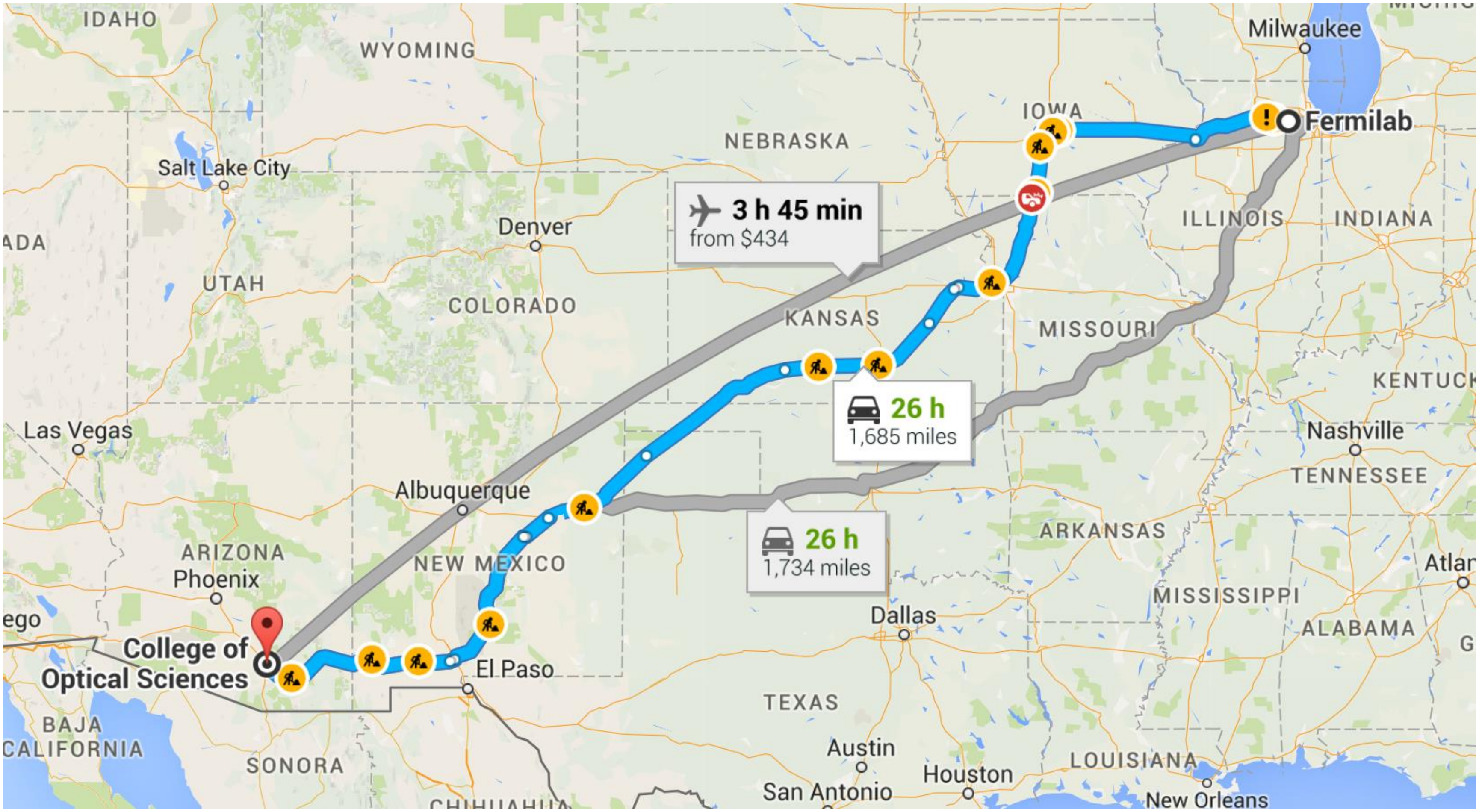
TURBO: Terabits/s Using Reconfigurable Bandwidth Optics

Dan Kilper, Madeleine Glick UA
Keren Bergman Columbia University

February 18, 2016

ARIZONA
LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY
CIAN

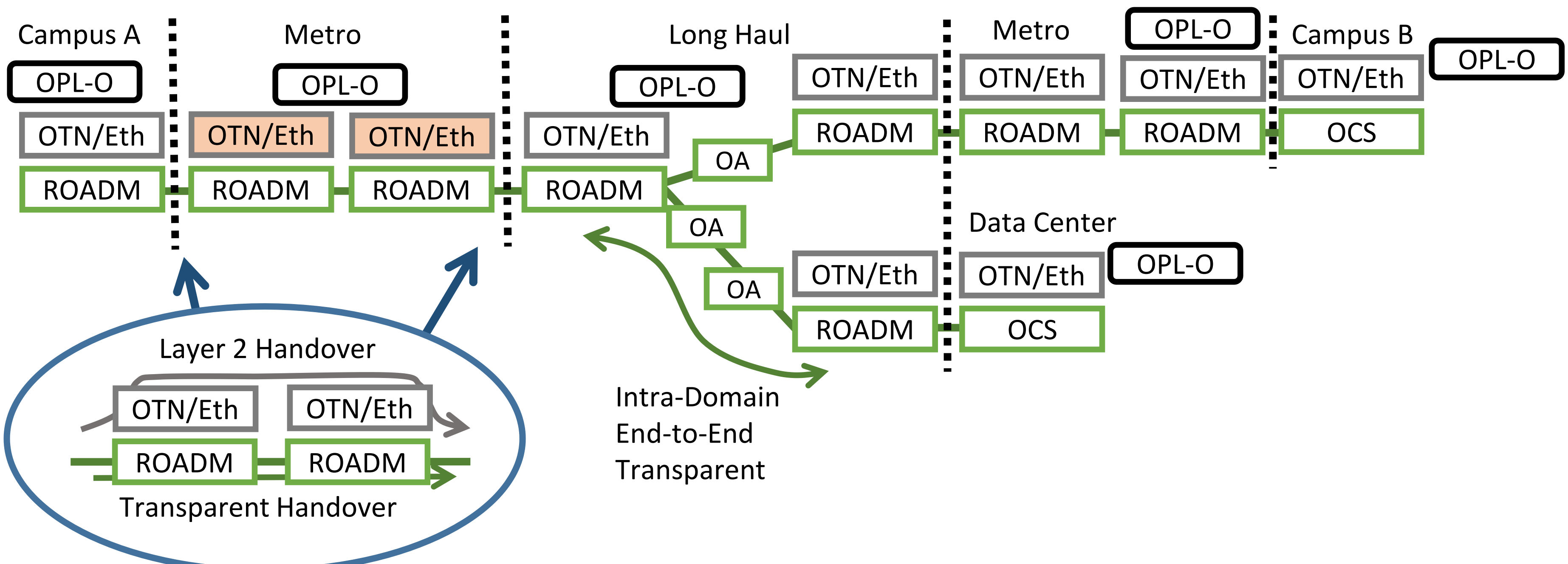
Adding Airlines to Google Maps



ARIZONA LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY CIAN

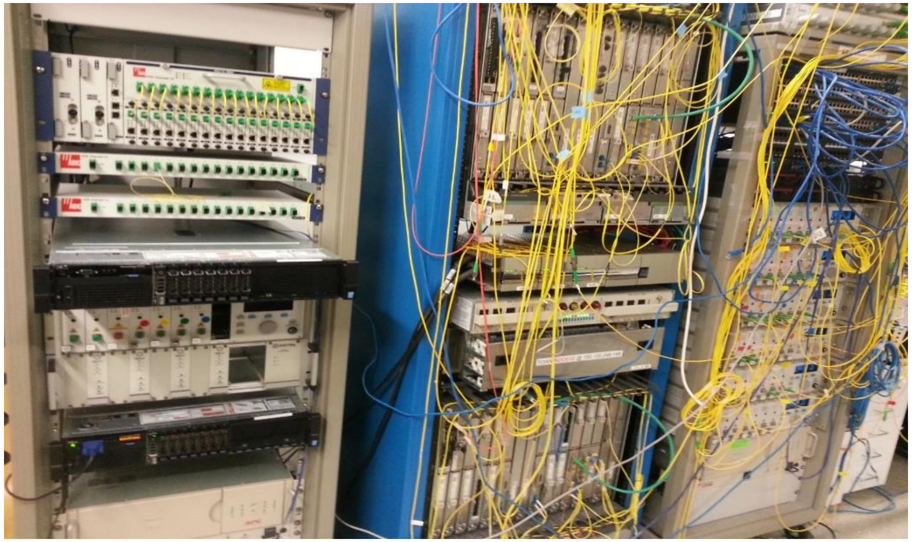
TURBO Concept

- Develop SDN control methods to establish end to end intra domain flexible optical spectrum paths
  - Layer 2 inter-domain connections
- Develop transparent cross-domain handover methods
- Create optical physical layer orchestrator



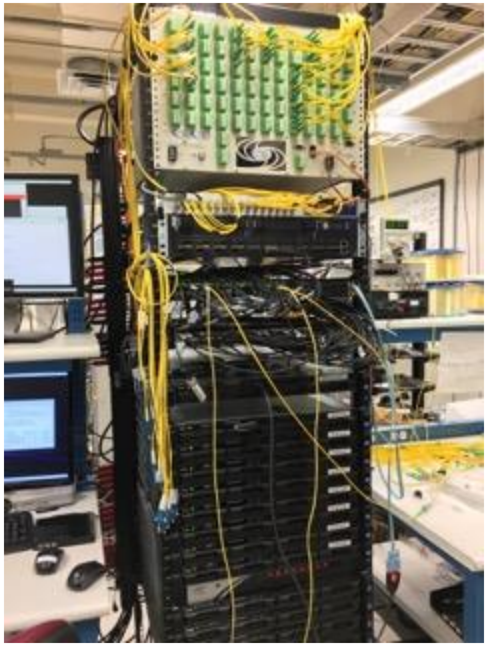
Team

- University of Arizona
  - D. Kilper
  - M. Glick
  - Transparent Optical Aggregation Networks Testbed
    - 30 Gbaud coherent modulation
    - Mesh network emulation platform
- Columbia University
  - K. Bergman
  - Lightwave Research Lab
    - Inter-data center testbed
- CIAN: Center for Integrated Access Networks
  - NSF ERC, 18 Industry members, 8 Universities



Arizona TOAN Lab

Columbia LRL Data Center Testbed

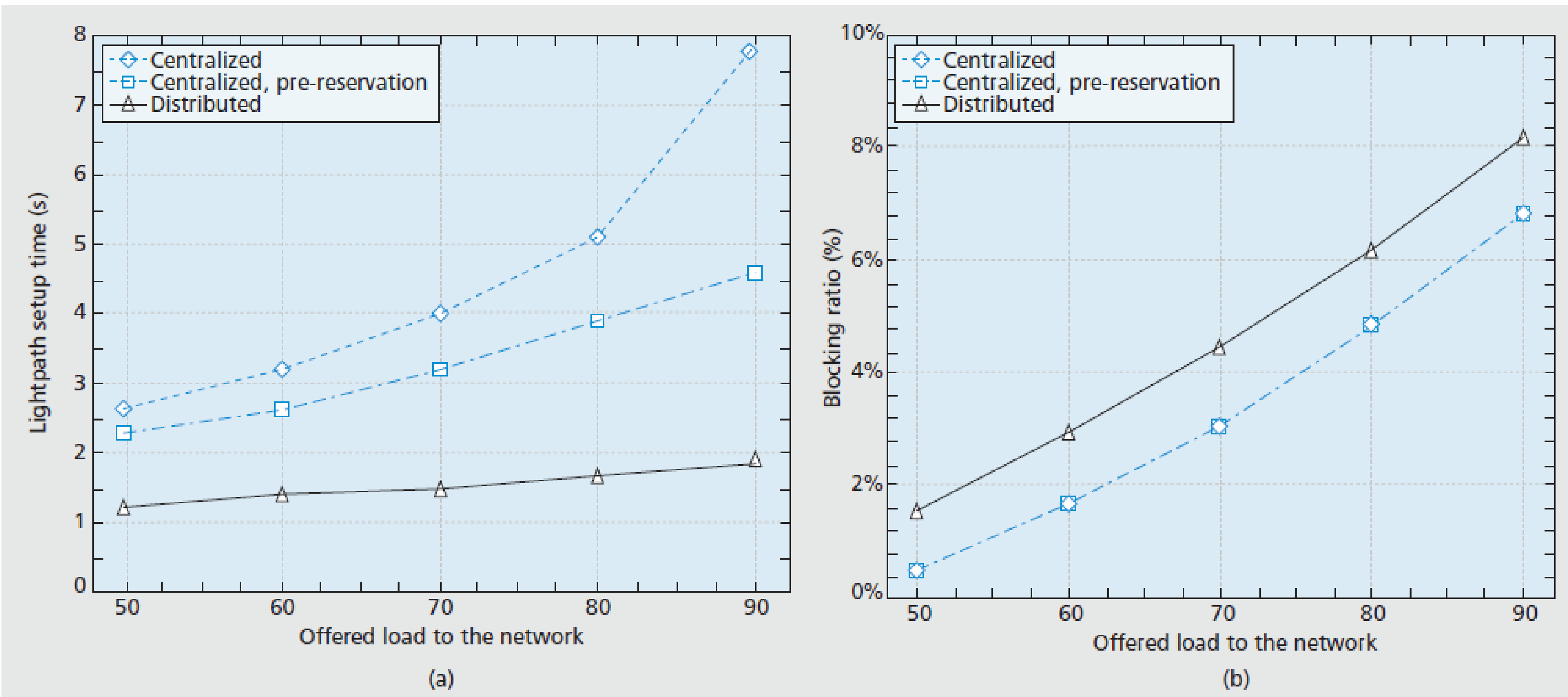


LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY

CIAN

Lightpath Configuration Time

Does not include physical device control and tuning delays from physical setup



Computation, signaling, and protocol part: ~ 1 second

CORONET: 700ms

DICONET Project, Angelou, et. al. IEEE Comm Mag. 2012

Optical Switches, but no optical switching networks

Infinera record:

8 Tb/s provisioned in 19 minutes

- 16 channels
- Over pre-determined path Amsterdam to Hamburg

"Optical burst switch developer Intune Networks in receivership" – Lightwave Mag.

www.guinessworldrecords.com

ARIZONA

LIGHTWAVE RESEARCH LABORATORY
COLUMBIA UNIVERSITY

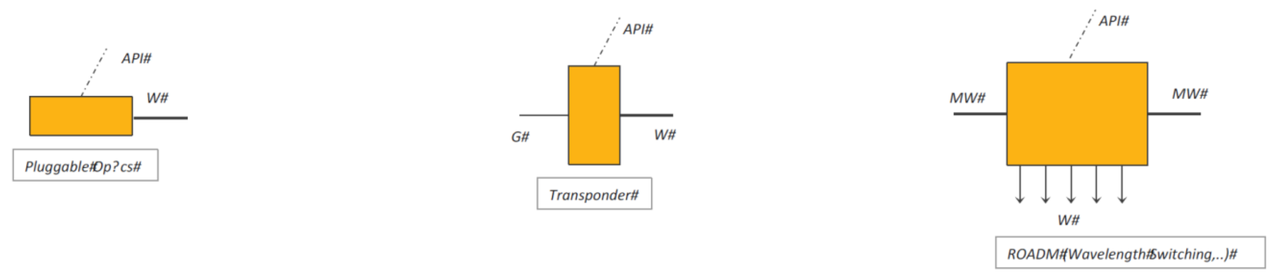
CIAN

ON Lab, AT&T: Want White Box Programmable ROADMs

Disaggregated ROADMs

Proposed Optical Functions in "White Box"

- We want to standardize the framework for optical functions
  - Multi-vendor, Interchangeable, inter-workable components supporting standard APIs for control
- Pluggable optics: Fully open to pluggable optics , used in a ROADM system or packet element, independently controllable
- Transponder: Fully open to pluggable optics on client and line; Interoperable with other vendors/pluggables on line side
- ROADM: Open, flexible interoperable ROADM; Multi-vendor in a Metro; Individually controllable CD or CDC



G: Grey (client, well covered in standards) W: Wavelength MW: Multi-Wavelength

6"

Martin Birk, Mehran Esfandiari, Kathy Tse, "AT&T's direction towards a Whitebox ROADM," ONS 2015.

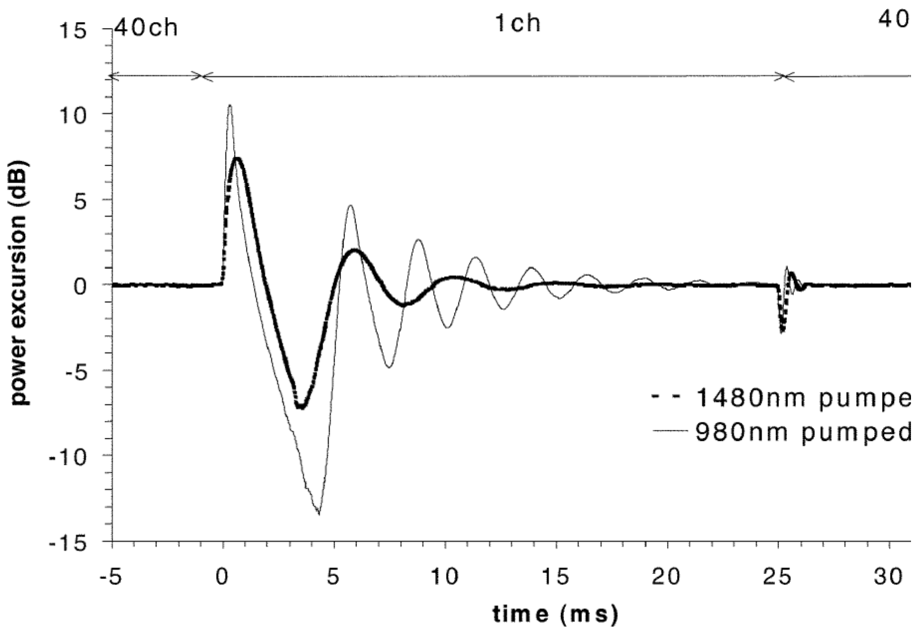
Optical Power Dynamics: Unsolved

- Network problem not an amplifier problem
  - Present even for perfect constant gain control
- Only a problem for optical transmission with real-time wavelength switching
- Power dynamics, similar to noise performance, polarization effects, nonlinear impairments, must be addressed and lead to a trade off between cost and performance
- Higher performance (less dynamics) leads to higher cost
  - Better/more components
  - Better/more complex control algorithms

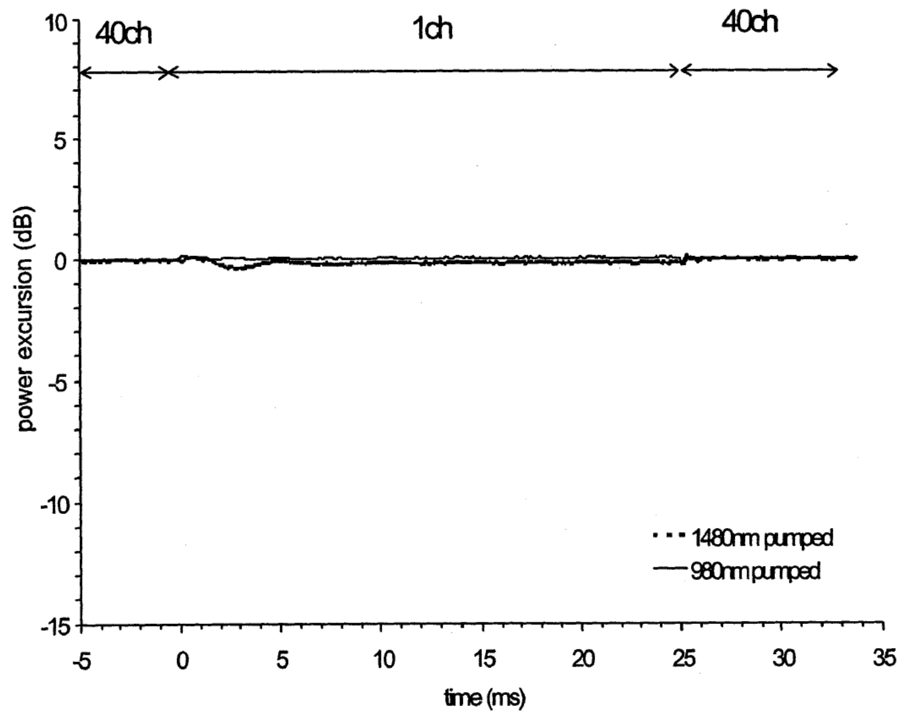
ARIZONA LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY CIAN

Optical Transients: Solved Problem

- Single EDFA problem
- Fast Feedforward Control & Nonlinear Feedback



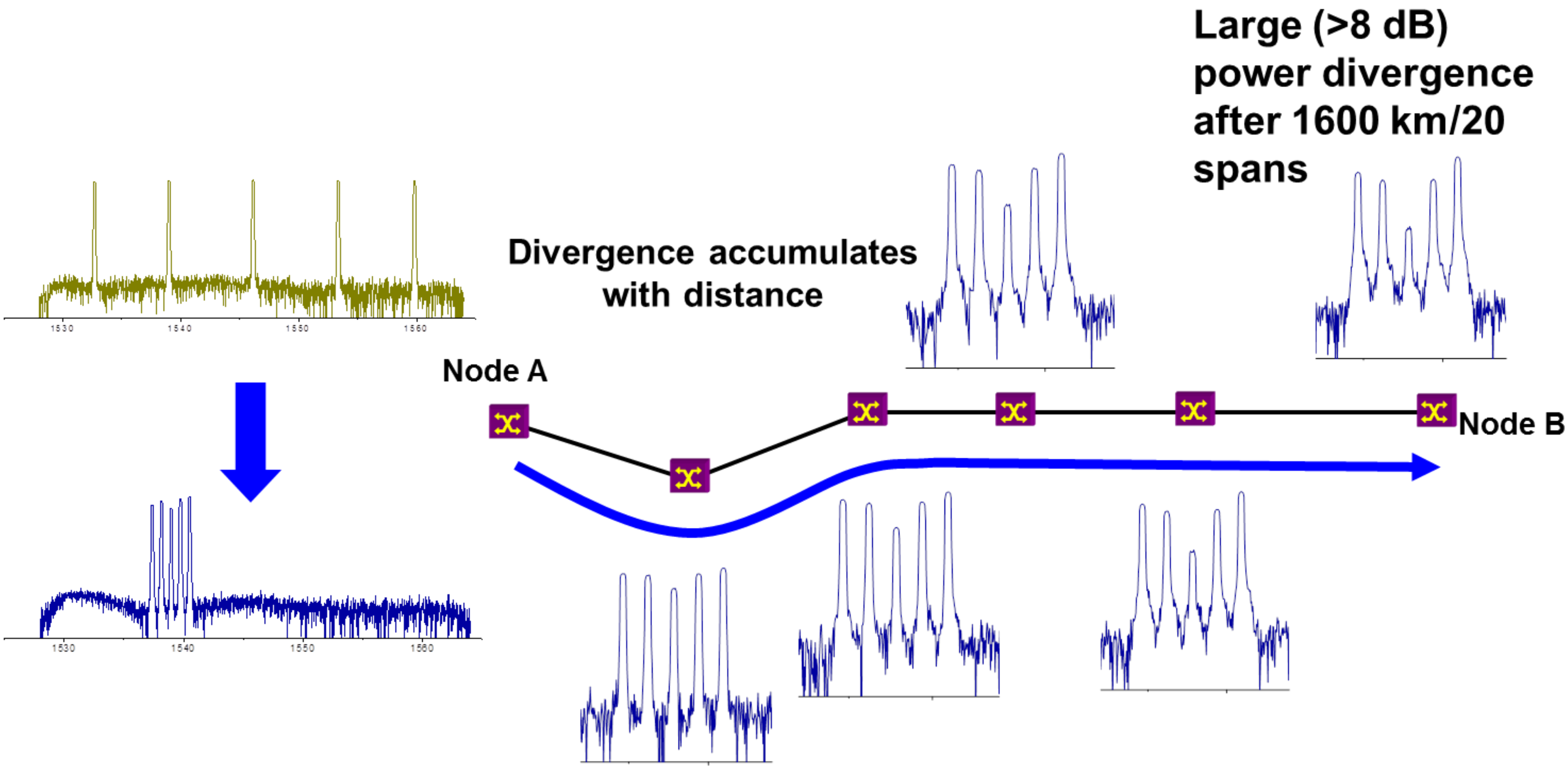
No Feedforward



With Fast Feedforward

Tian & Kinoshita, JLT 2003

Optical Power Dynamics



F. Smyth, et. al. JLT 2009

TURBO Goals

- Realize a white box optical transmission system control system
  - Only proprietary today
  - Allow researchers to program new algorithms and investigate new abstractions

- Realize a programmable and transparent SDX
- Demonstrate end to end intra- and inter-domain flex grid transparent path creation using these new capabilities

- In each case these are v1.0 implementations to open the door for further development and promote opening up of transmission systems

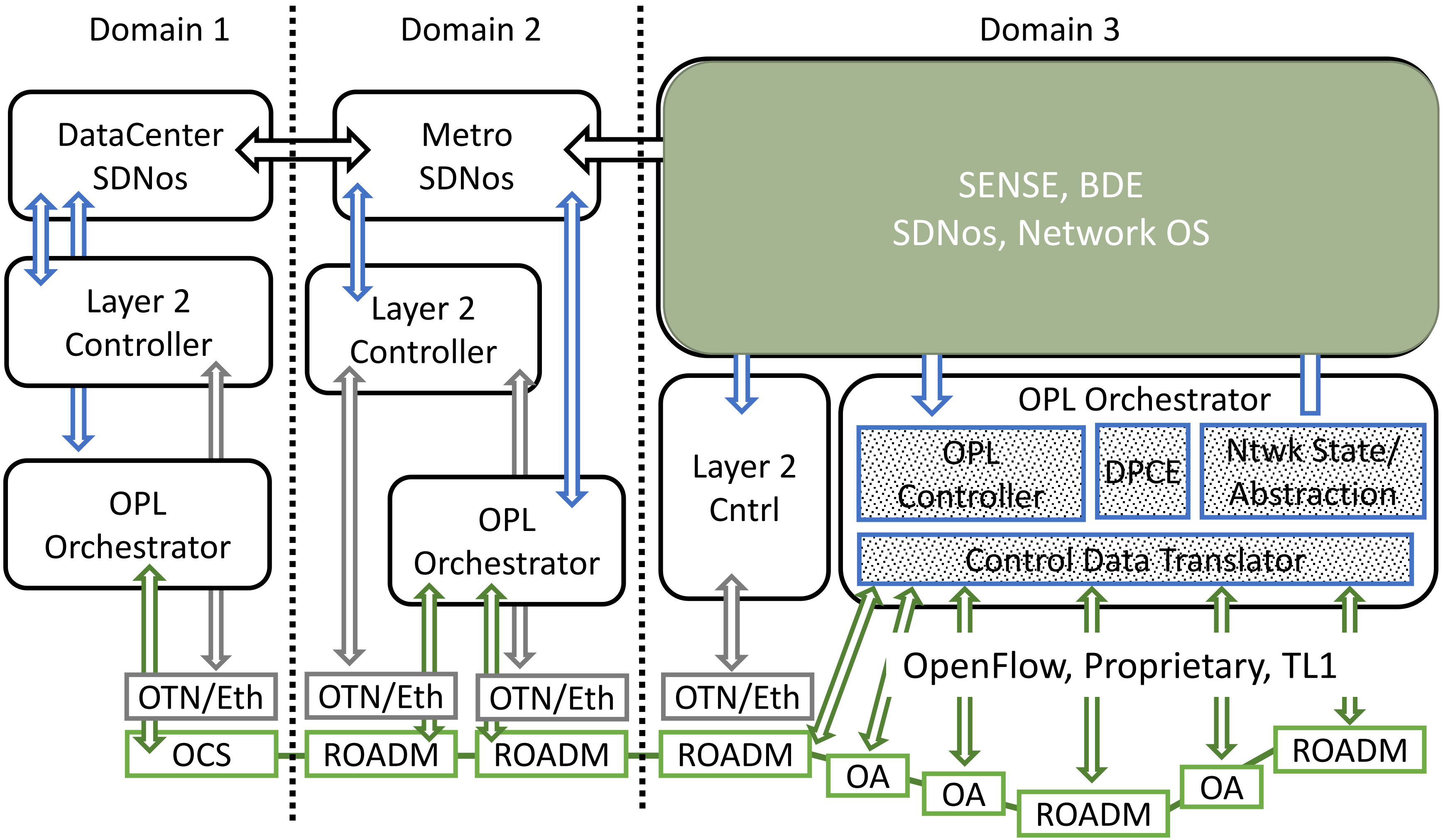
TURBO Impact

- Bring optical transmission system (ROADM) control into research domain
  - Don’t expect commercial systems to ever be entirely open, but this approach enables experimentation of where that line should be drawn

- Enables White Box ROADMs, Disaggregated ROADMs, etc.
  - Stimulate new area of research
  - Promote creation of SDN interfaces in optical elements
  - Enable demonstrations (ON Lab) to include optical trans.
  - Encourage system vendors to open up their products to more programmability

ARIZONA
LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY
CIAN

OPL-O: Optical Physical Layer Orchestrator



ARIZONA LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY CIAN

Role of OPL Orchestrator

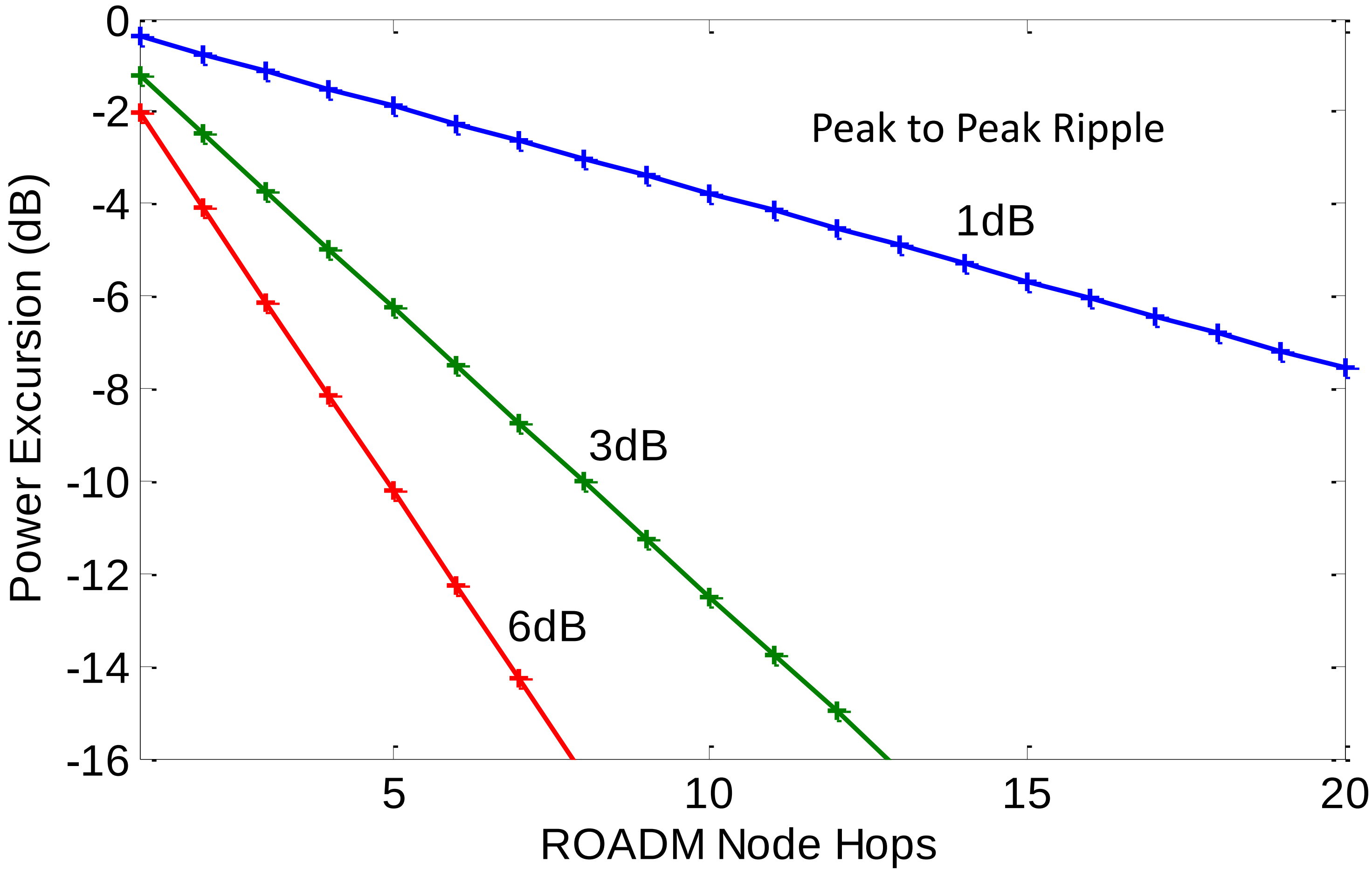
- Control diverse set of optical transmission hardware to operate network
  - Provision channels
  - Tune amplifiers
  - Tune channel powers
  - Manage faults, e.g. node loss, transient recovery
  - Defragmentation
  - Real time route selection*
  - Real time elastic bandwidth/flex grid management*
  - Wavelength layer protection
  - ….

Current propriety solution

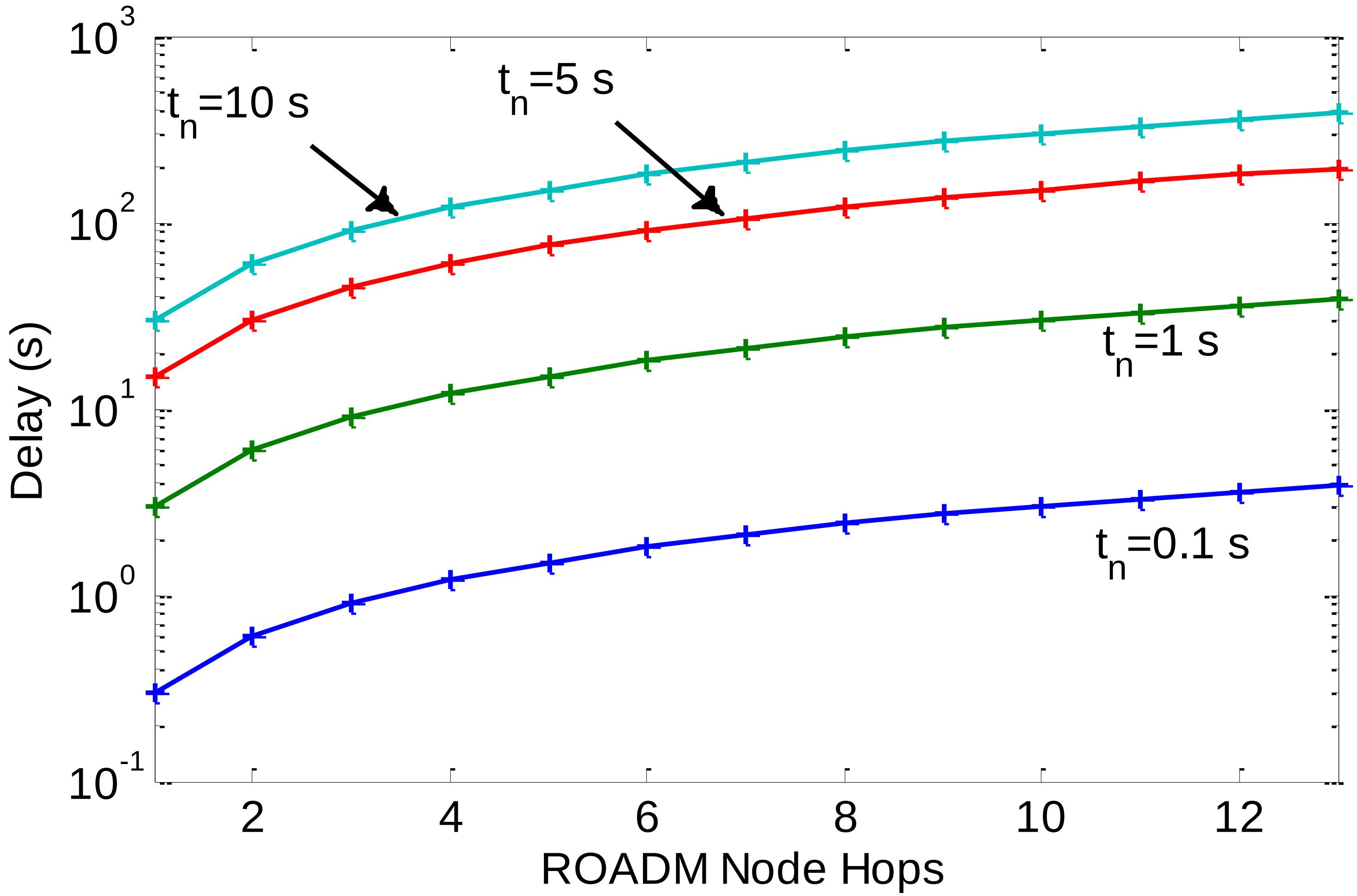
Future

Worst Case Power Excursion: Remove 1 Chn

Consider accumulated ripple between ROADM nodes: 3-4 dB
Channels flattened at each ROADM in steady state



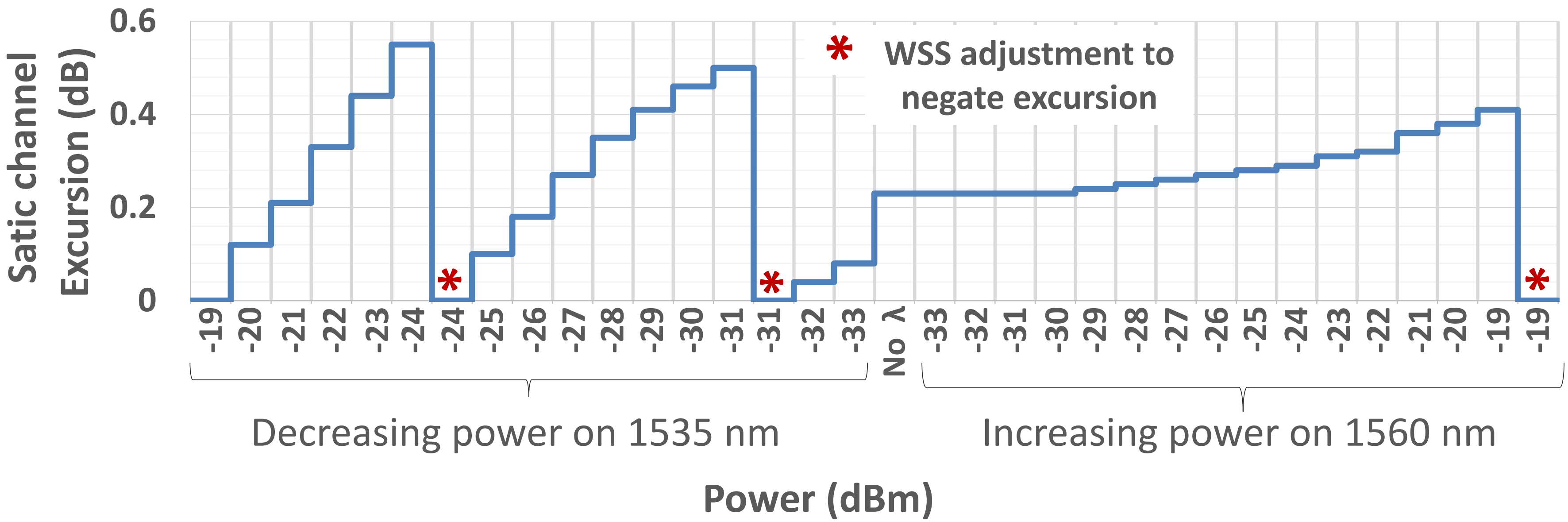
Delay Accumulation with Node Hops



te=2tn, ΔP_{ref} = 1 dB, 3 dB ripple

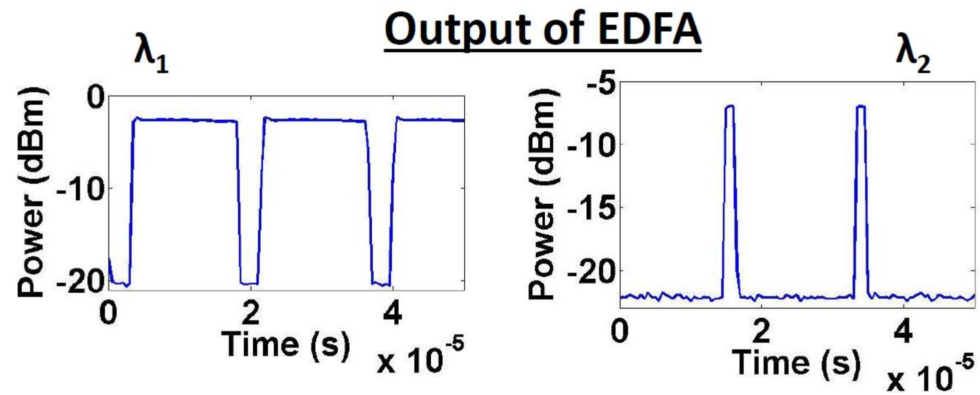
Wavelength Switching: Step by Step

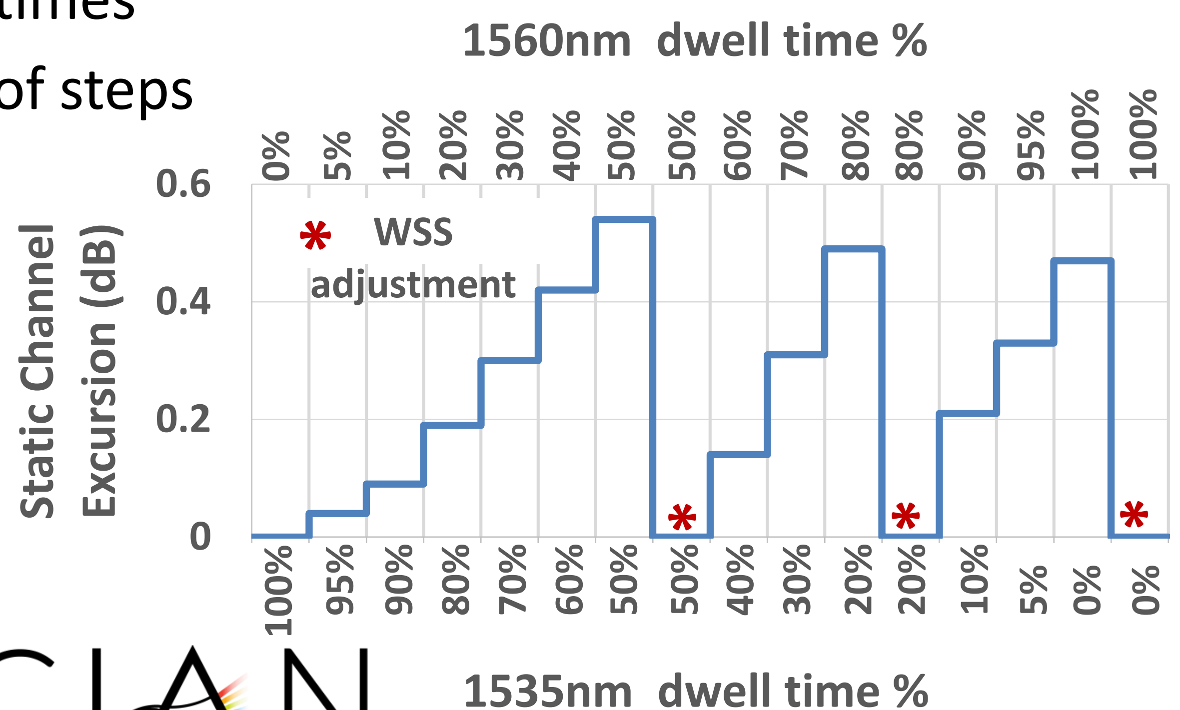
- Open channel and bring up/down slowly



Wavelength Switching: Fast Tunable Laser

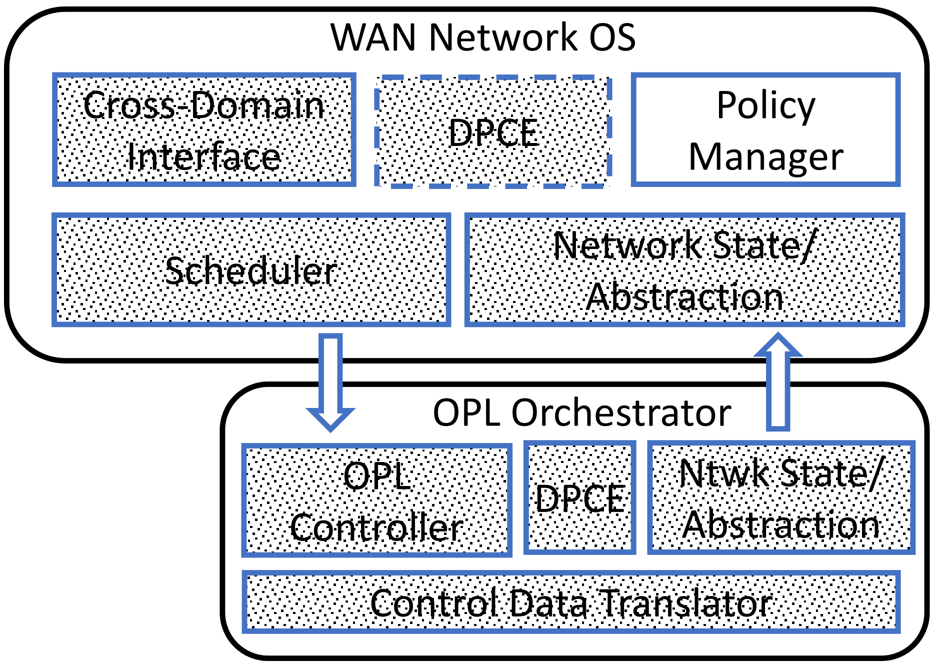
- Switch laser faster than EDFA response time
- Vary dwell time on each wavelength
- Full power at all times
- Reduce number of steps





SDN Control Plane

Z. Wang JLT 2014



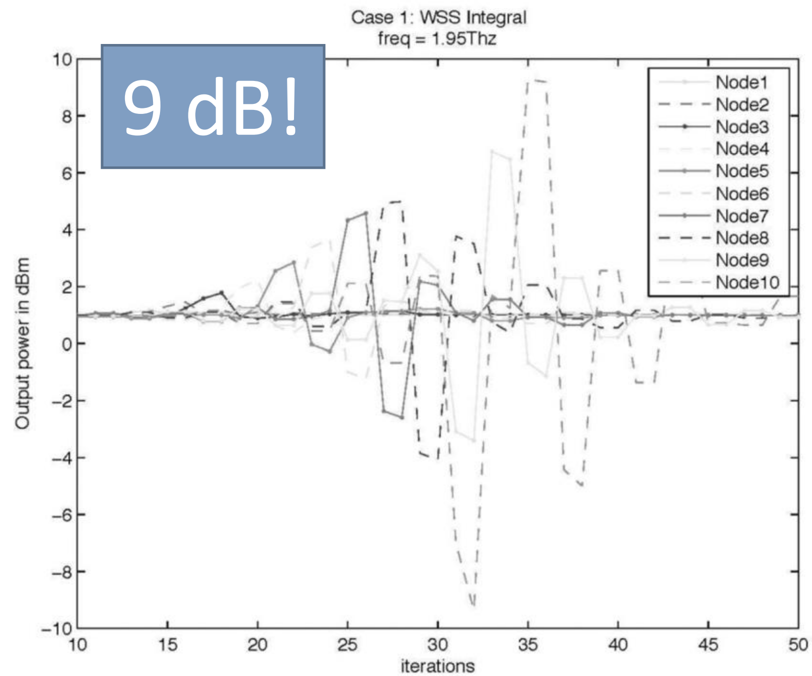
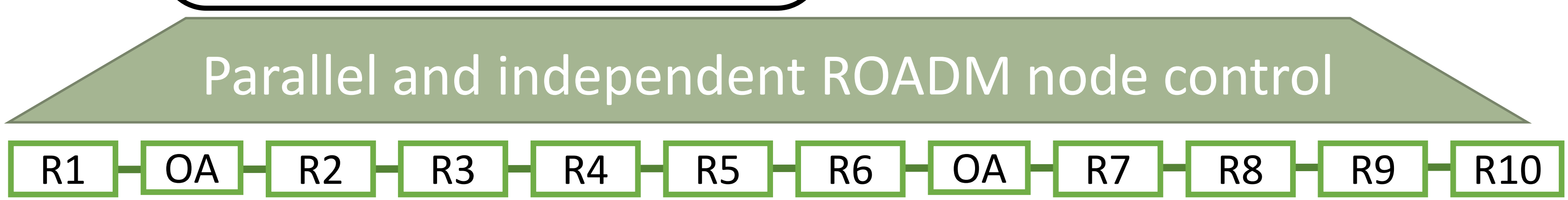


Fig. 10. Scenario 1 with WSS Integral Control (10 nodes).

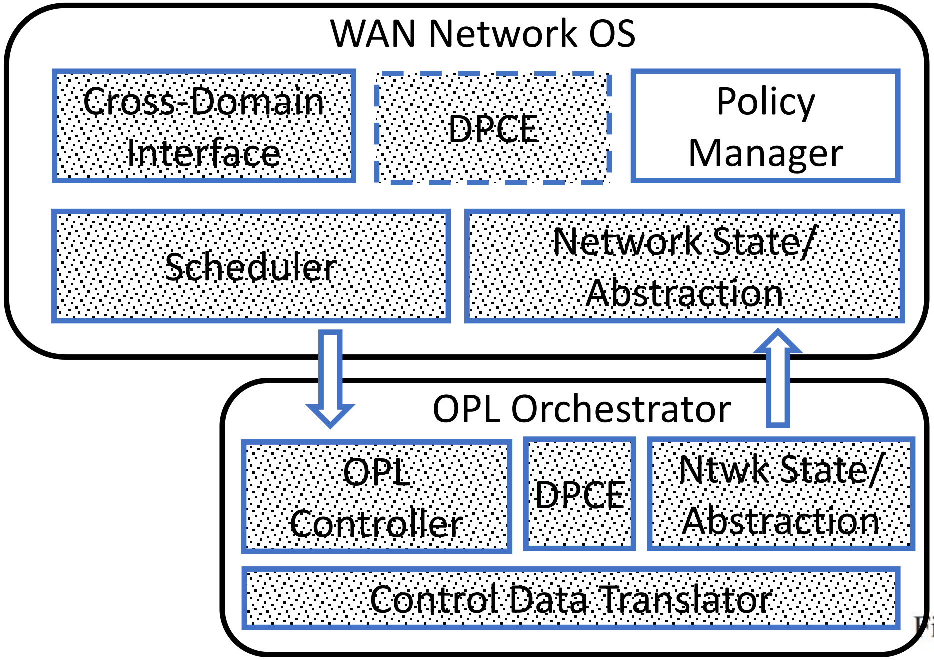


Factors that Impact Power Dynamics

- Order and timing of node adjustments
- Node control algorithm
- Channel loading and configuration
- Timing of wavelength switching
- Wavelength Route Characteristics

SDN Control Plane

Z. Wang JLT 2014



<2.5 dB!

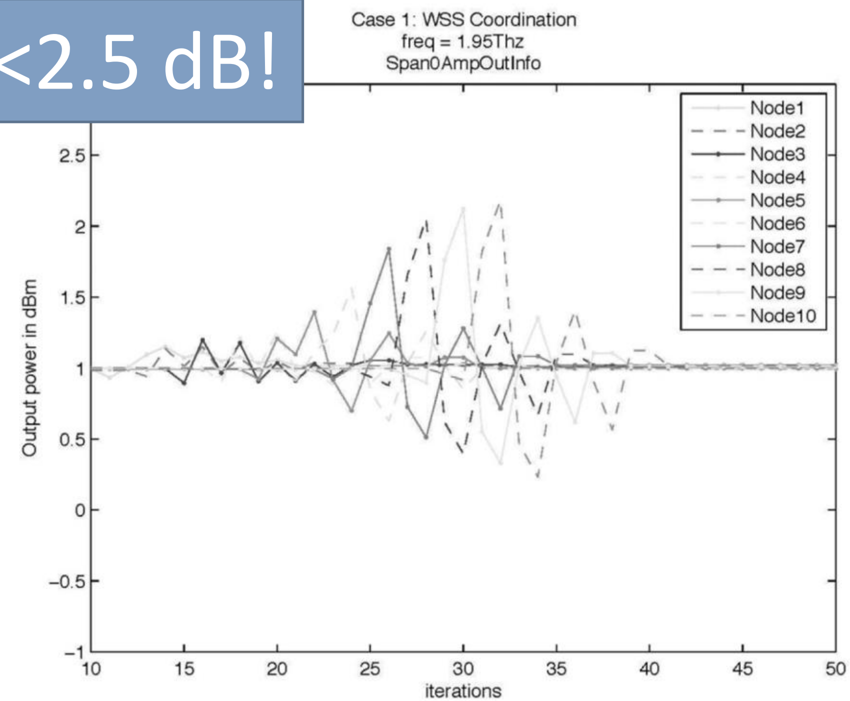
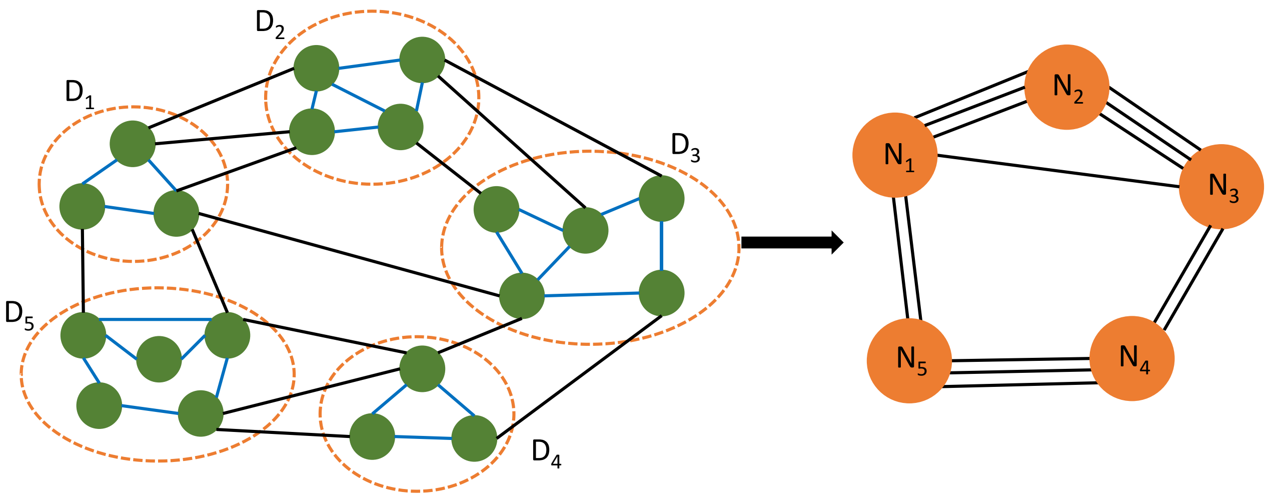


Fig. 11. Scenario 1 with modified WSS control (10 nodes).

Appropriate Abstractions for OPL?

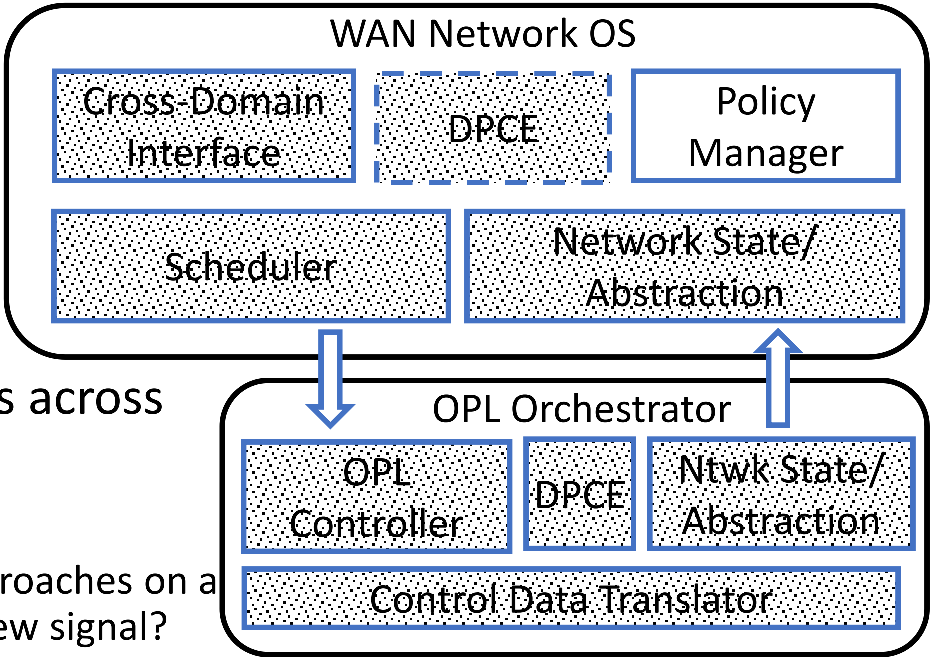
- Layer 2/Ethernet switch: details are hidden, complexity goes to OPL
  - Problem: Only works for small networks, large margins
  - Problem: wavelength blocking, reach and power dynamics



- Network Models: a network of five nodes with multiple ports
  - Stable reconfiguration using OPL orchestrators for each domain
  - Colored ports: BW, latency, setup time, osnr, …

ARIZONA
LIGHTWAVE RESEARCH LABORATORY
COLUMBIA UNIVERSITY
CIAN

OPL Orchestrator

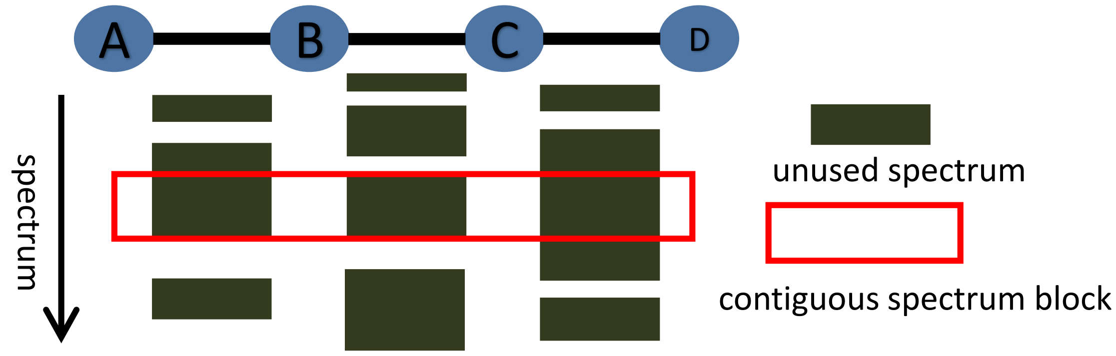


- OPL Controller
  - Implements flexgrid assignments across many nodes and switches
    - Tuning of WSS controls
      - What happens when a filter encroaches on a live signal to allow room for a new signal?
- Dynamic PCE
  - Rules and logic for spectrum assignment and path selection
- Abstraction Model
  - Representations of available spectrum and paths throughout network
- Cross-Domain Interface
  - What spectral information gets shared?
  - How to represent path dependent spectral information between domains?

ARIZONA
LIGHTWAVE RESEARCH LABORATORY COLUMBIA UNIVERSITY
CIAN

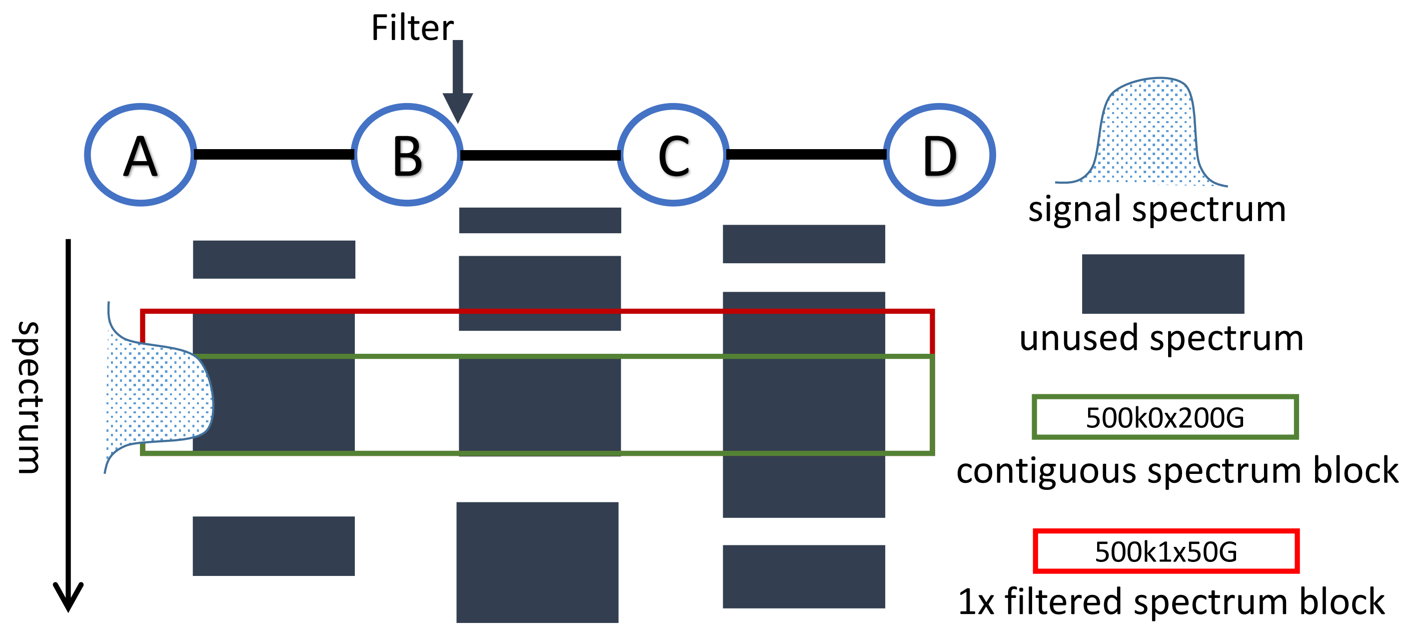
Optical Flexigrid

- Fixed grid: assign wavelengths to rigid spectral slots or channels
- Flex grid: wavelengths can be assigned to an arbitrary spectral location and allocated different spectral widths
  - Channel widths can be variable
  - Spatial dimentions (multi-fiber, multicore) can also be used
- Flexgrid capabilities have unique operational and control characteristics
- Spectrum may become fragmented



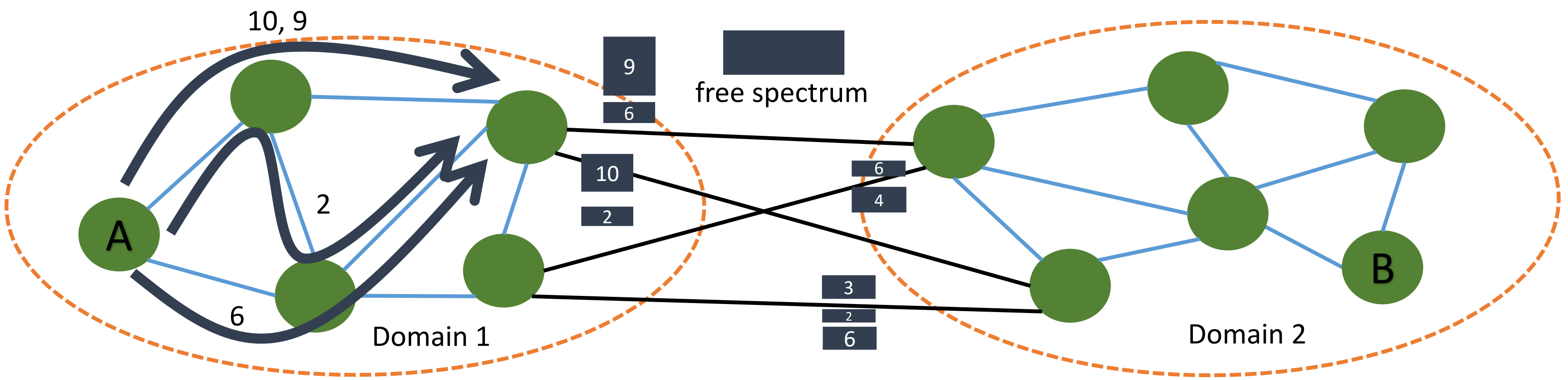
spectrum continuity constraint

Multi-Hop Spectrum Continuity



- Spectrum is not all or nothing
- Wide passbands for filter cascades & spectral broadening
  - Varying filtering conditions can be managed along path
  - Need to manage crosstalk
- How to manage used BC spectrum that overlaps ABCD assignment?

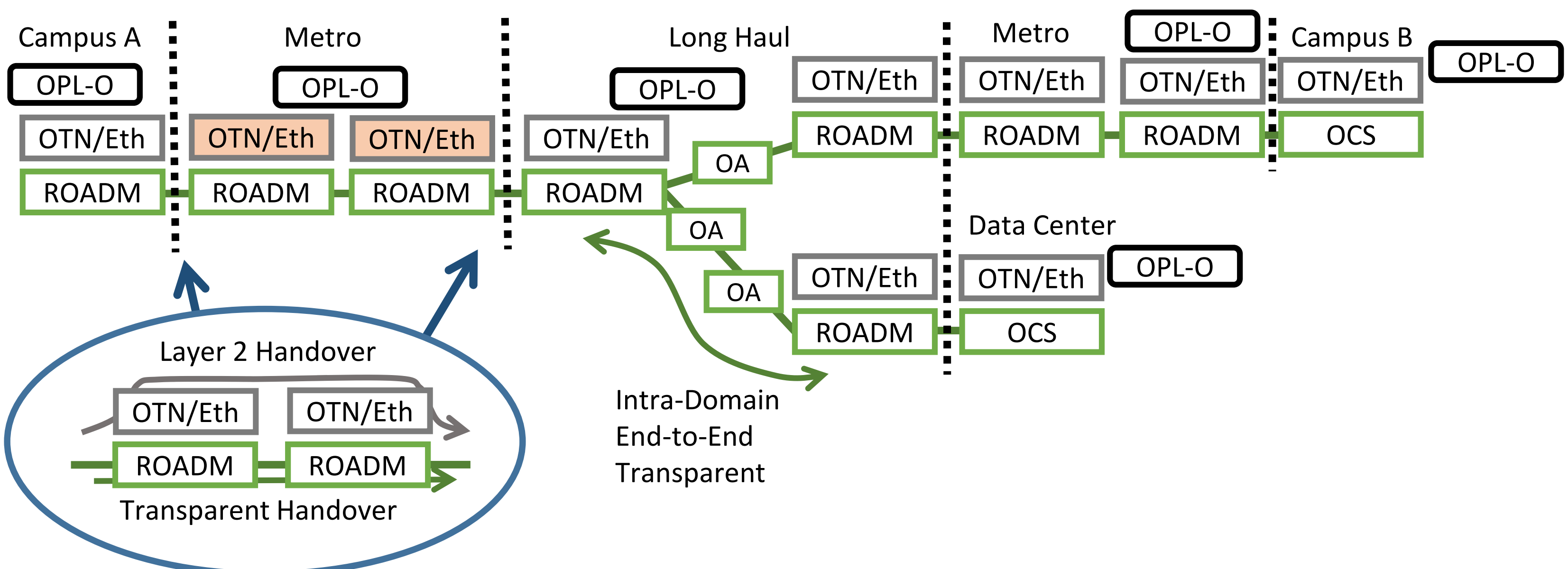
Cross-Domain Abstractions



- Performance weights for available routes
- Investigate defragmentation policies for common cross domain spectrum
- DPCE: Flex grid performance constraints with IA-RWA
  - Use AOPM at boundaries

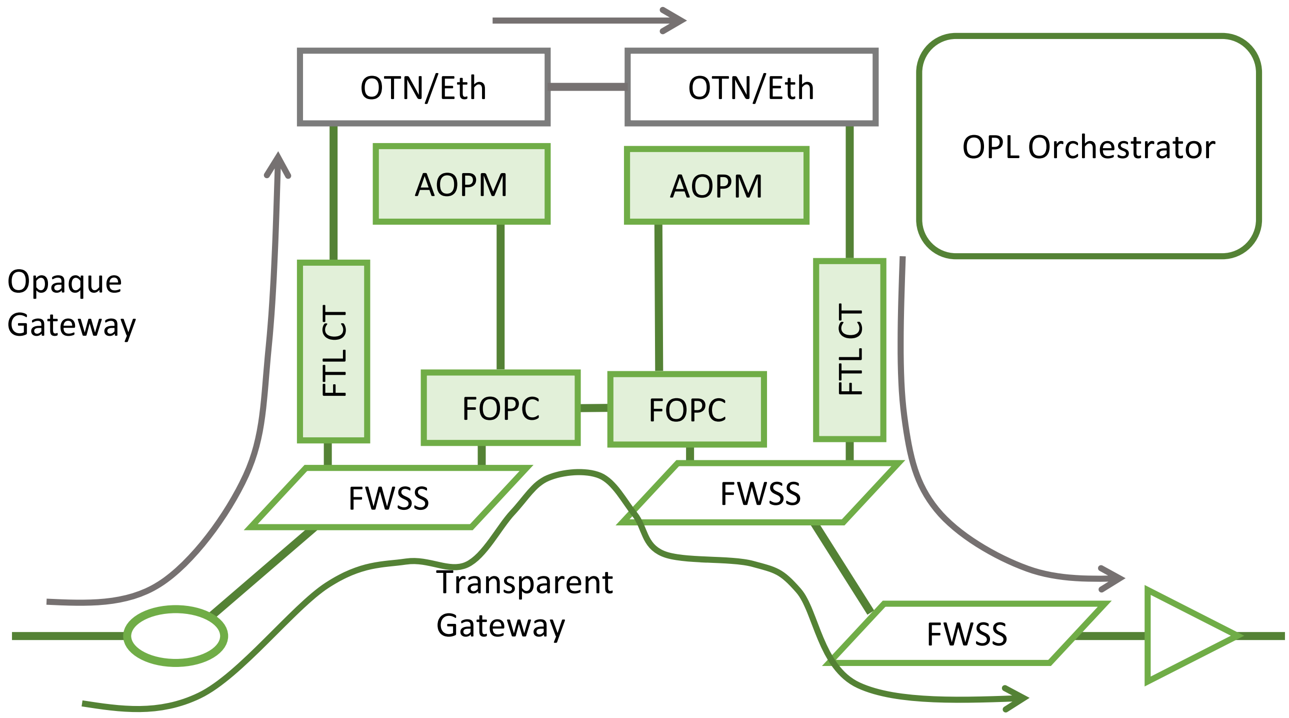
Transparent Domain Boundary

- How to achieve spectrum continuity across domains?
- Need guarantees for SLAs
  - Who's to blame if something goes wrong



Dual Layer SDX Handover

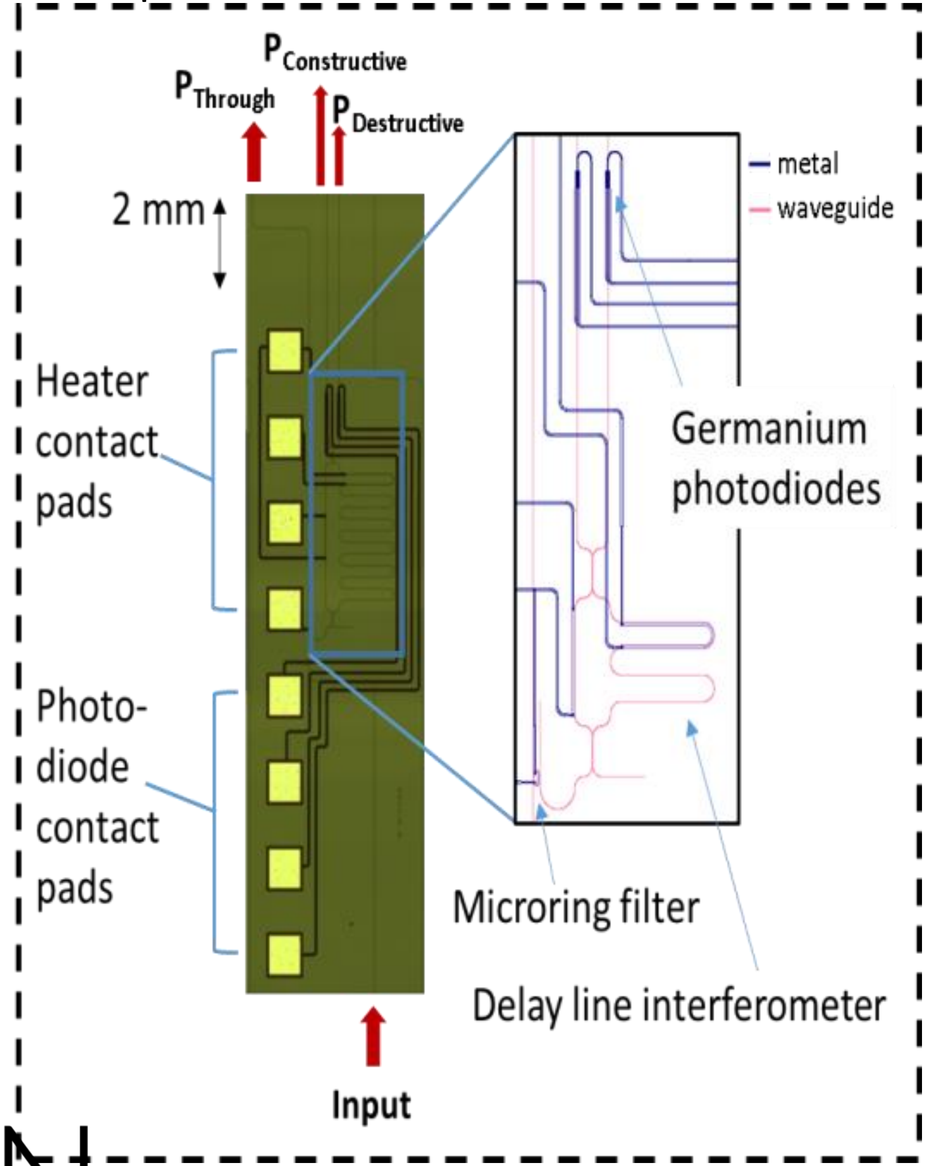
- SLA based on advanced Optical Performance Monitoring (AOPM)
- Flexgrid WSS: enforce spectrum continuity



Transparent SLAs

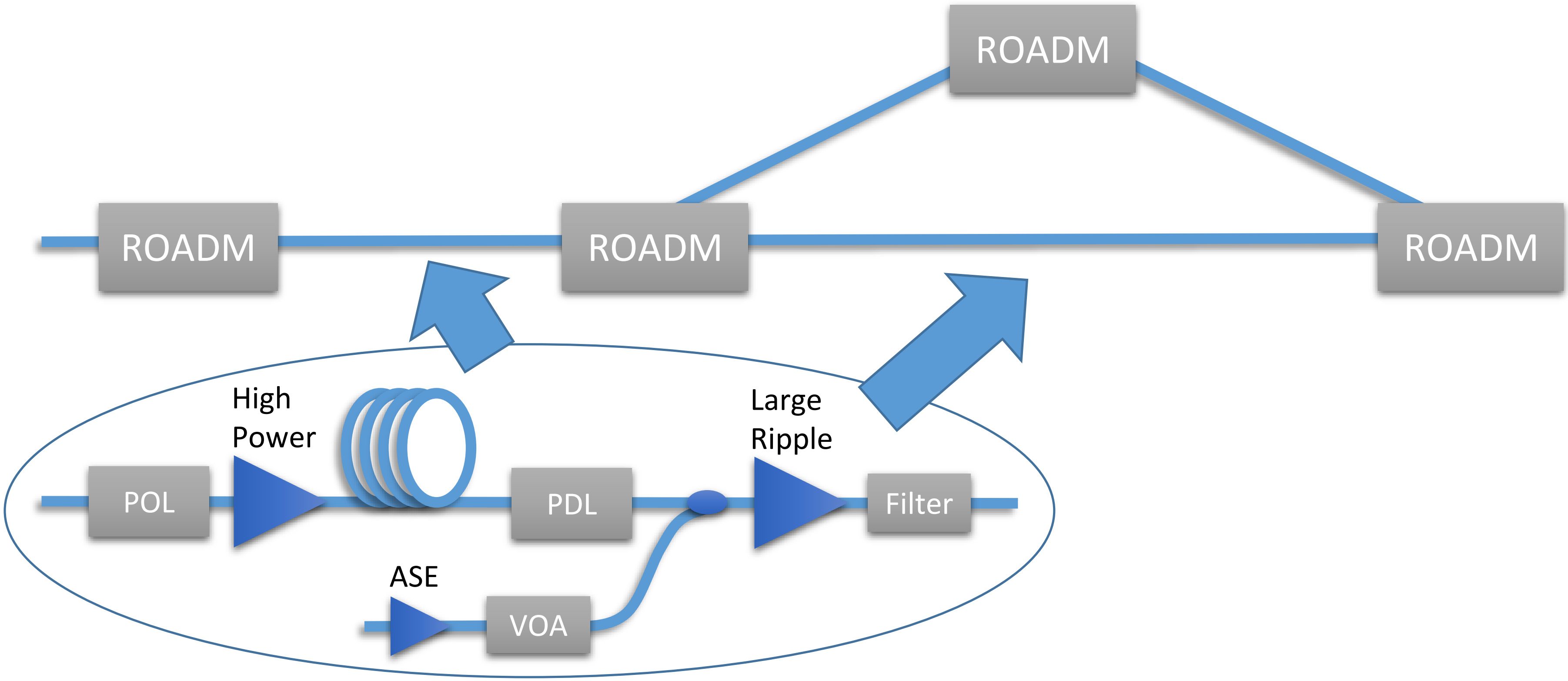
- Use spectrum continuity and guardbands as specification
- Use OSNR for performance guarantee
  - Key performance parameter for coherent
- Silicon photonic OSNR monitor
  - Coherent
  - Polarizaiton Independent
  - Modulation Calibrated

Chip Scale OSNR Monitor

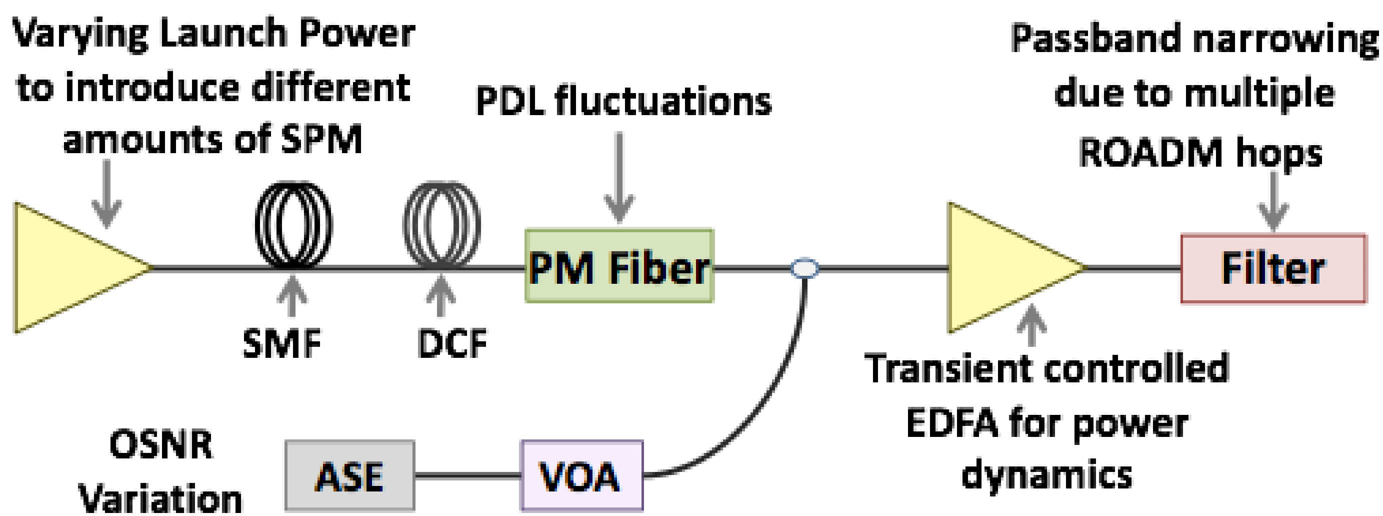


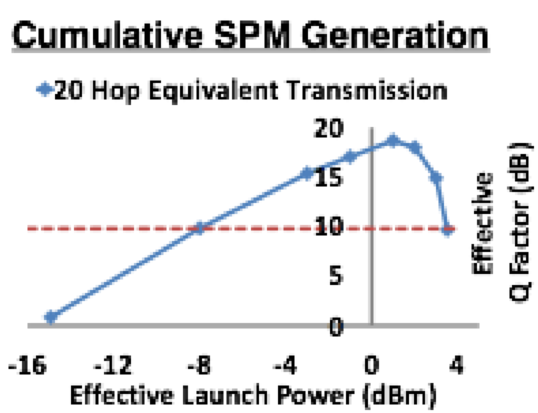
Network Transmission Emulation

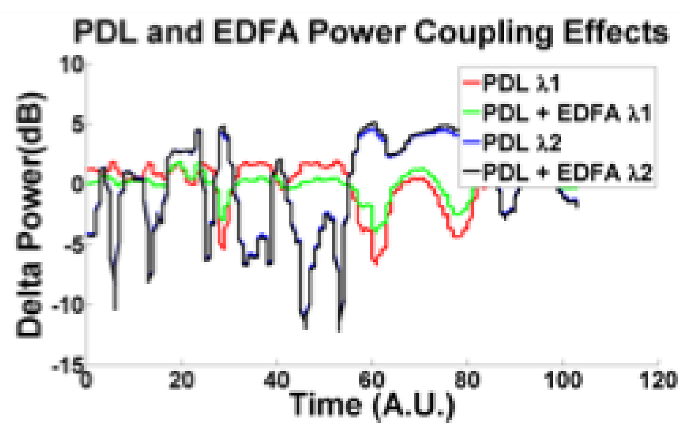
- Introduce multiple impairments to reproduce range of phenomena

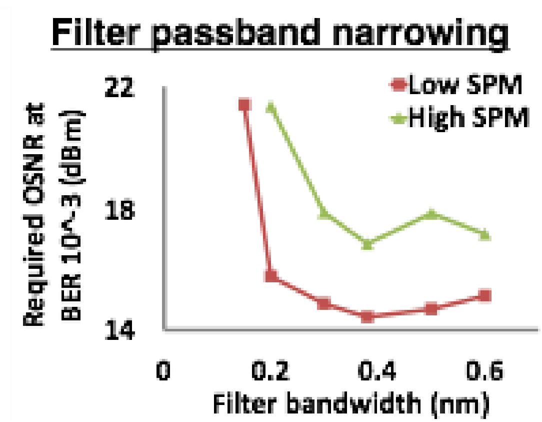


Distance Emulation









TURBO Deliverables

Year 1

- Define use cases
- Optical physical layer orchestrator implemented in testbed
- Prototype of transparent SDX

Year 2

- Optical physical layer abstraction models for single domain control
- Optical physical layer control algorithms for single domain, performance with SDN
- Multi-domain transparent path establishment

Year 3

- Physical layer abstraction models for multi-domain control
- Experiments on dynamic real-time provisioning of optical connections across multiple network domains in the emulated optical networking platform

Roles and Responsibilities

- UA
  - Path setup and control (OPL Controller)
  - Flexgrid Optical transmission, inter- and intra- domain
  - Transparent SDX
  - OPL abstraction

- Columbia
  - SDN Implementation and interface to network OS
  - Wavelength resource management/rwa: DPCE

Looking forward 10 years