topology consisting of OpenFlow switches and OCAs.



Step I: End-to-end connection initialization

OCA initiates Intra-Domain Traffic Engineering Database (IDTED).

SDN controller initiates Global Traffic Engineering Database (GTED).

Step II: End-to-end path computation in SDN controller

Preliminary result: SDN controller runs path computation algorithm based on its global view from the GTED of IP over OTN.

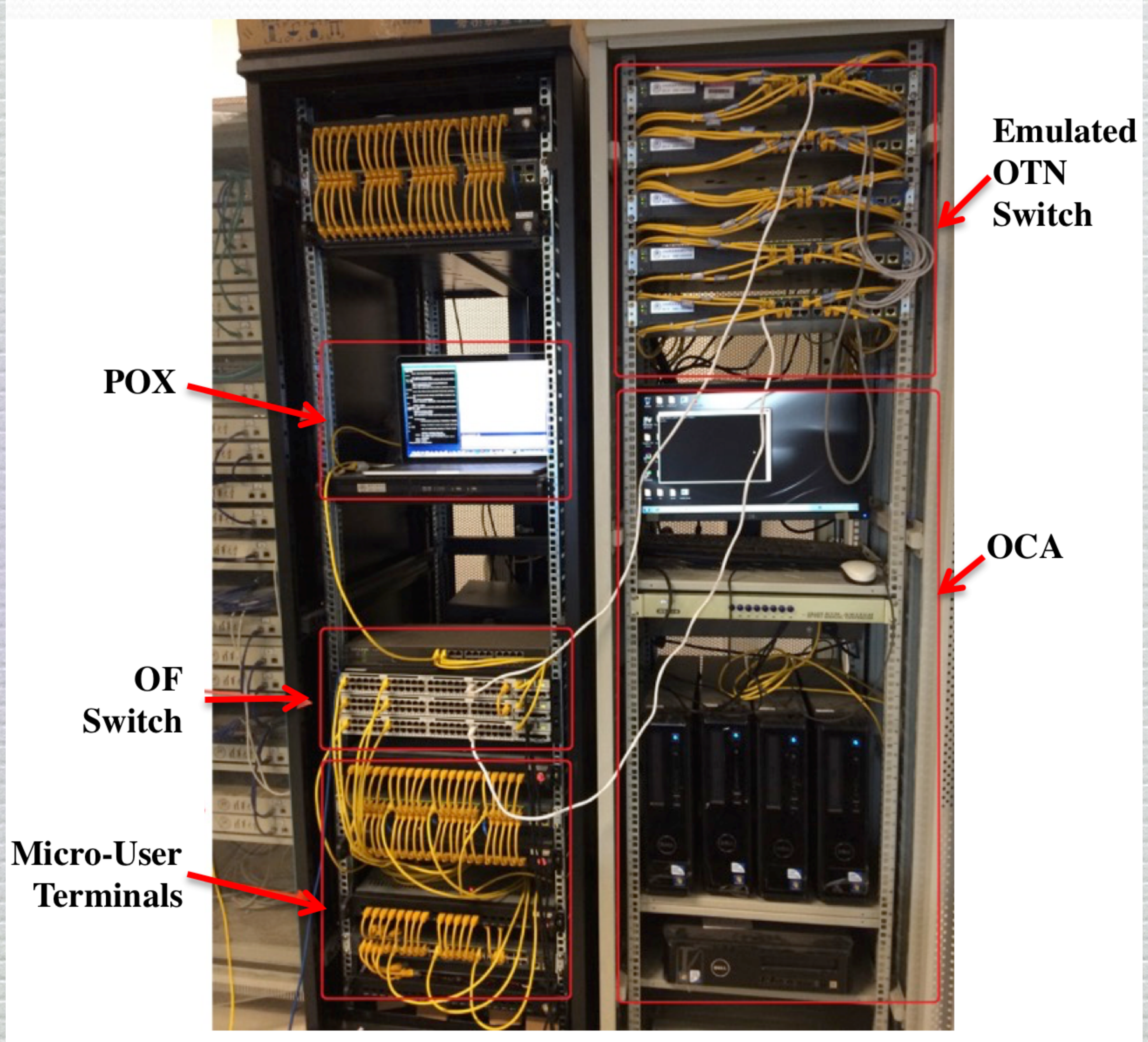
Step III: Intra-domain optical path computation in OCA

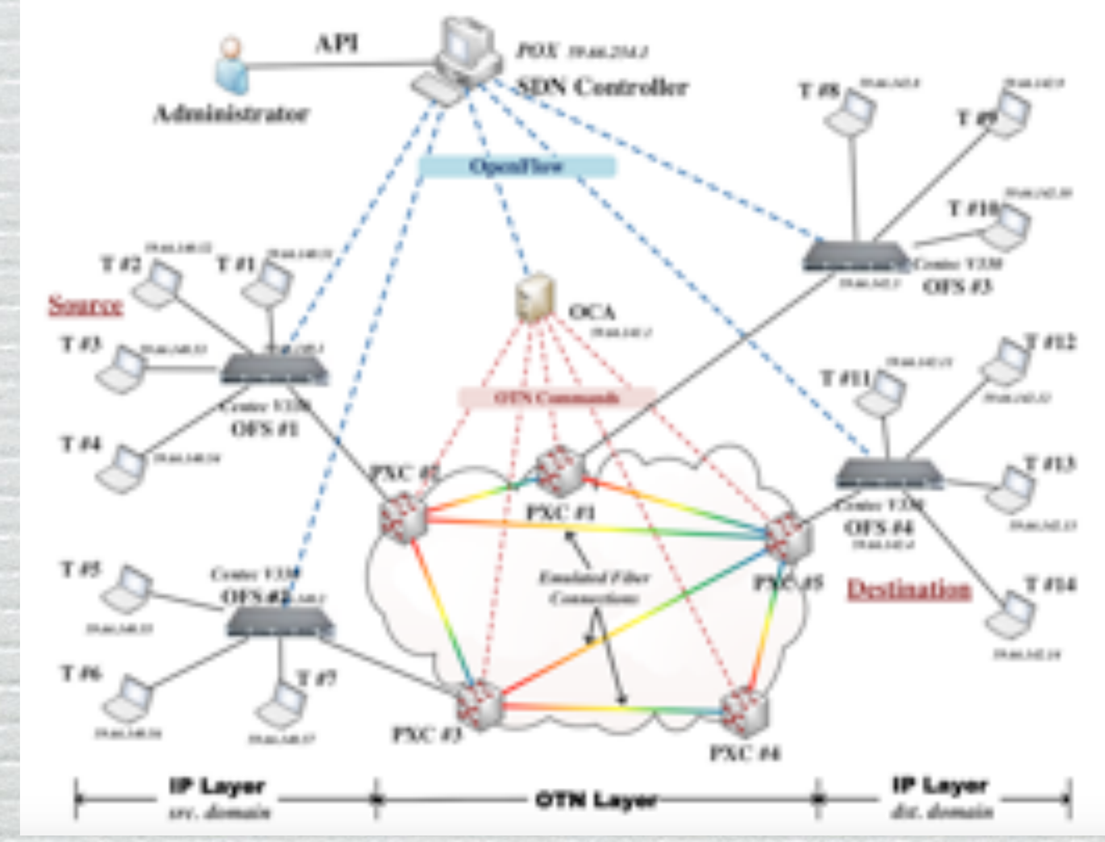
OCA runs optical path computation algorithm based on its regional view from the IDTED.

Step IV: End-to-end connection setup

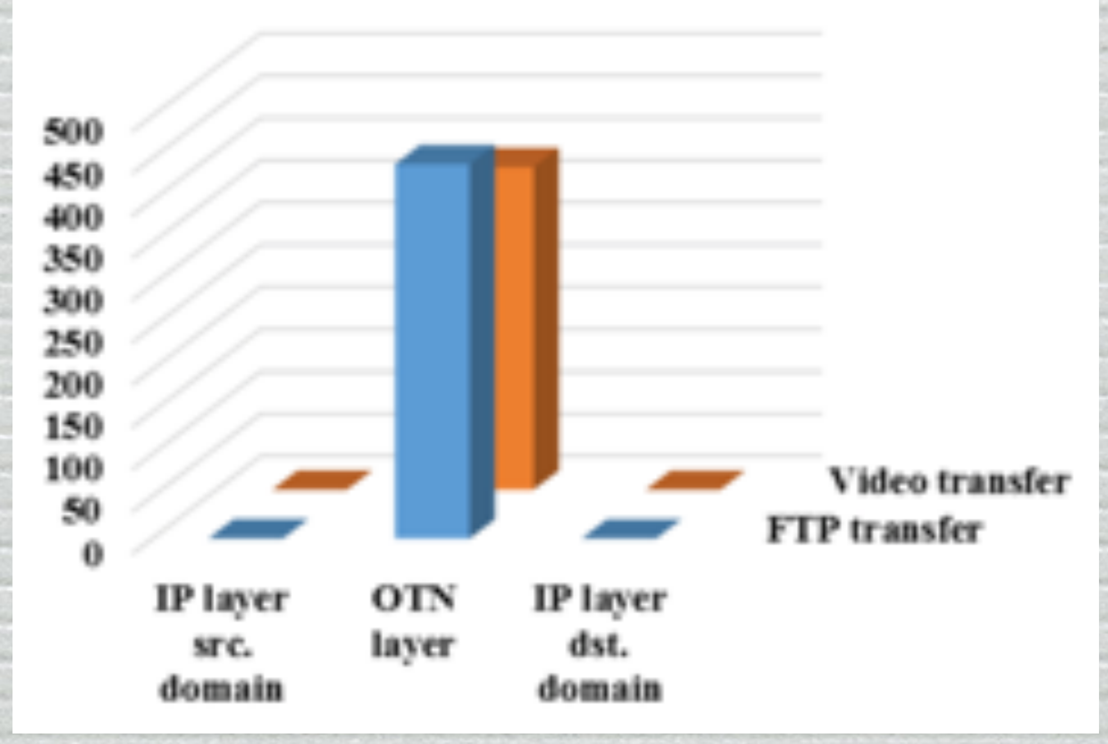
SDN controller and OCA send relating commands to data layer infrastructures.

Experiment & Results





	IP layer src. domain	OTN layer	IP layer dst. domain
FTP transfer	0.137	443	0.122
Video transfer	0.146	382	0.098



- This test-bed consists of two IP layers and one OTN layer.
- In both IP layers commercial Centec V330 OpenFlow switches and PC terminals are employed.
- In OTN layer, the OTN switching nodes are emulated by commercial Cisco switches with VLAN binding for circuit switch.
- Both FTP service and video service are tested on this test-bed.
- The transfer delay in OTN layer is much longer than IP layer.

Publication

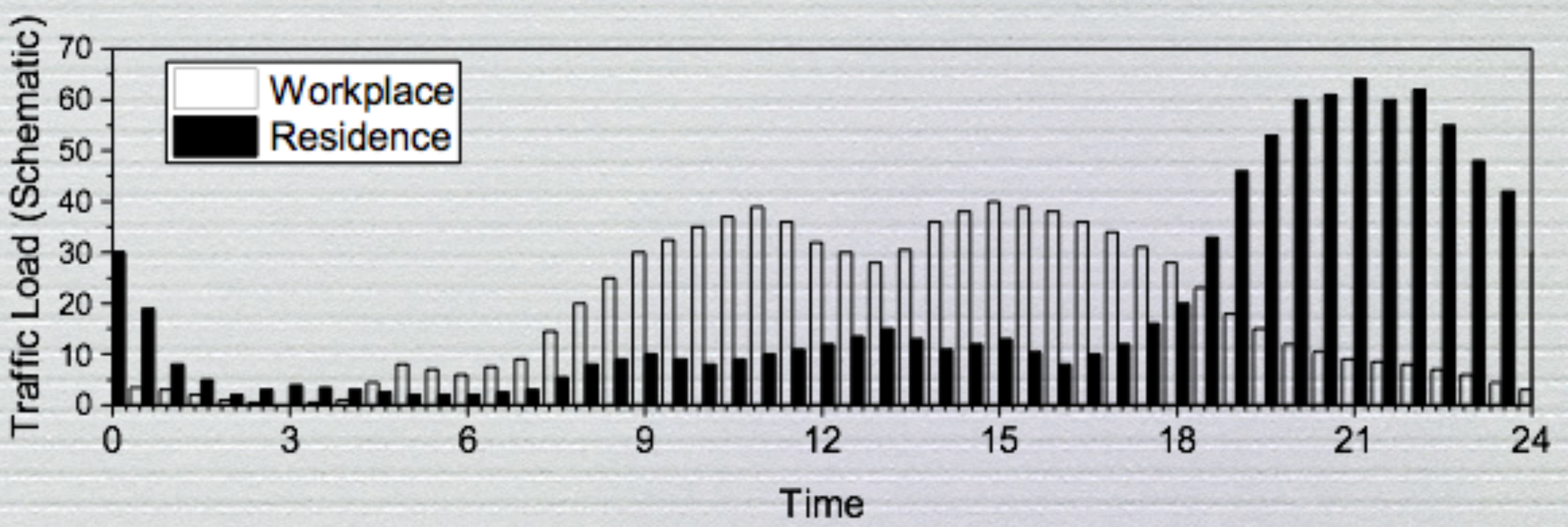
- Zhizhen Zhong, Xiaohui Chen, Nan Hua, Yanhe Li, and Xiaoping Zheng, "**Unified Control for IP over Optical Transport Networks Based on Software-Defined Architecture**," *Proc. IEEE/OSA Asian Communications and Photonics Conference (ACP)*, Shanghai, China, Nov. 2014.
- Xiaoping Zheng, Nan Hua, and Zhizhen Zhong, "**Achieving Heterogeneous Packet-Optical Networks Inter-Connection with a Software-Defined Unified Control Architecture (invited)**," *Proc. IEEE International Conference on Optical Communications and Networks (ICOCN)*, Nanjing, China, Jul. 2015.
- Xiaoping Zheng, Nan Hua, and Zhizhen Zhong, "**A Unified Control Architecture and Key Technologies for Hybrid Packet-Optical Networks(invited)**," accepted by *IEEE Optoelectronic Global Conference (OGC)*, Shenzhen, China, Aug. 2015.

Chapter II:

Tidal traffic dispatching through differentiated grooming

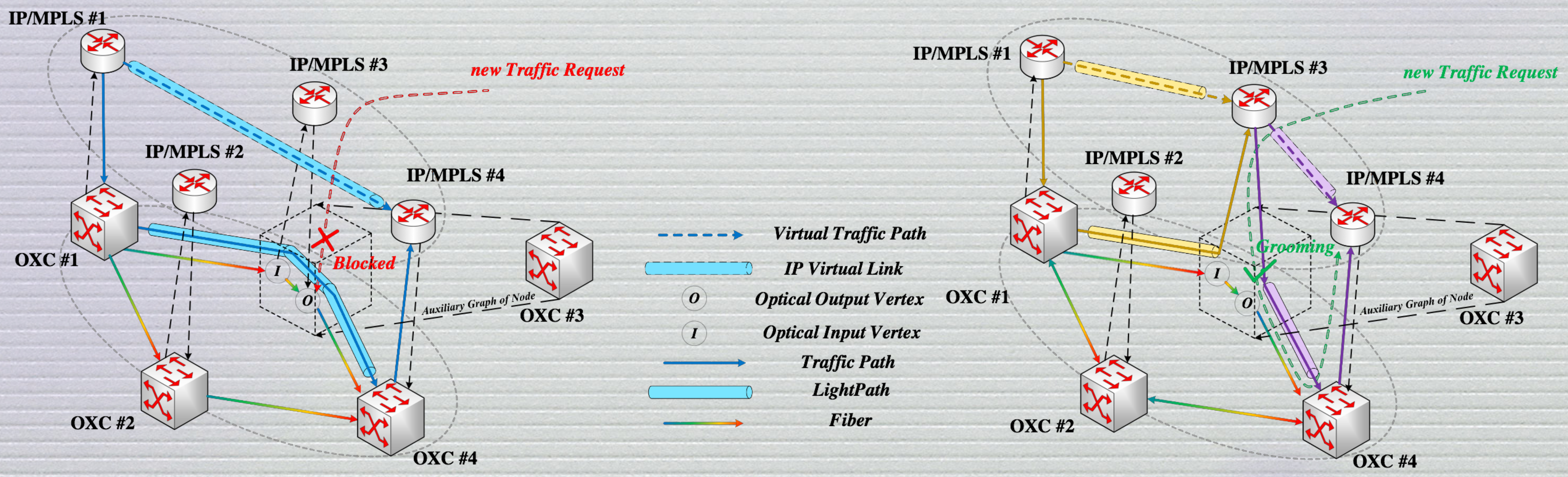
Motivation and Definitions

- **Tidal traffic:** traffic peak varies in both temporal and spatial domains.
  - *for example, most of the traffic are generated in workplace during the daytime, while at night the traffic concentrate at the residence.*
- **Tide-peak:** this node endures large amount of traffic load during a certain period of time.
- **Tide-valley:** this node endures little amount of traffic load during a certain period of time.
- Tide peak nodes may result in high blocking probability, and this problem need to be solved by enabling more access opportunities in tide-peak nodes.



TIDAL Scheme

- **T**raffic-aware **I**ntelligent **D**ifferentiated **A**llocation of **L**ightpaths
- tide-peak node: node under large traffic load
- tide-valley node: node under light traffic load
- **The network adopts MinTHV (transceivers more constrained) policy, except for the tide-peak nodes. If one node is selected as tide-peak node, then this node cannot be bypassed to make every wavelength-link of this node available for grooming.**

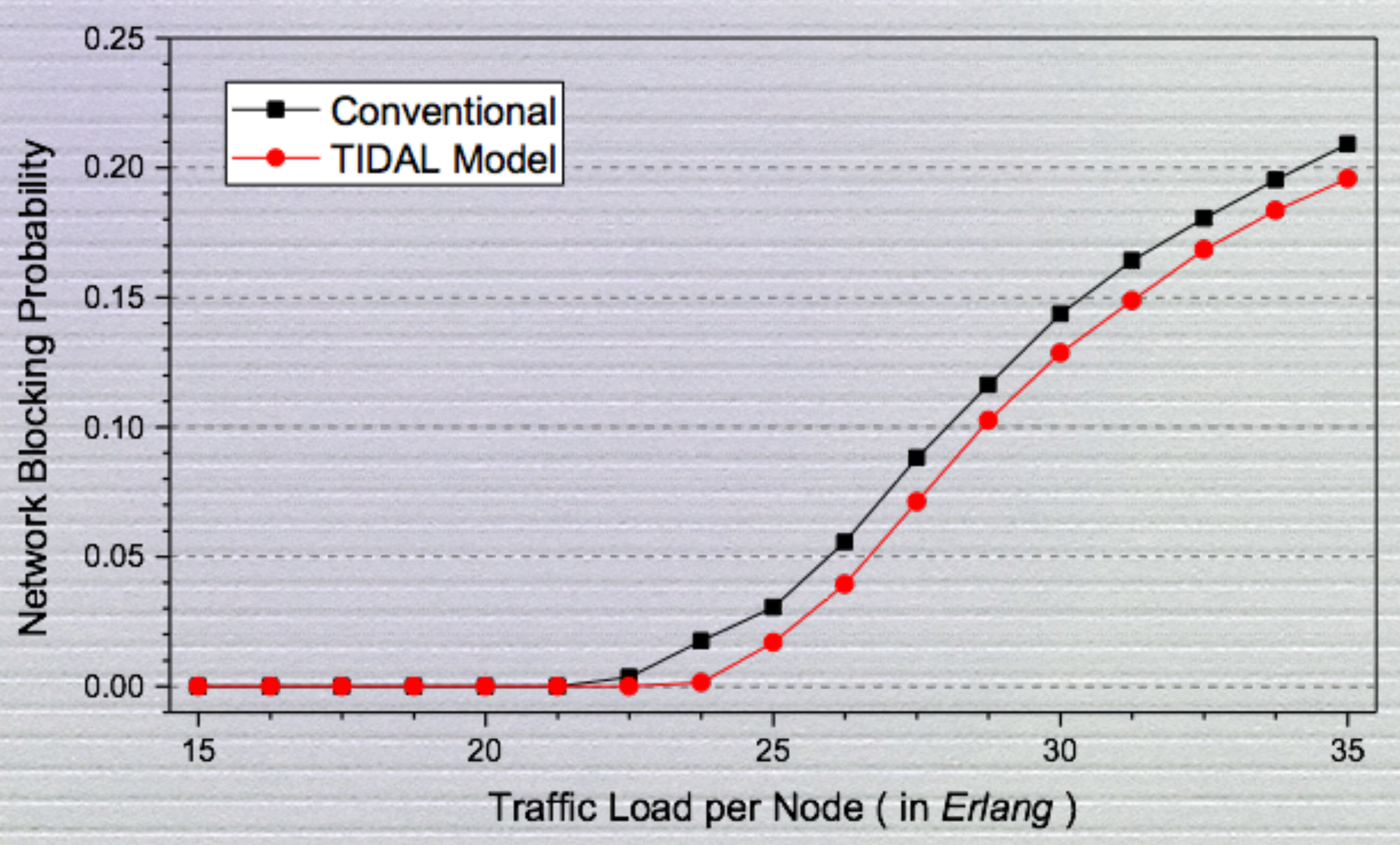


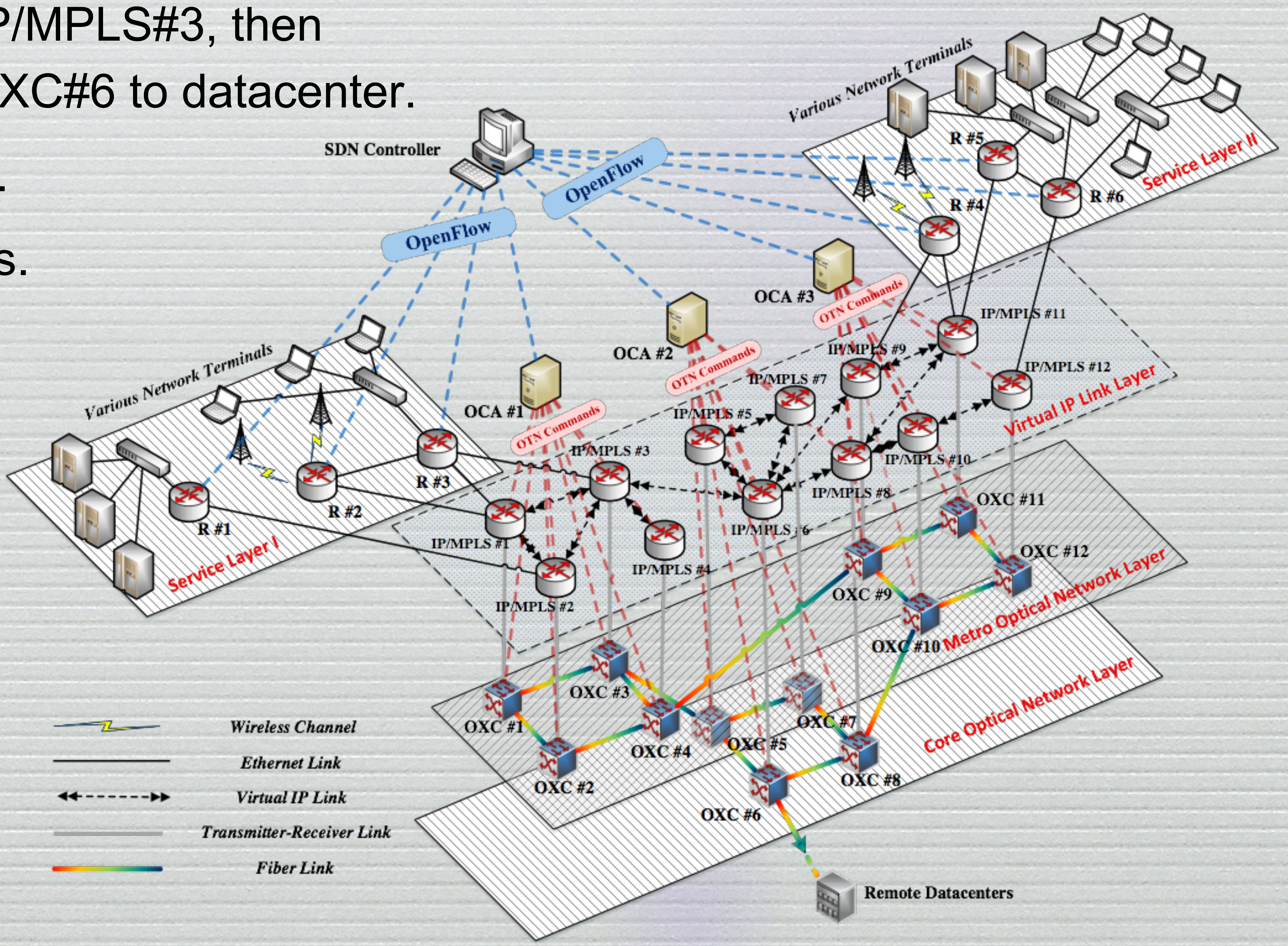
Conventional strategy in ***Tide-peak*** *areas (OXC#1-4 are* ***Tide-peak*** *nodes)*

TIDAL strategy in ***Tide-peak*** *areas (OXC#1-4 are* ***Tide-peak*** *nodes)*

Simulation and results

- Set service area I to be tide-peak and service area II to be tide-valley .
- Traffic scenario: the major traffic are generated in R#1, R#2, R#3 as well as aggregated into IP/MPLS#1, IP/MPLS#2, IP/MPLS#3, then groomed into the OXC layer and finally routed to OXC#6 to datacenter.
- 32 transceivers, bidirectional fiber, 16 wavelengths.
- Poisson arrivals, negative exponential holding times.





Publication

- Zhizhen Zhong, Nan Hua, Haijiao Liu, Yanhe Li, and Xiaoping Zheng, "**Considerations of Effective Tidal Traffic Dispatching in Software-Defined Metro IP over Optical Networks**", *Proc. IEEE OptoElectronic Communications Conference (OECC)*, Shanghai, China, Jun. 2015

- Extended version (next chapter) of this work is being discussed and prepared to submitted to a journal.

Chapter III:

Quasi-static stateful grooming with ILP formulation

(ongoing)

Problem analysis

In TIDAL scheme, the selection of tide-peak nodes is important to the result.

1. **Stateful grooming:**

   the node operates under different states, so we should formulate is state transition into FSM (finite state machine).

2. **Tide-peak nodes seletion:**

   - pros: make full use of lightpath for grooming, more access opportunities for tide-peak traffic.
   - cons: use more transceivers at tide-peak nodes and cause larger energy.

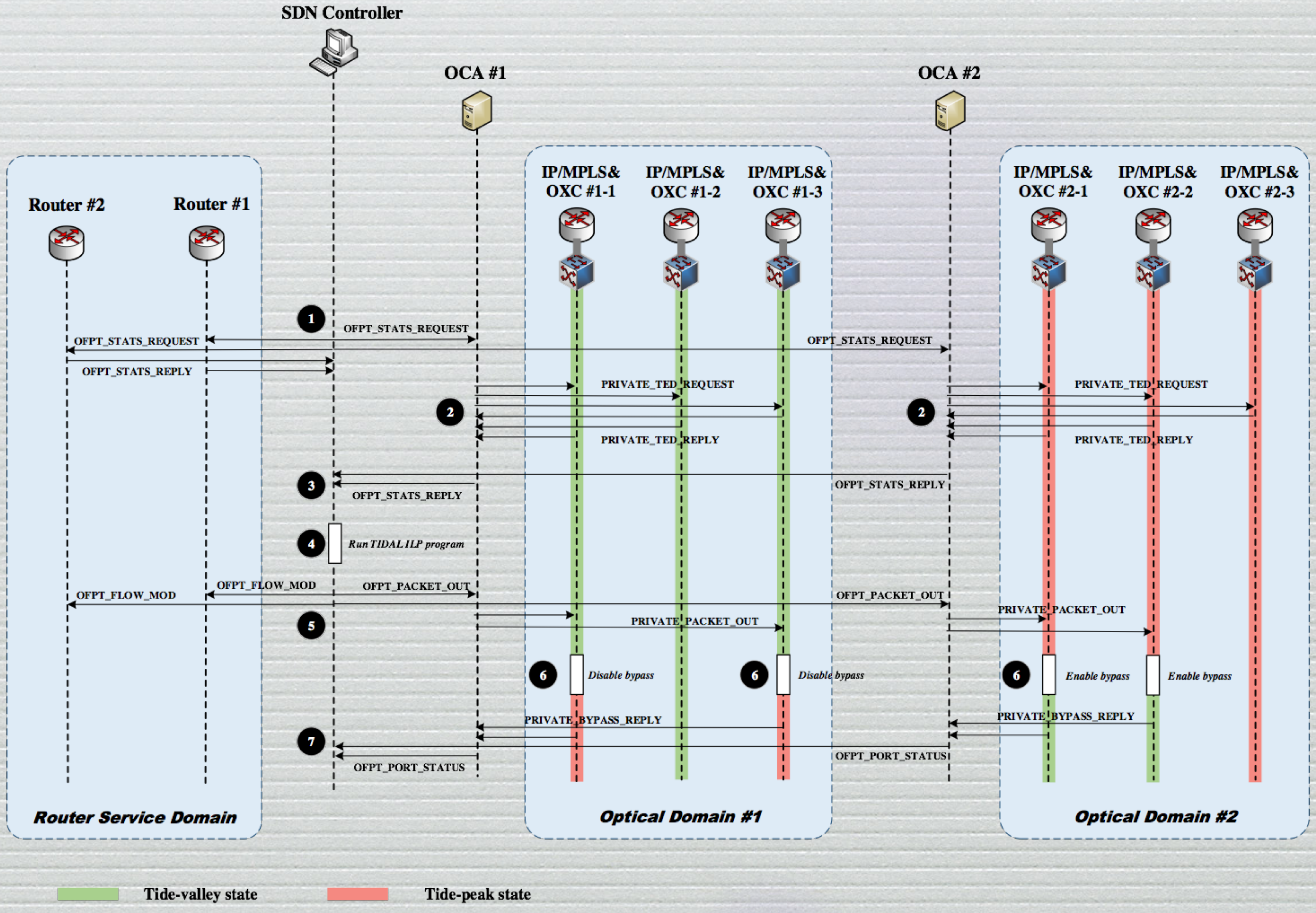
   So the selection of tide-peak nodes is an **multi-objective ILP optimization (network blocking probability vs. energy efficiency)** problem.

3. **Quasi-static algorithm and the trigger for restart**

   As the tide-peak is moving from the day to night, so the selection of tide-peak nodes acquired by multi-objective ILP should also be changed. Thus we apply the quasi-static stateful grooming, which will restart the multi-objective ILP if triggered. So the trigger of ILP is another problem to solve.

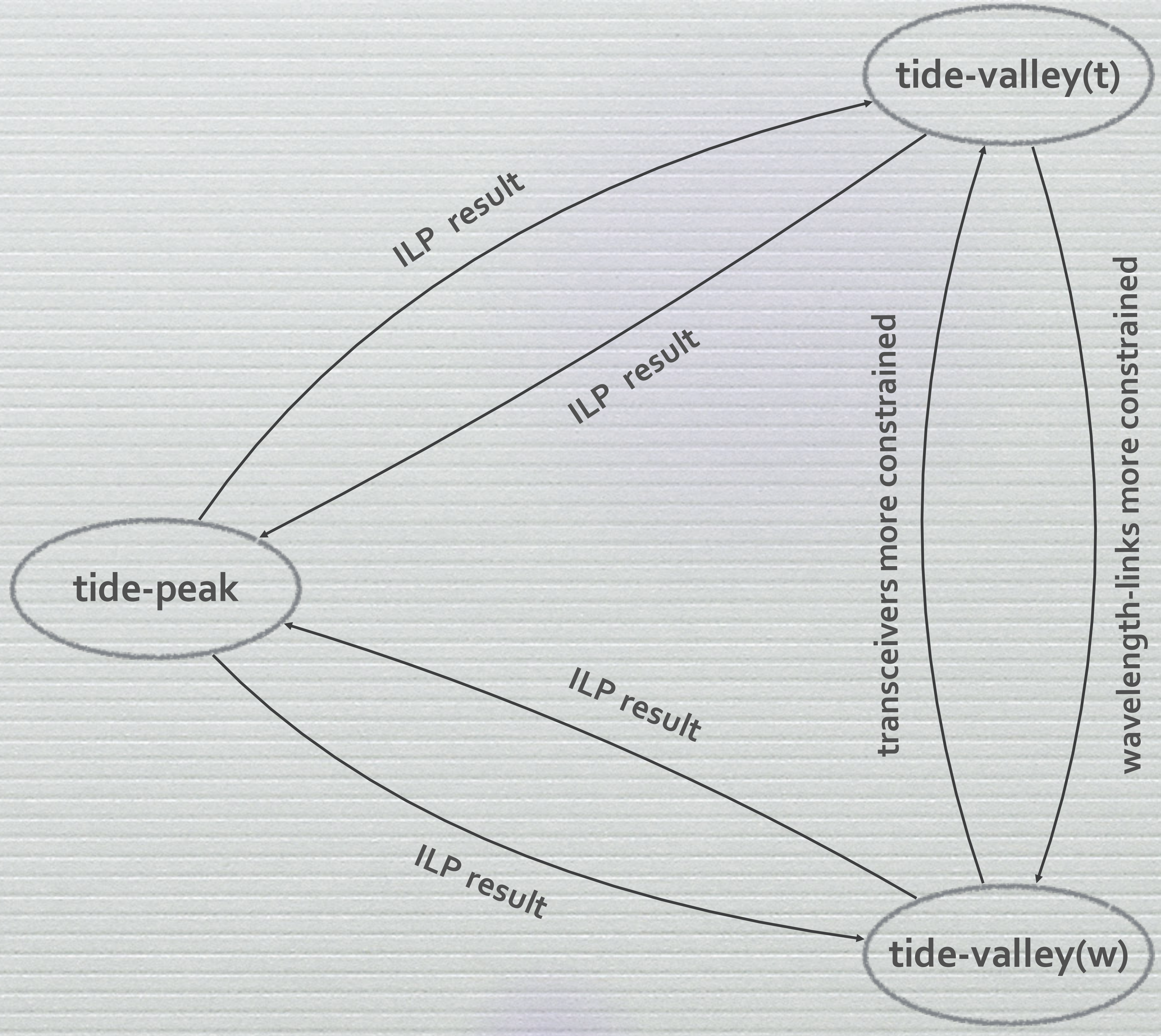
Stateful grooming

In stateful grooming, every node can shift the state of grooming policy independently, which means that the whole network enables multiple grooming policies at the same time. This stateful grooming is enabled by OpenFlow based on software-defined IP over optical networks architecture.



Stateful grooming

- **Stateful grooming:**
  - Tide-peak state: the node cannot be bypassed.
  - Tide-valley(t) state: the node adopts MinTHV if transceivers are more constrained
  - Tide-valley(w) state: the node adopts MinTHP if wavelength-links are more constrained.
  - more state to accommodate more complex traffic…?
- **State transition:**
  - ILP optimization takes much time.
  - can we transit the state of node without running ILP everytime?…pattern recognition and matching?…



Trade-offs: Energy efficiency vs blocking probability

- If one node is selected as tide-peak node, then there will be more chance for traffic to be groomed in the the lightpath, which enhance the network performance. However, as every lightpath cannot be bypassed and the transceivers will be highly utilized, there will also result in large energy consumption. So this is a Multi-Objective ILP problem:

Minimize:

network probability;

network energy consumption;

Constraint:

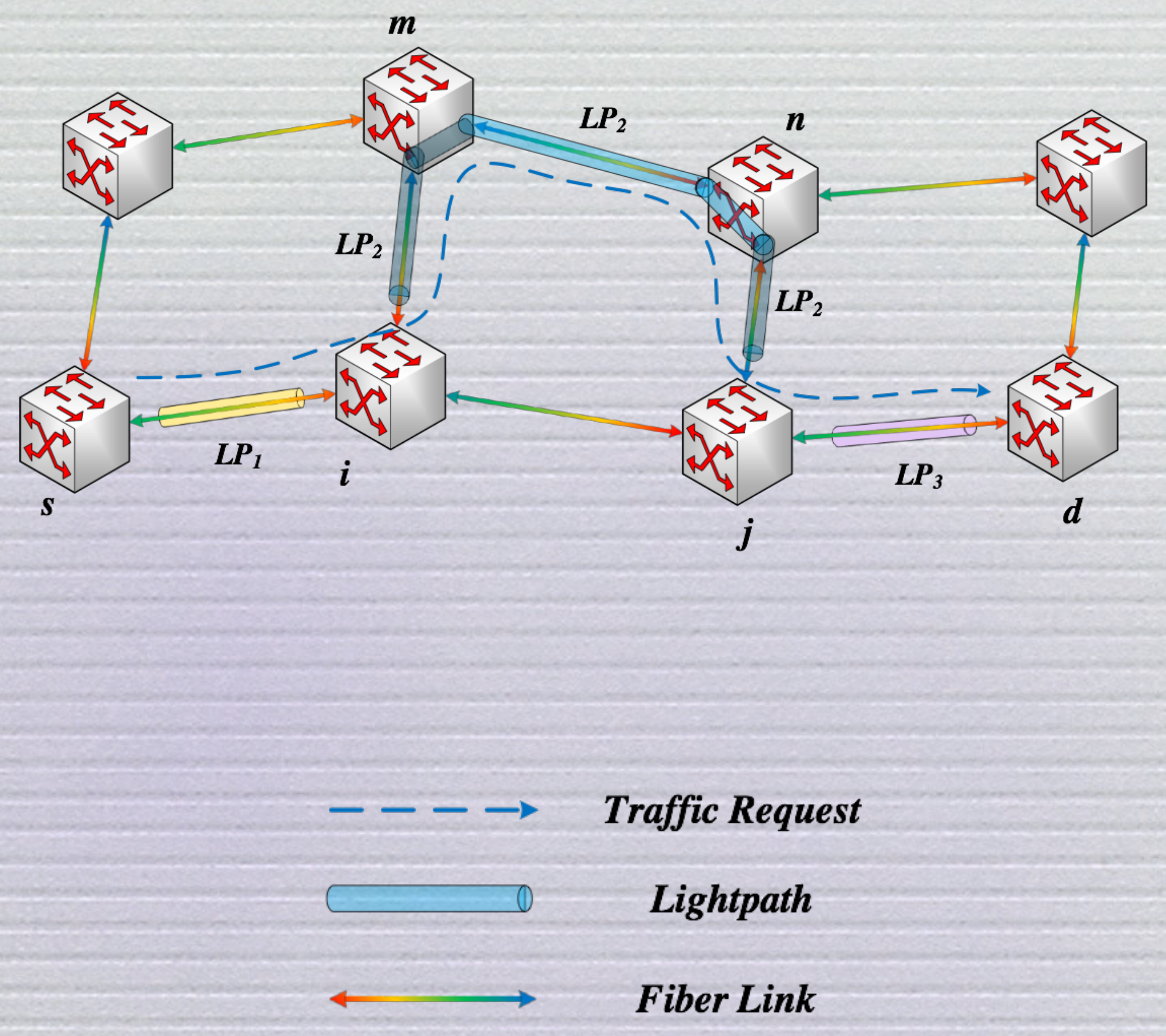
tide-peak nodes constraints;

static grooming constraints like flow conservation on virtual/physical topology, etc.;

We use the ***pareto front*** principle to transform the multi-objective ILP into single-objective ILP.

Besides, the network blocking probability (BP) can be measures in multiple ways considering the Service Level Agreement. For example, traffic service level weighed BP, traffic existing time weighed BP, traffic bandwidth weighed BP. And all these measurements have different optimization results.

Formulation



Given:

- $G(N, E)$: a physical topology, N denotes the set of nodes, and E denotes the set of edges composed of fiber links.
- $H(N, L)$: a virtual topology of the physical topology mentioned above, N denotes the set of nodes (same as the node set on physical topology), and L denotes the set of virtual edges composed of lightpaths.
- As depicted in Fig. 3, s, d denote the source and destination of an end-to-end traffic request, i, j denote the originating and terminating nodes for a lightpath, and m, n denote the end points of a physical fiber link that might occur in a lightpath.
- T: the set of traffic requests.
- B: the set of granularities of traffic requests.
- b_{sd}^t: the granularity of traffic request t between (s, d).
- W: numbers of wavelengths per fiber, and we assume that all the fibers carry the same number of wavelengths.
- F_{mn}: numbers of unidirectional fibers connecting from node m to node n.
- C: maximal capacity of each wavelength.
- $TR(n)$: number of transmitters inside node n.
- $RE(n)$: number of receivers inside node n.
- ρ: decision threshold for the tide-peak node selection.
- Π: the maximum number of tide-peak nodes.

Variables:

- π_x: binary decision variable, which takes the value of one if node x is selected as the tide-peak node.
- V_{ij}: integer variable, which denotes the number of lightpaths from node i to node j on virtual topology.
- V_{ij}^w: integer variable, which denotes the number of lightpaths from node i to node j on wavelength w.
- $P_{mn}^{ij,w}$: binary decision variable, which takes the value of one if lightpath (i, j) routed through fiber (m, n) on wavelength w.
- R_{sd}^t: binary decision variable, which takes the value of one if the traffic request t between (s, d) is successfully accessed.
- $\lambda_{ij,b}^{sd,t}$: binary decision variable, which takes the value of one if the traffic request t between (s, d) with granularity b employs lightpath (i, j) as an intermediate virtual link.

Optimize:

Maximize the total throughput of the network.

$$Maximize : \sum_{t \in T} b_{sd}^t R_{sd}^t \tag{1}$$

Constraints:

$$\pi_x \le \frac{\sum_{t \in T}(b_{xd}^t + b_{sx}^t)}{\rho} \quad \forall x \in N \tag{2}$$

$$\sum_{x \in N} \pi_x = \Pi \tag{3}$$

$$P_{mn}^{ij,w} \le 1 - \pi_m \quad if\ m \ne i, j \quad \forall w \in W \tag{4}$$

$$P_{mn}^{ij,w} \le 1 - \pi_n \quad if\ n \ne i, j \quad \forall w \in W \tag{5}$$

$$\sum_{j \in N} V_{ij} \le TR(i) \quad \forall i \in N \tag{6}$$

$$\sum_{i \in N} V_{ij} \le RE(j) \quad \forall j \in N \tag{7}$$

$$\sum_{w \in W} V_{ij}^w = V_{ij} \quad \forall i, j \in N \tag{8}$$

$$\sum_{m \in N} P_{mi}^{ij,w} = 0, \quad \forall i, j \in N \quad \forall w \in W \tag{9}$$

$$\sum_{n \in N} P_{jn}^{ij,w} = 0, \quad \forall i, j \in N \quad \forall w \in W \tag{10}$$

$$\sum_{m \in N} P_{mj}^{ij,w} = V_{ij}^w, \quad \forall i, j \in N \quad \forall w \in W \tag{11}$$

$$\sum_{n \in N} P_{in}^{ij,w} = V_{ij}^w, \quad \forall i, j \in N \quad \forall w \in W \tag{12}$$

$$\sum_{m \in N} P_{mk}^{ij,w} = \sum_{n \in N} P_{kn}^{ij,w}, \quad if\ k \ne i, j \quad \forall i, j, k \in N \quad \forall w \in W \tag{13}$$

$$\sum_{i,j \in N} P_{mn}^{ij,w} \le F_{mn}, \quad \forall m, n \in N \quad \forall w \in W \tag{14}$$

$$\sum_{i \in N} \lambda_{id,b}^{sd,t} = R_{sd}^t, \quad \forall s, d \in N, b \in B, t \in T \tag{15}$$

$$\sum_{j \in N} \lambda_{sj,b}^{sd,t} = R_{sd}^t, \quad \forall s, d \in N, b \in B, t \in T \tag{16}$$

$$\sum_{i \in N} \lambda_{is,b}^{sd,t} = 0, \quad \forall s, d \in N, b \in B, t \in T \tag{17}$$

$$\sum_{j \in N} \lambda_{dj,b}^{sd,t} = 0, \quad \forall s, d \in N, b \in B, t \in T \tag{18}$$

$$\sum_{i \in N} \lambda_{ik,b}^{sd,t} = \sum_{j \in N} \lambda_{kj,b}^{sd,t}, \quad if\ k \ne s, d \quad \forall s, d, k \in N \quad \forall t \in T \tag{19}$$

$$\sum_{t \in T} b_{sd}^t \lambda_{ij,b}^{sd,t} \le V_{ij} C, \quad \forall i, j \in N \tag{20}$$

Quasi-static Grooming Algorithm

As the peak of the tidal traffic shifts, the static ILP optimization results can only be maintained for a certain period of time, so we need to repeat the running of the ILP at a certain time interval during the day. Our work in this chapter is to measure the optimal time period between two adjacent ILP running. And the stateful grooming is further described as quasi-static stateful grooming.

So how to decide when to restart the running of ILP?
We need a trigger criteria…

Quasi-static Grooming Algorithm

Here we define the concept, Degree of traffic disequilibrium (DTD),

$$DTD_t = \frac{\sum_{\forall i,j \in N} \left| {load_i}^t - {load_j}^t \right|}{2m}$$

- here, DTD_tmeans the DTD at moment t, ${load_i}^t$means the traffic load at node *i* at moment t, *m* means the estimation value of the maximum of $\sum_{\forall i,j \in N} \left| {load_i}^t - {load_j}^t \right|$ according to the traffic history in the past, specially, this estimation value is different between weekdays and weekends.
- If DTD_t is beyond a threshold ε, then the program of multi-objective ILP will be performed, if DTD_t is below the ε, then all nodes will stay in tide-valley grooming state and saving energy.
- Thus we make a quasi-static stateful grooming scheme and provide a solution for the trigger of grooming state transition.

Chapter IV:

Future work

Future work

Convergence of optical-access and wireless networks for tidal traffic.

- Perhaps the re-formulation of VPONs, and the allocation of VPON in C-RAN architecture to achieve traffic adaptability and energy efficiency.
- more…

Thanks for your attention!