Data Center Cloud, Fog, Edge, Interconnect Networks: Using SDN to Make Networks Transparent

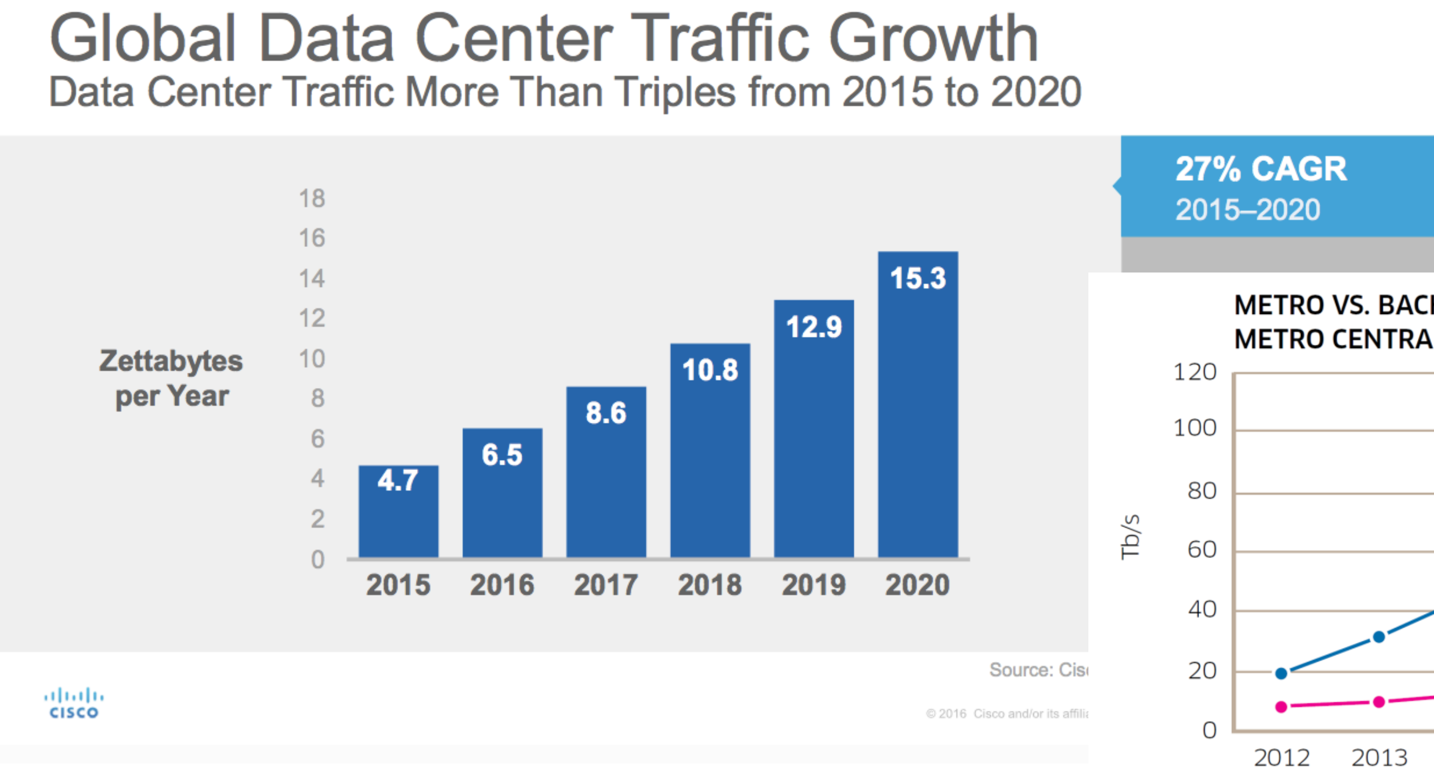
Dan Kilper, Yao Li

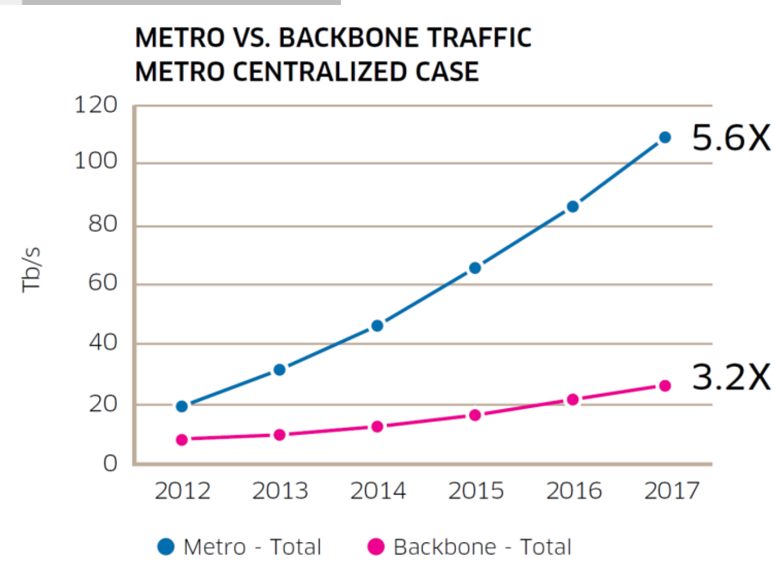
May 16, 2017

Outline

- Optical Network Evolution and Cloud, Fog, Edge, DCI Networks
- Optical Networking in C/F/E/D Networks
- The Multi-Domain Dilemma & Transparent Software Defined Exchange (tSDX)
- Conclusions

Rapid Growth in Metro and Data Centers





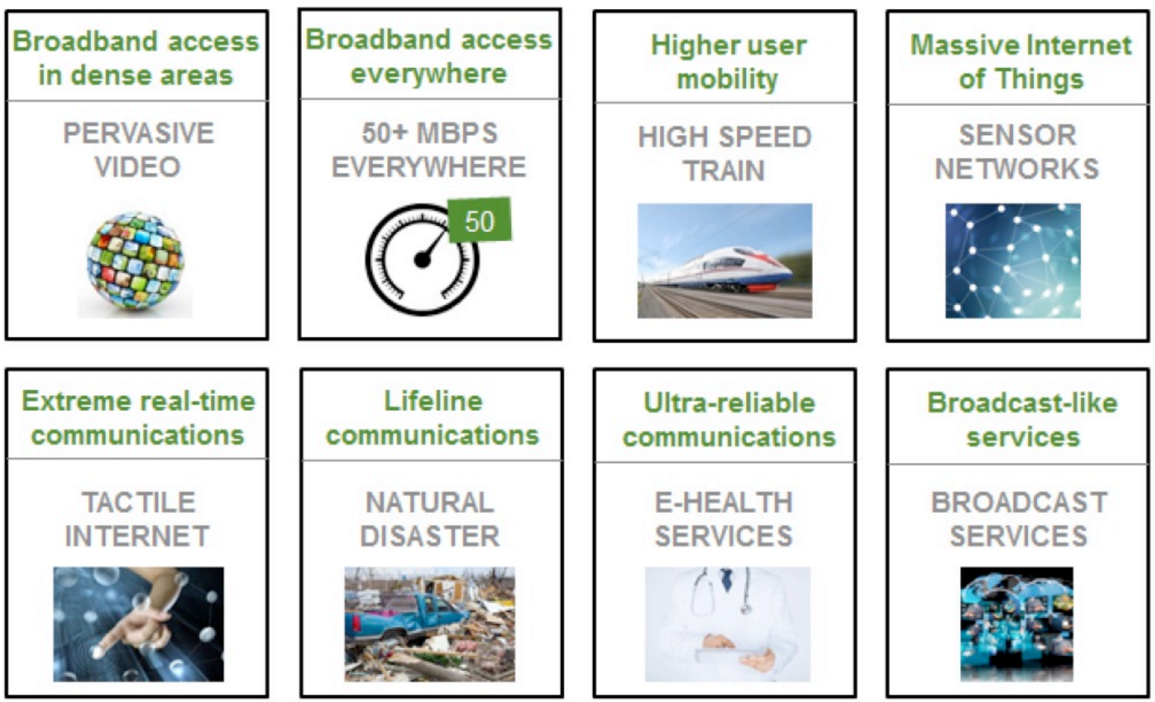
Still doubling every 2-3 years

Bell Labs Metro Network Traffic Growth: An Architecture Impact Study, Alcatel-Lucent Strategic White Paper, 2013

5G Wireless

- Next mobile standard expected in 2020
- Wireless access rates up to 1-10 Gb/s
  - 10 Tb/s/km^2 peak dense urban
- ~1 ms latency for tactile applications

5G white paper
NGMN, ngmn.org



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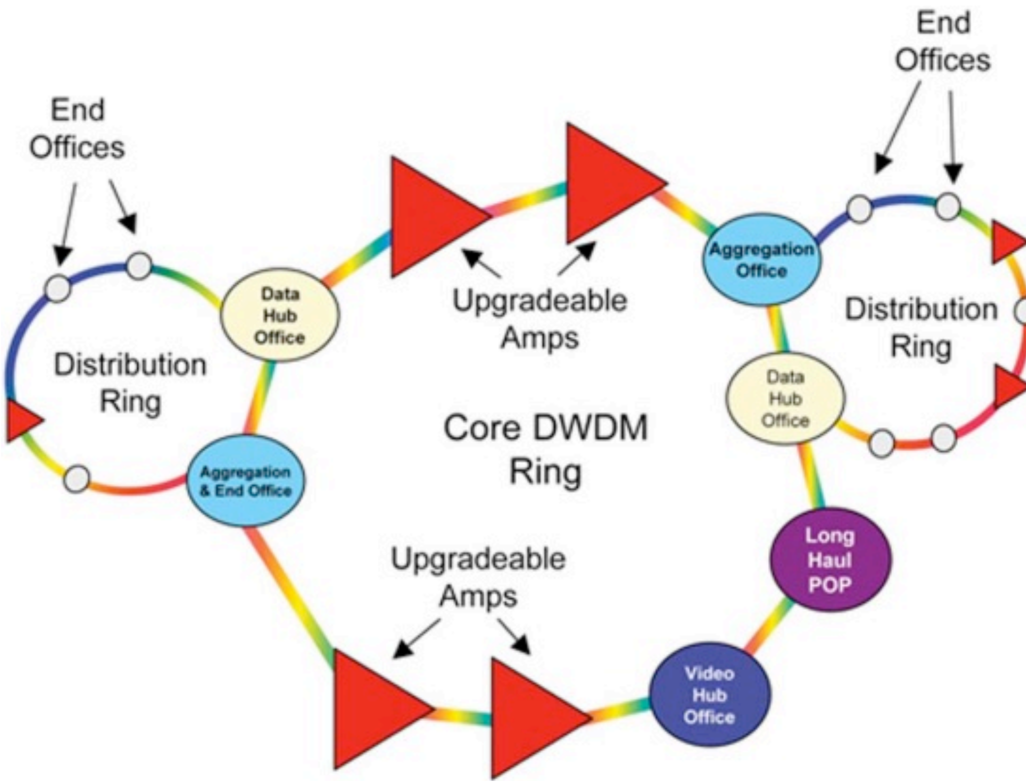
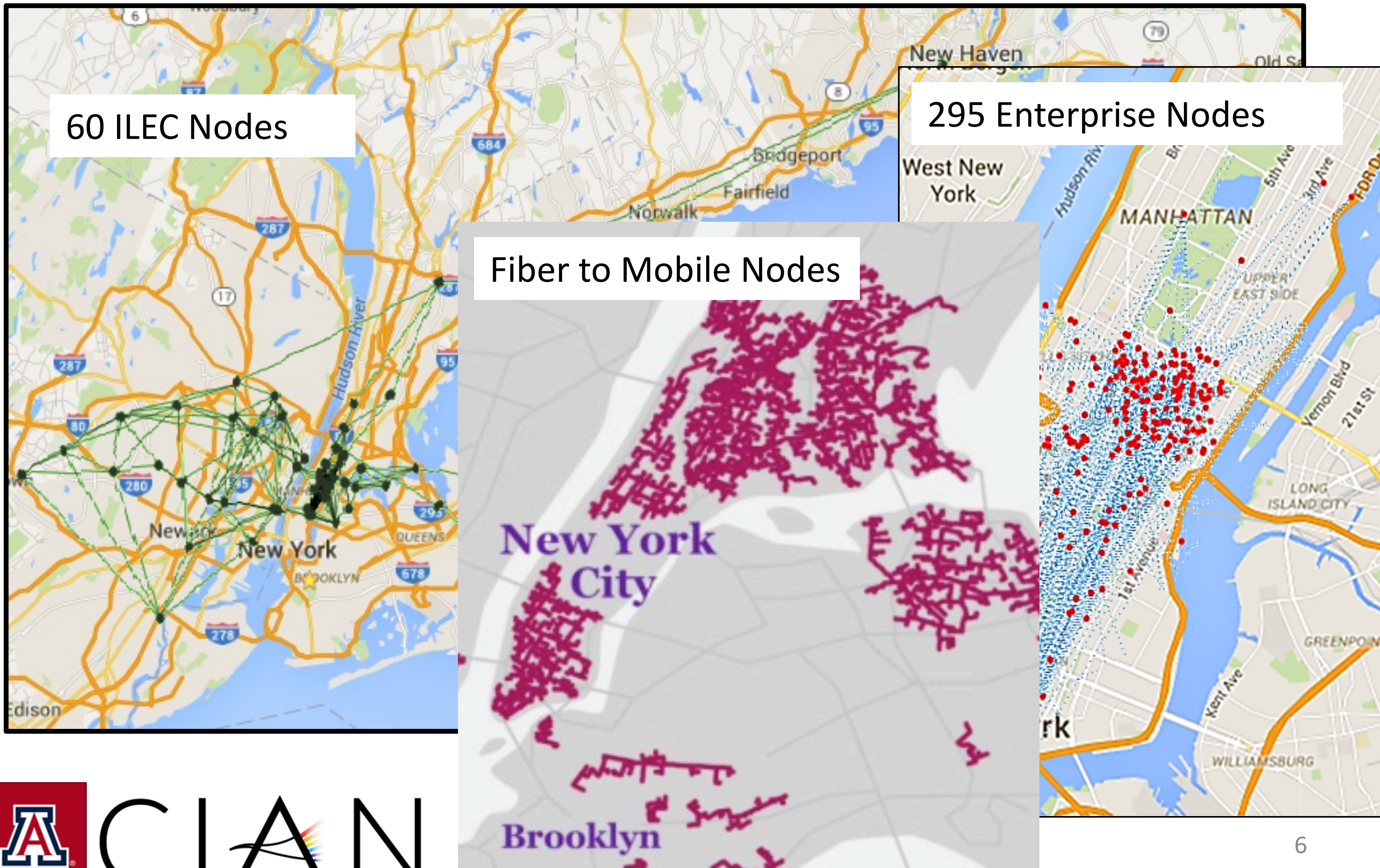
Metro Optical Networks circa 2006

- A few nodes on simple interconnected rings



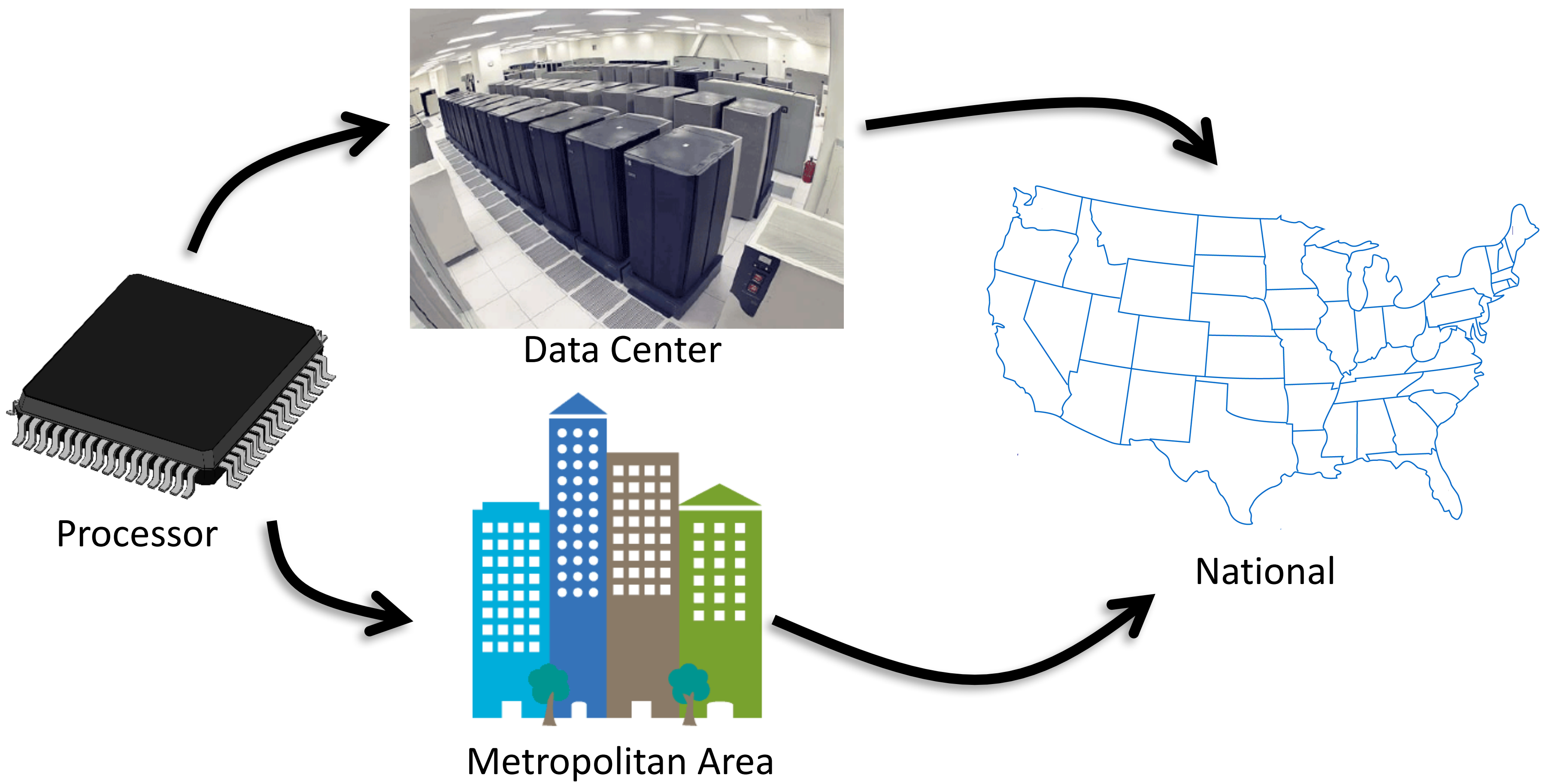
B. Basch, et. al. JSTQE 2006

Metro Optical Networks Today



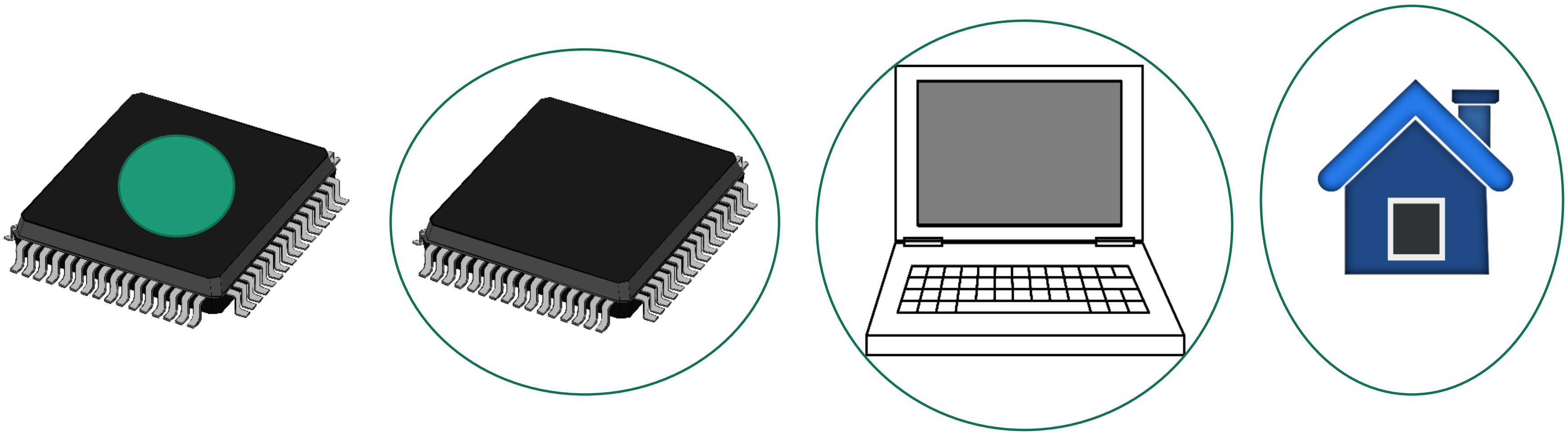
Network Capacity Scaling

What's the total ingress-egress traffic/capacity at different length scales?



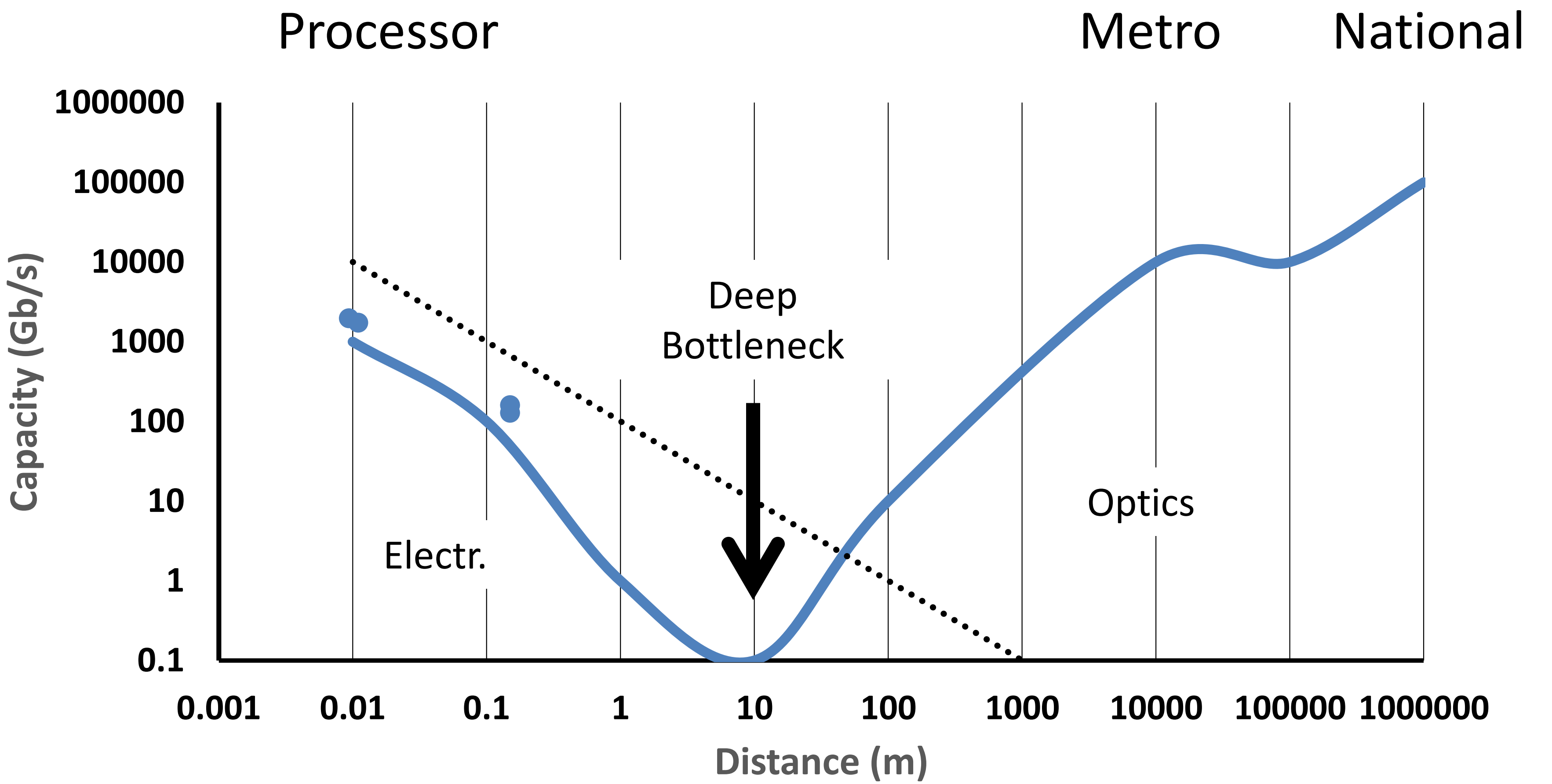
Network Scales (Metro Model)

Internal Chip Buses	External Chip Buses	Computer	Home



1 cm	10 cm	1 m	10 m
1 Tb/s	100 Gb/s (PCIe)	1 Gb/s	100 Mb/s

Network Capacity Scaling: Metro Model



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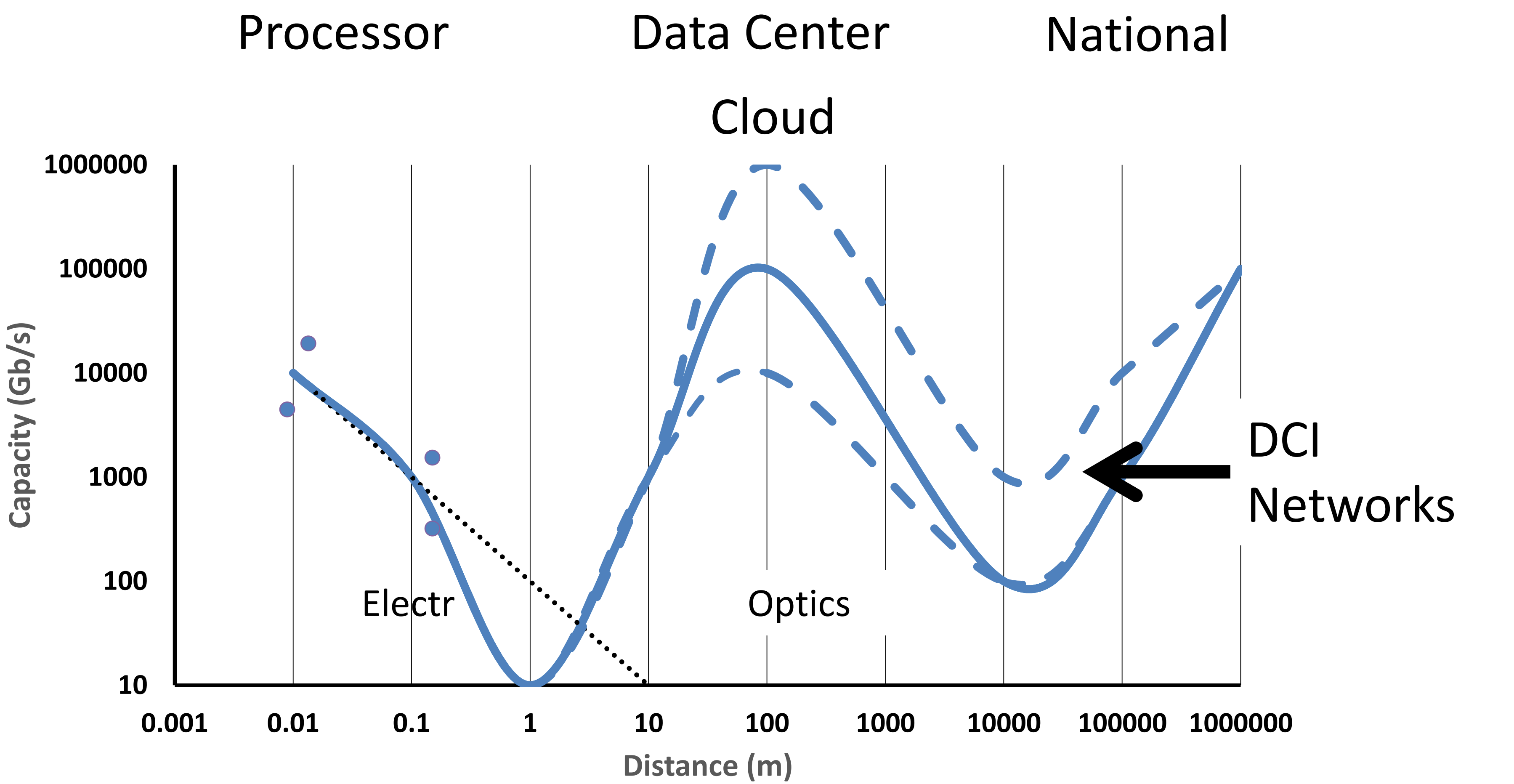
Kilper & Rastegarfar, Phil Trans A 2016

Network Capacity Scaling: Data Center Model



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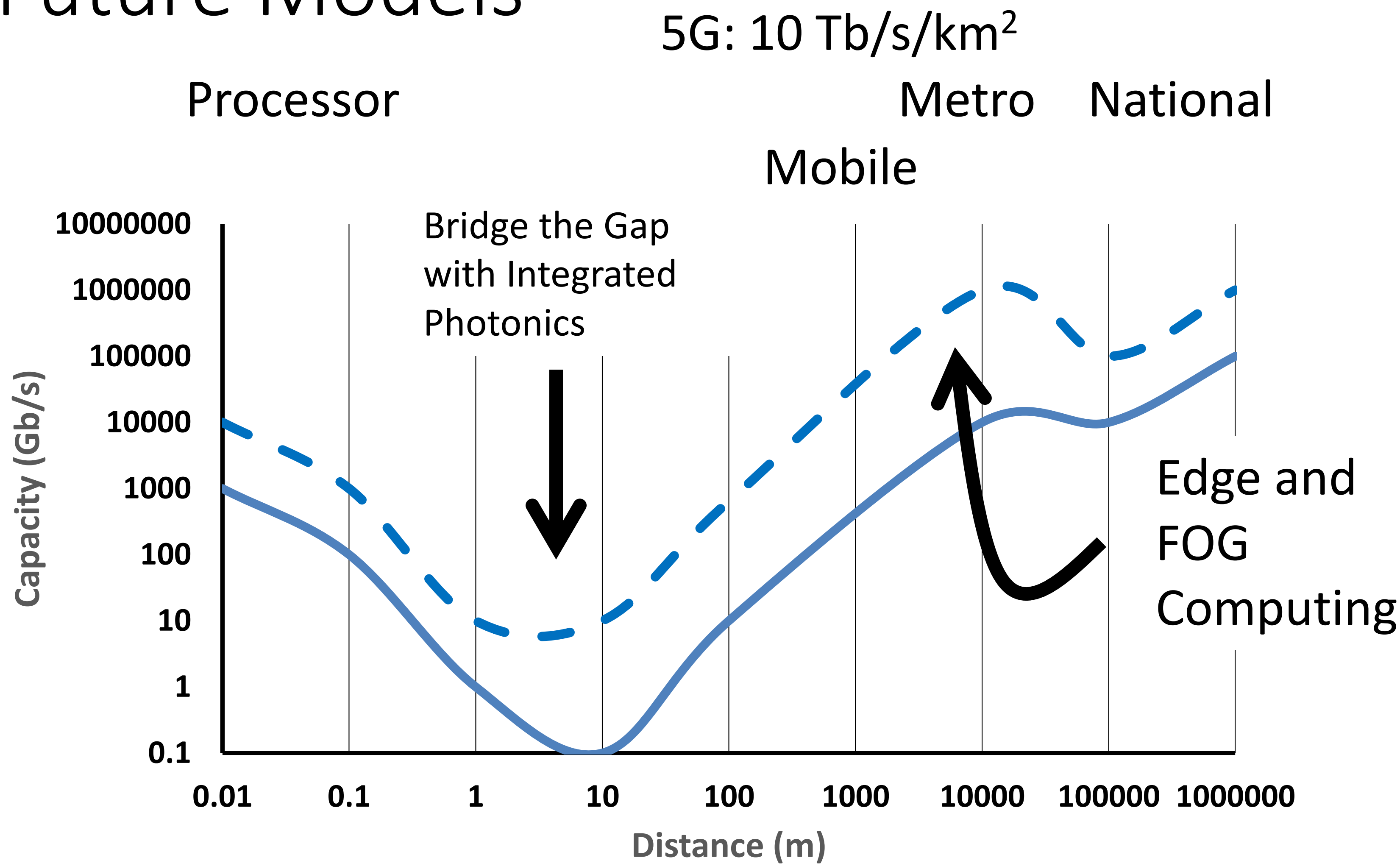
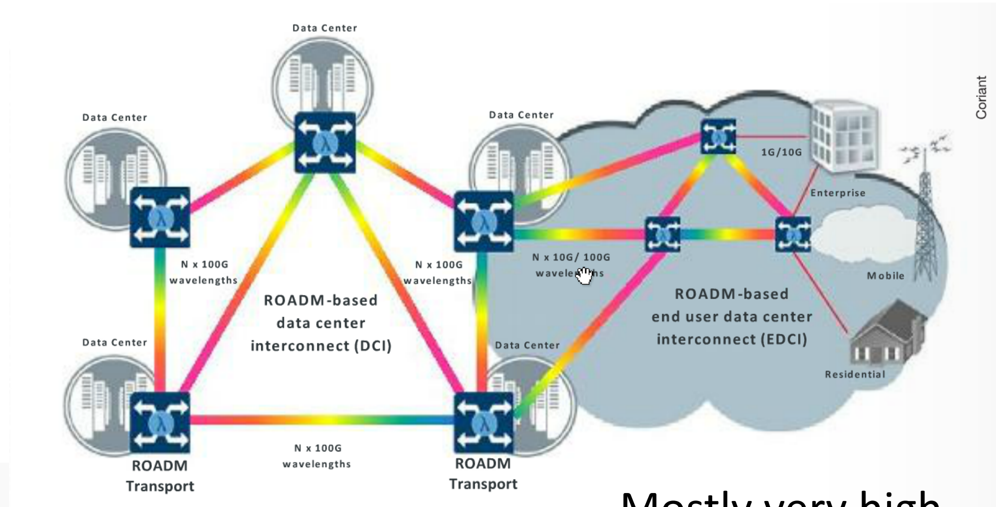
Network Capacity Scaling: Future Models



Data Center Interconnect (DCI)

- Internet companies want to lower cost of sending data between data centers
  - Facebook, Google

TELECOM INFRA PROJECT



Mostly very high capacity point-to-point using ROADMs for multiplexing

Standard hardware

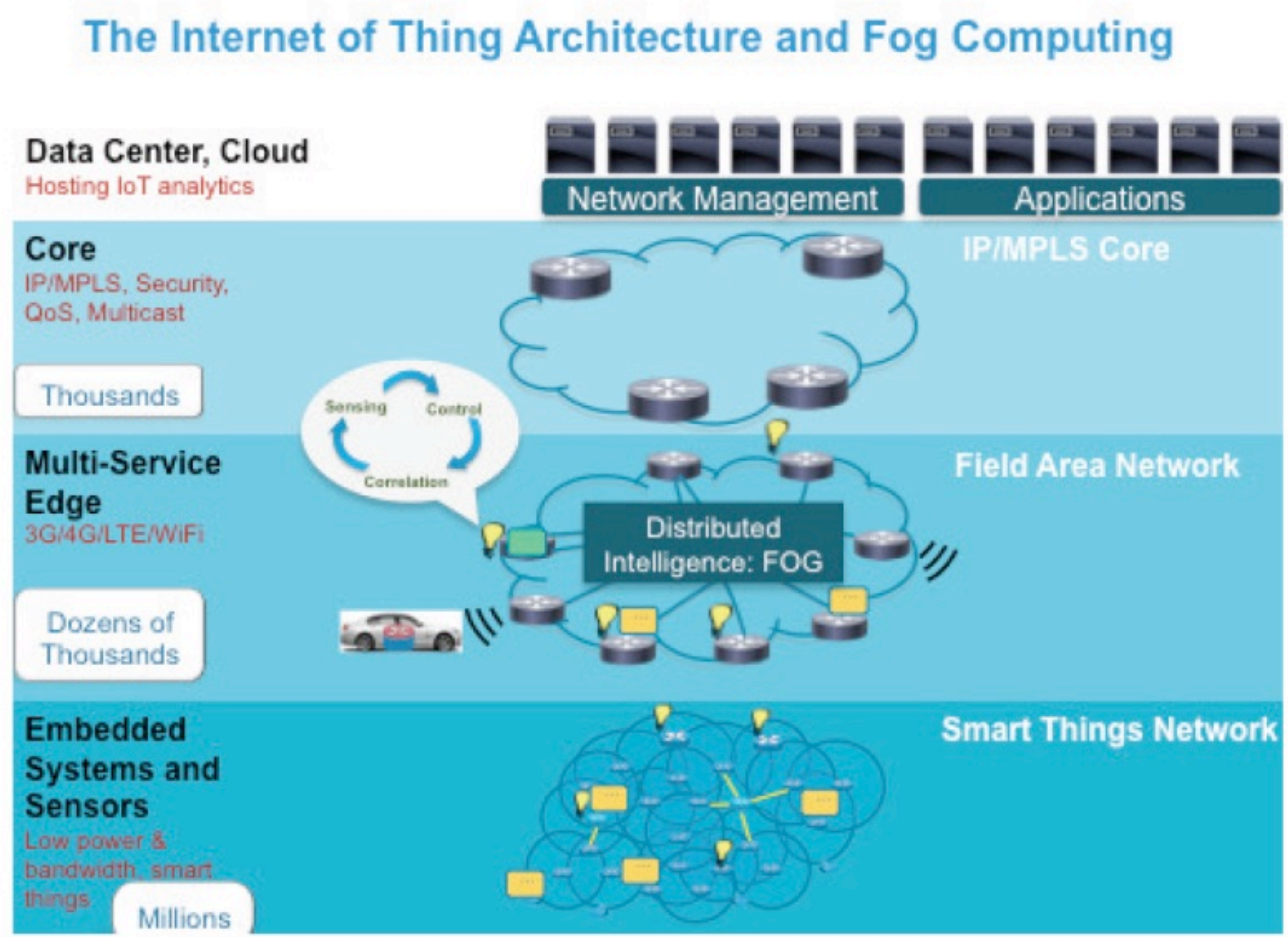
Open Optical Packet Transport

Co-chaired by Hans-Juergen Schmidtke, Facebook and Ihab Tarazi, Equinix

OPENCONFIG

Standard management software

FOG Computing



F. Bonomi, et. al. MCC 2012

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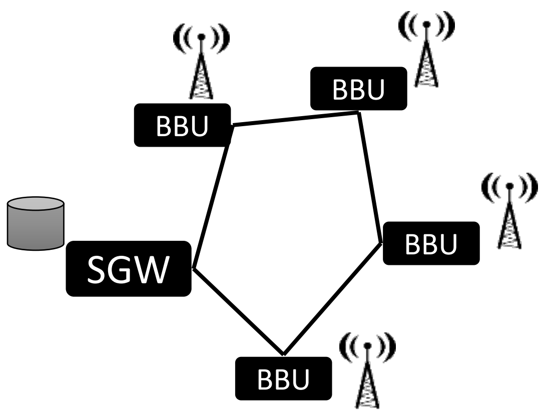
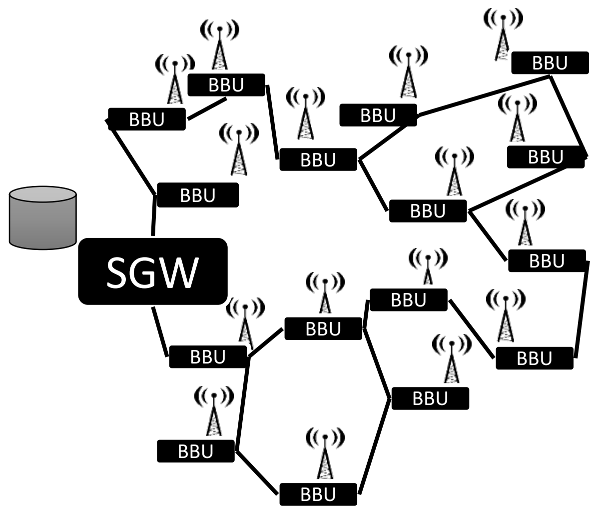
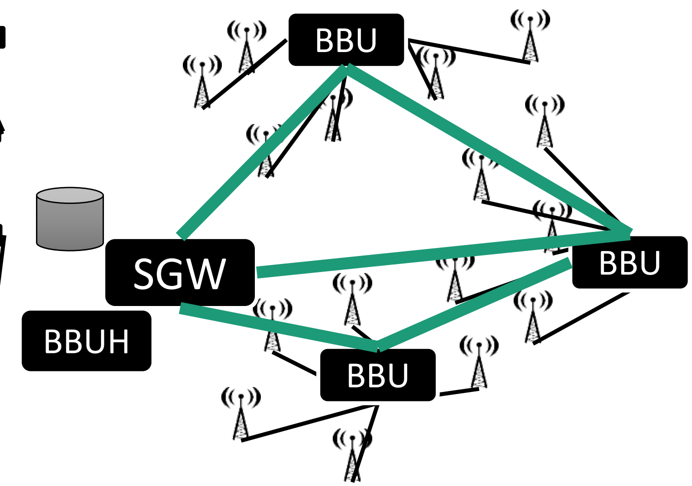
Cloud Radio Access Networks (C-RAN)

KDDI study: real time vs daily adapt, 2x benefit







4G Macro-Cell Network

- Base-band processing unit (BBU) at every tower
- WDM or PON fiber network to Service Gateway (SGW)

4G for Small Cells/5G

- 10x+ in capacity
- 10x+ in cost: everything multiplies
- Need capacity & latency of fiber to each cell

5G Cloud Radio Access

- BBU hoteling/sharing
- Need programmability to realize ‘cloud’
- Avoid 10x+ cost

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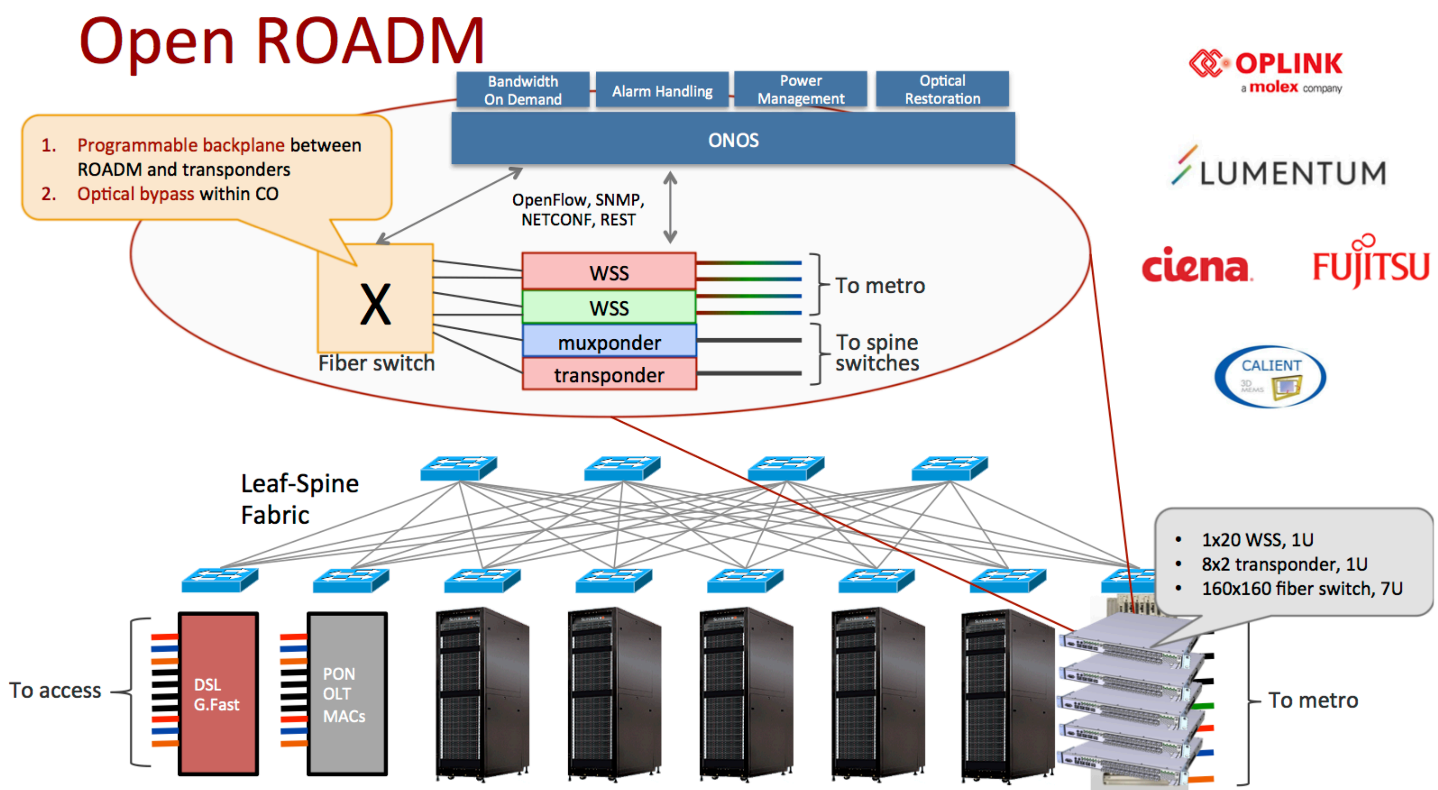
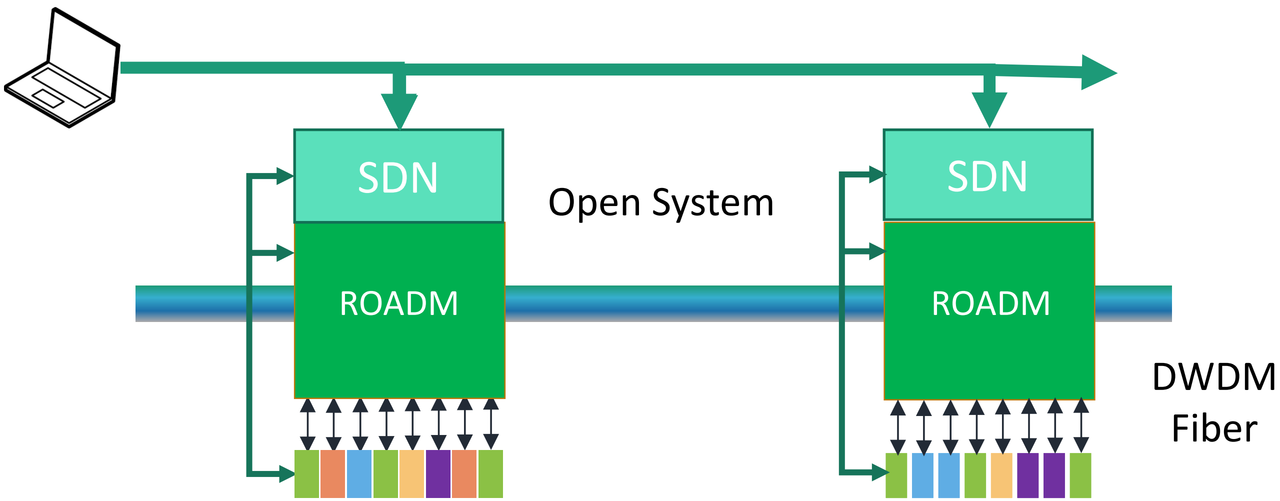
CORD: Central Office Re-architected as a DC



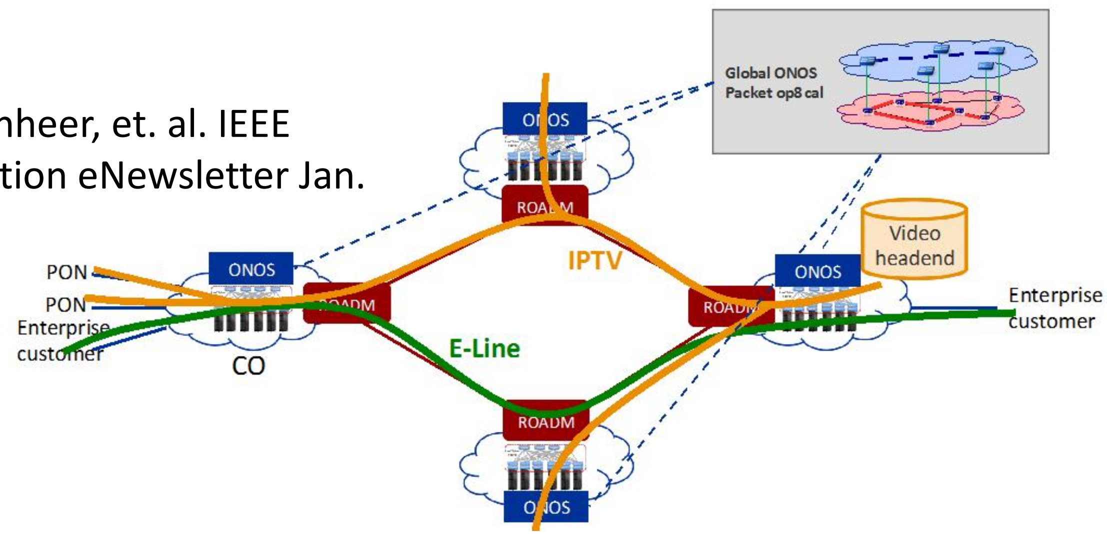
ONOSproject.org

OpenROADM MSA: AT&T

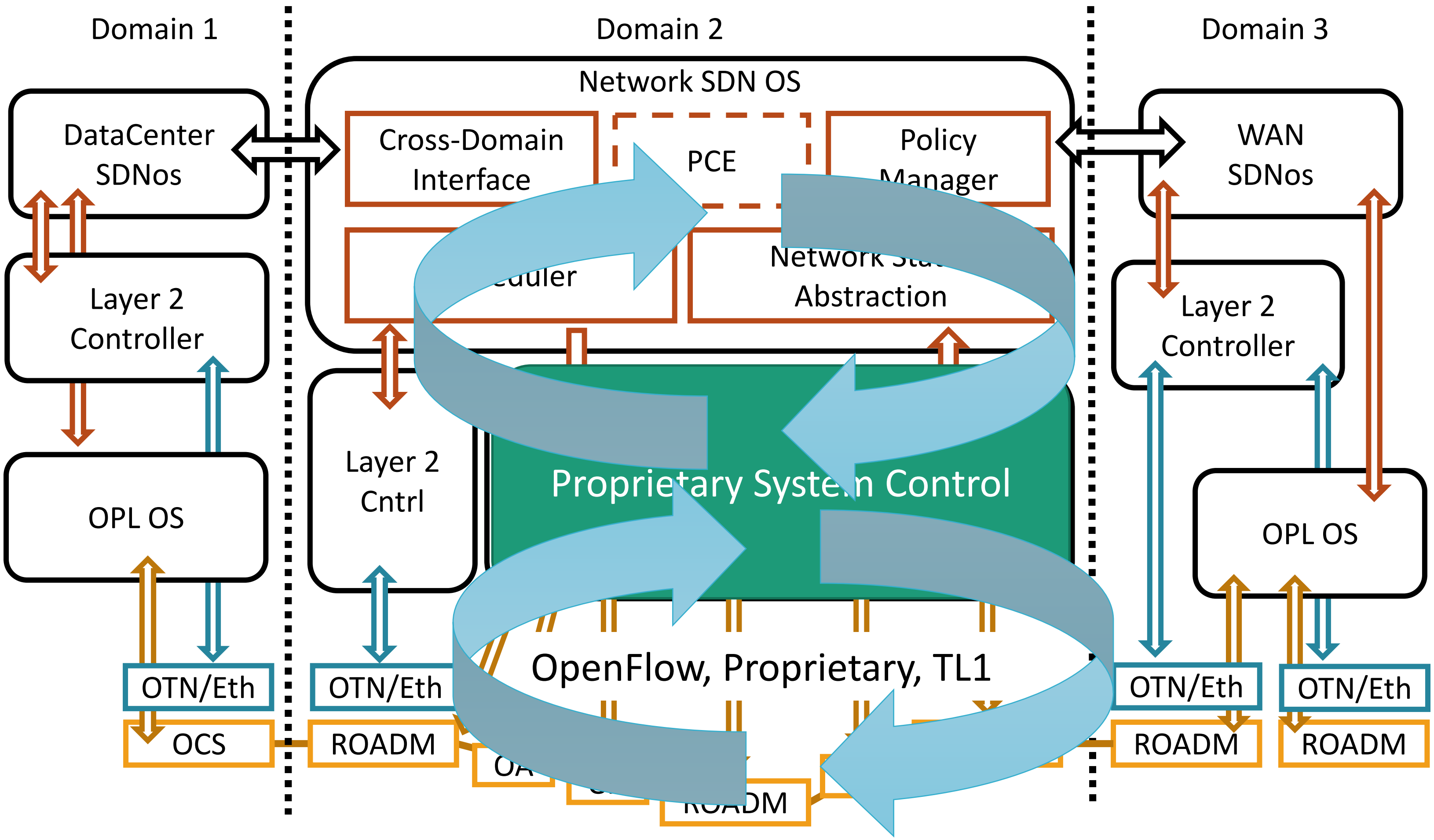
Disaggregated ROADMs



M. De Leenheer, et. al. IEEE Softwarization eNewsletter Jan. 2016

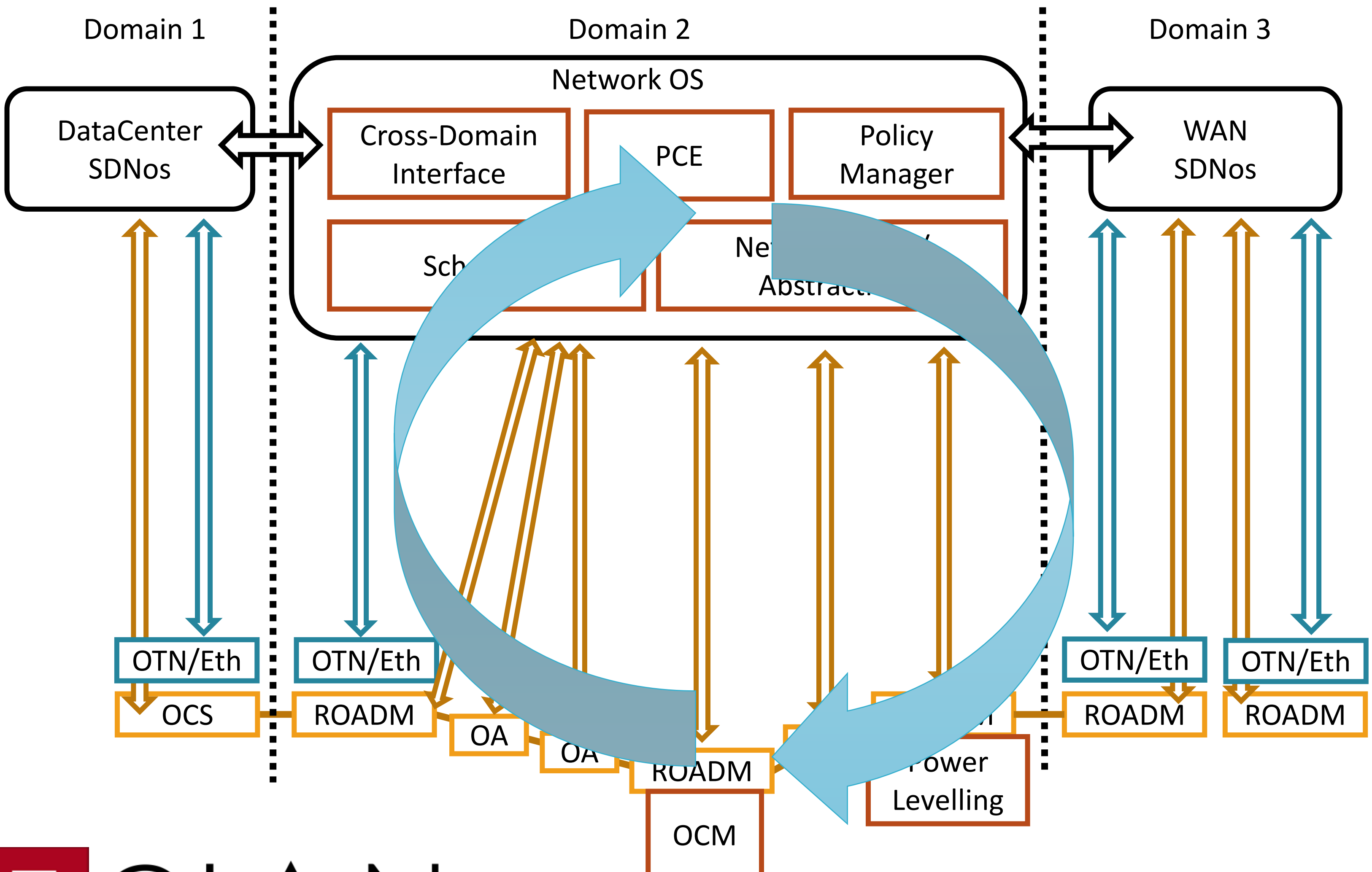


SDN Control

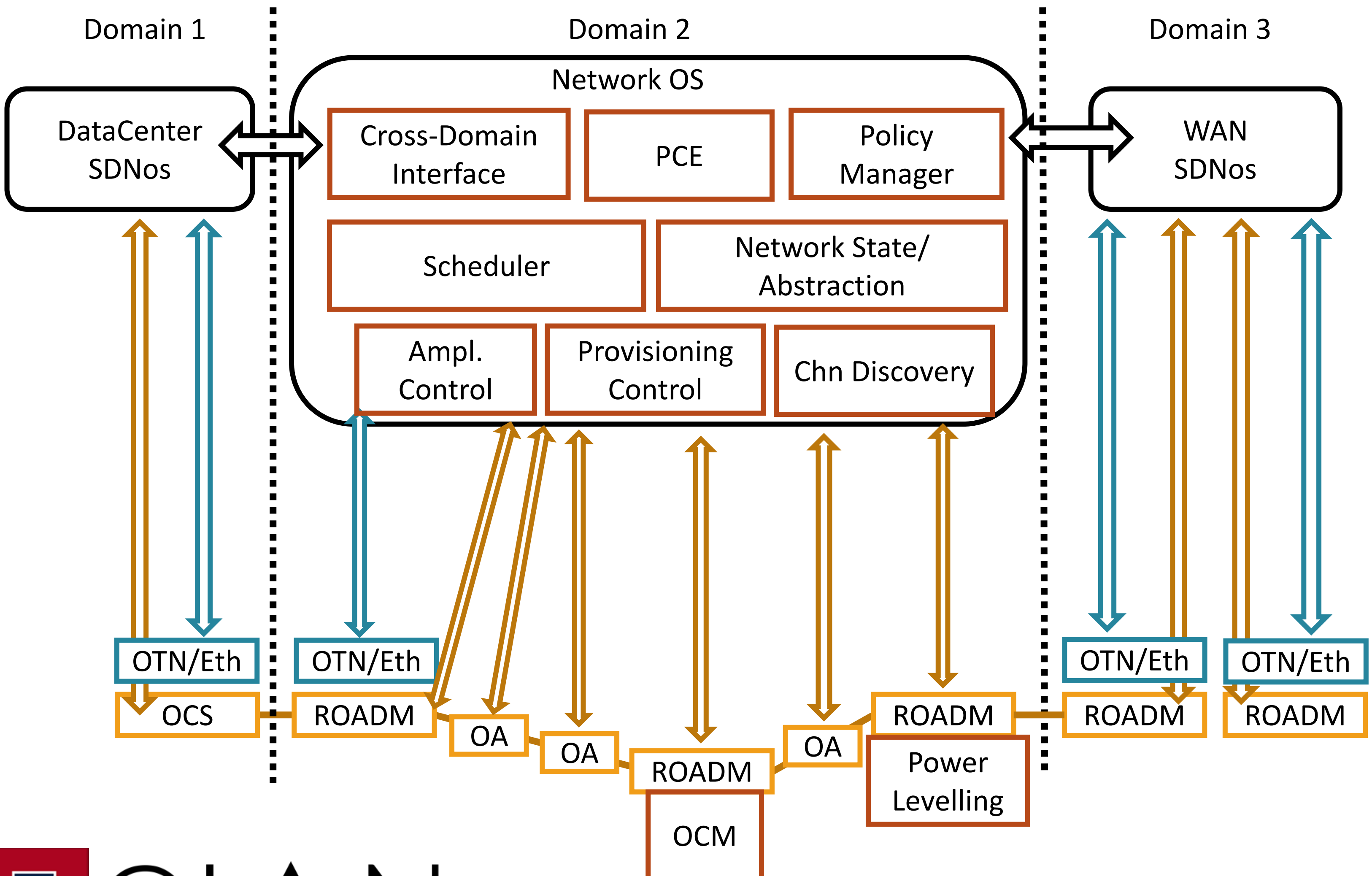


Domain 1
Domain 2
Domain 3
Network SDN OS
DataCenter SDNos
Cross-Domain Interface
PCE
Policy
WAN SDNos
Abstraction
Layer 2 Controller
Layer 2 Cntrl
Layer 2 Controller
Proprietary System Control
OPL OS
OPL OS
OpenFlow, Proprietary, TL1
OTN/Eth
OTN/Eth
OTN/Eth
OTN/Eth
OCS
ROADM
ROADM
ROADM

White Box Optical Control



White Box Optical Control



Functions of Optical Physical Layer Controllers

- 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
  - Tune/control transceivers
  - Real time elastic bandwidth/flex grid management
  - Real time route selection
  - Wavelength layer protection
  - Defragmentation
  - ….

Current propriety solutions

Future

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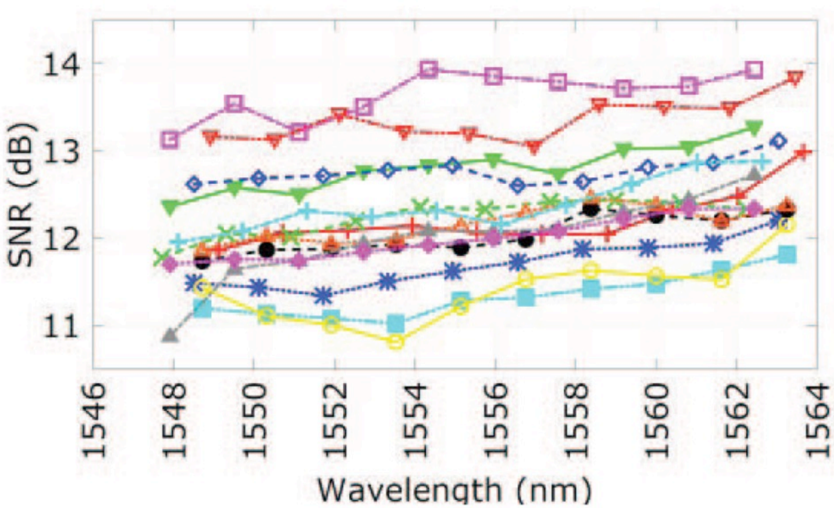
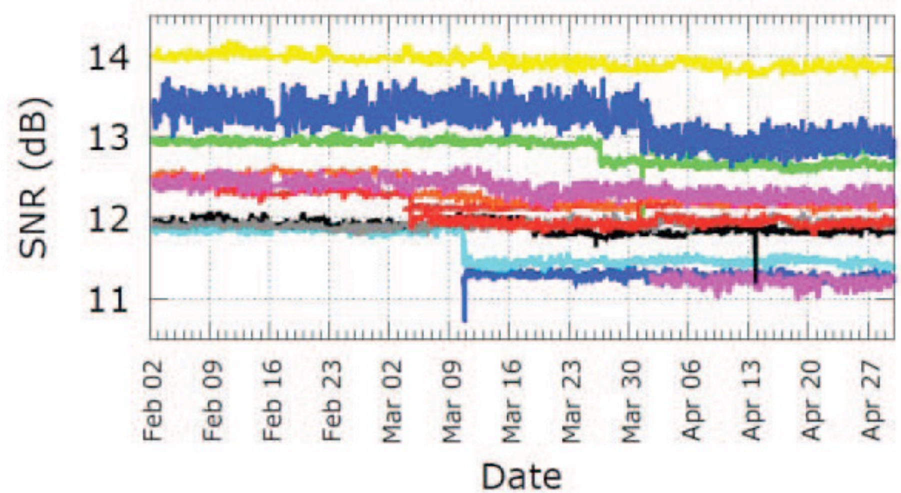
Variations in the Field

- Production system measurements
- Performance varies by wavelength & route over time

Wavelength & Route Dependence:



Time Dependence:



Ghobadi, et. al. OFC 2016

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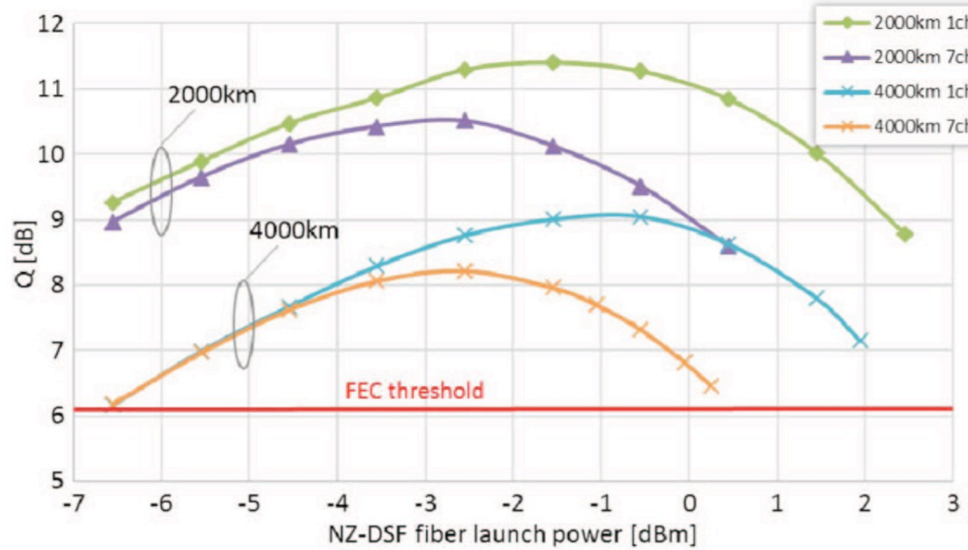
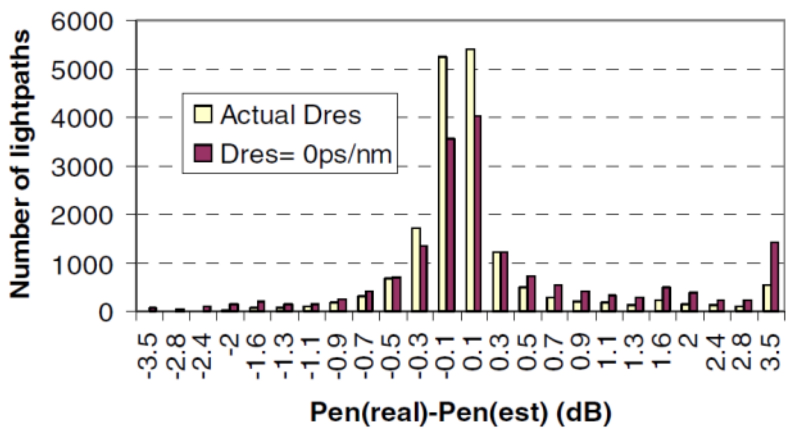
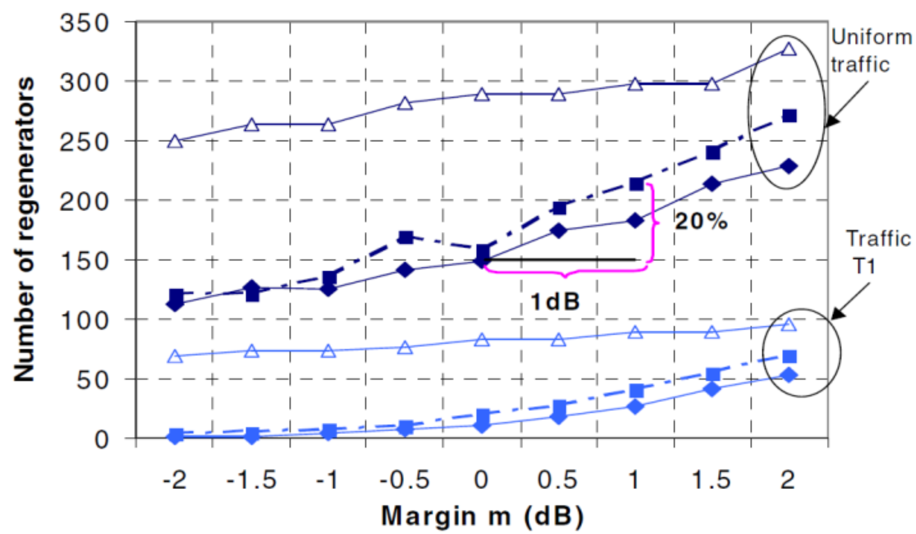
Margin and Regeneration Game

Filer, et. al. JOCN 2016

- Need to keep signal power within allowed margins
- Use performance estimations (PCE) IA-RWA
- Trade-off margins and regeneration/cost







Leplingard et. al. OFC 2008

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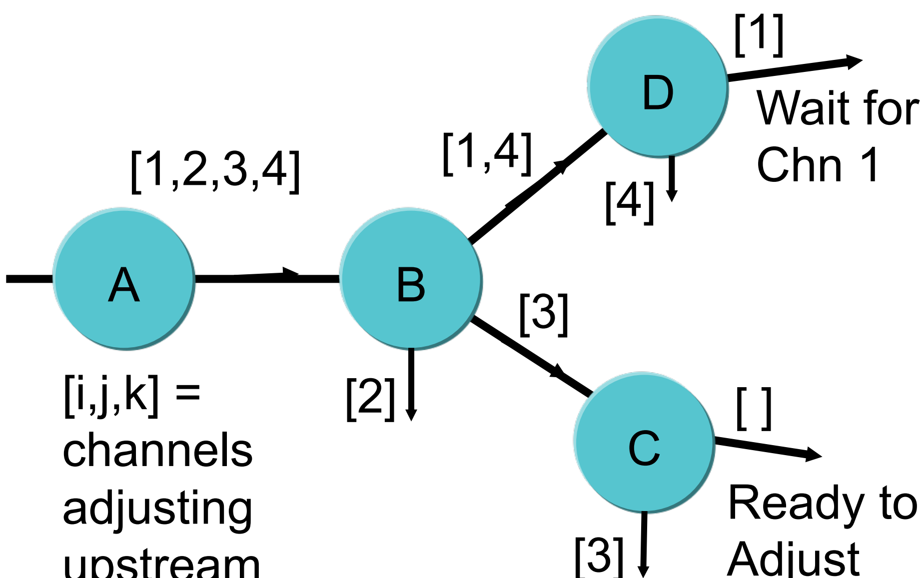
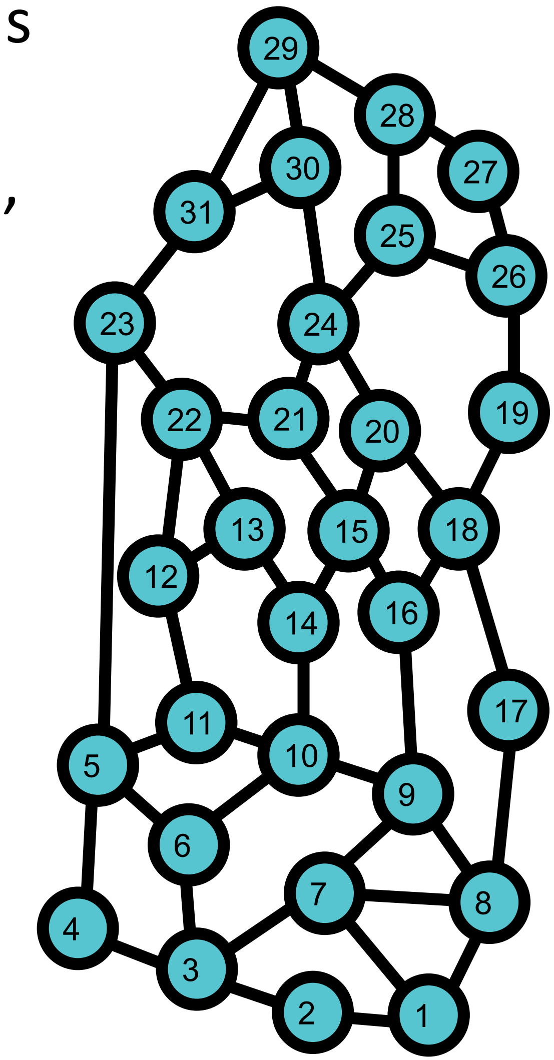
Optical Power Control Algorithm

- Power drifts over time and new channels are provisioned: need periodic power control to stay within margins
- Adjust nodes in parallel within ‘optically’ isolated domains
  - Node ordering based on channel routes





Kilper & White OFC 2007

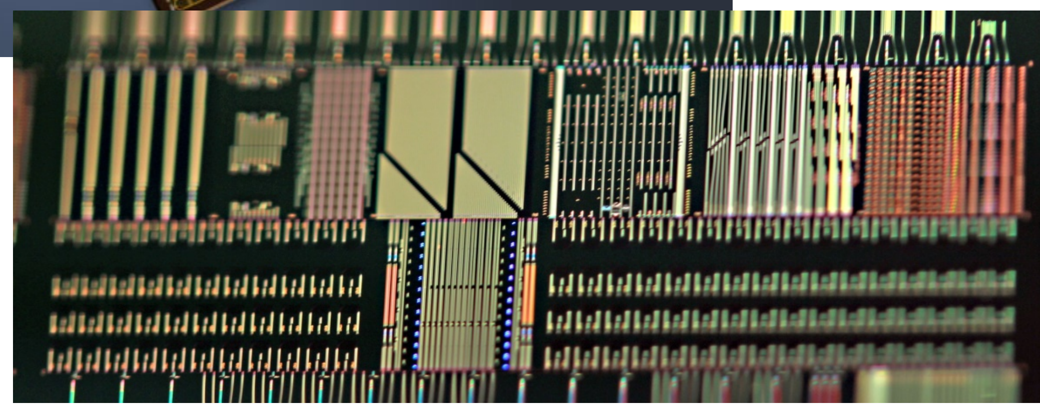
Optical System Environment Today

- Large mesh networks, multiple wavelengths per node
  - Numbers of nodes, not distance
- Networks are growing fastest near the edge where traffic is bursty and service oriented
- Optical systems use margin engineering to provision ‘wavelengths’
  - Need sophisticated algorithms to predict and manage

- **Everything points to a need for highly integrated, software controlled systems at the metro edge**

Ciena Wavelogic Ai

Photonic Integrated Circuits/Silicon Photonics



- Change cost structure of optical systems
- Essential for high volume, ubiquitous optics

Columbia (Lipson) – interferometer w/ Ge detect. performance monitor
UCSD (Mookherjea) – pol. insensitive 4x Add-Drop-VOA for WDM
Caltech (Scherer) – sensor-type information processing chip
UCSD (Fainman) – waveguides & structures for sidewall gratings
Berkeley (Chang-Hasnain) – grating for III-V on SOI integration
Univ. Arizona (Norwood) – athermal polymer clad ring modulators

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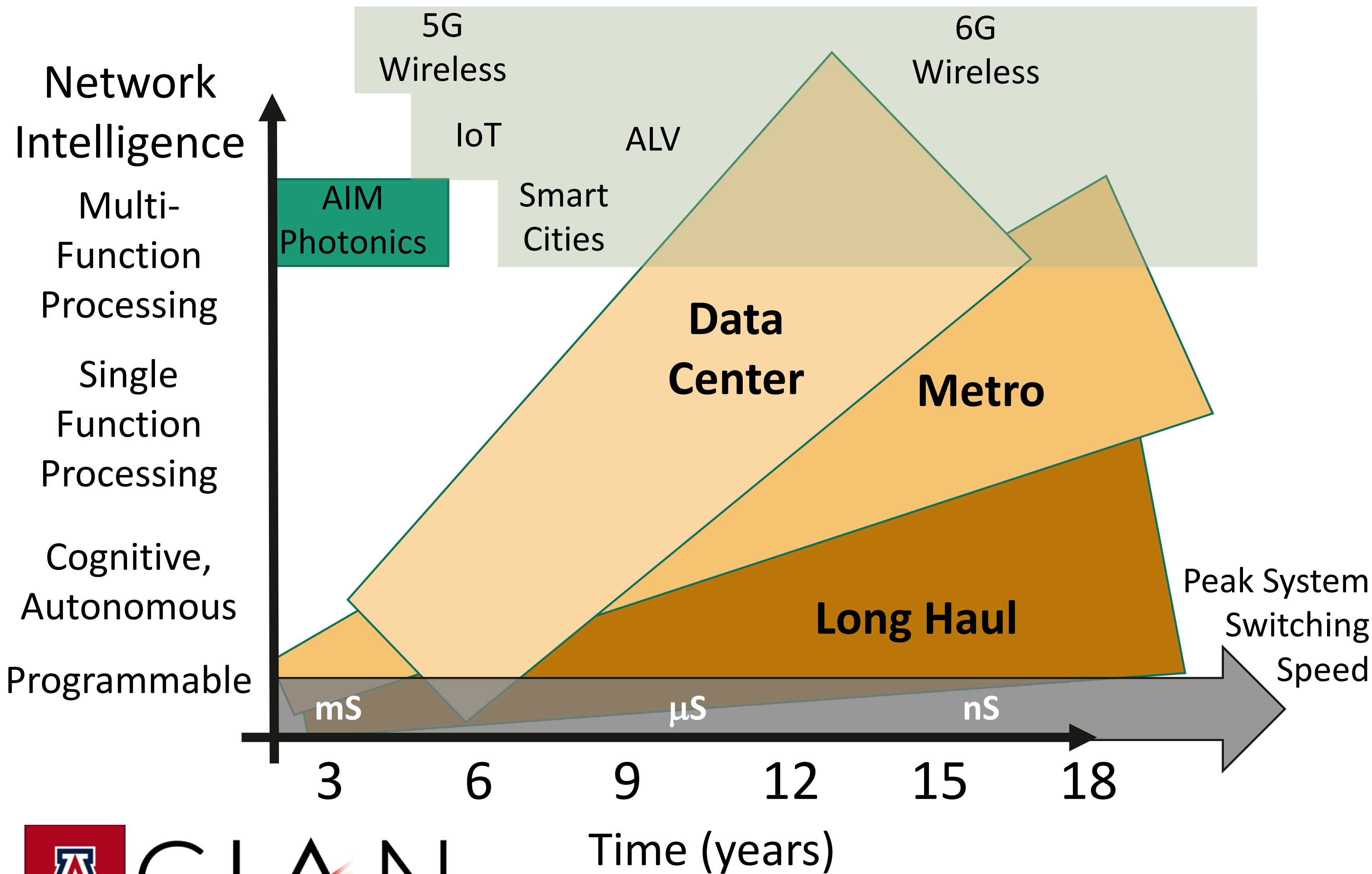
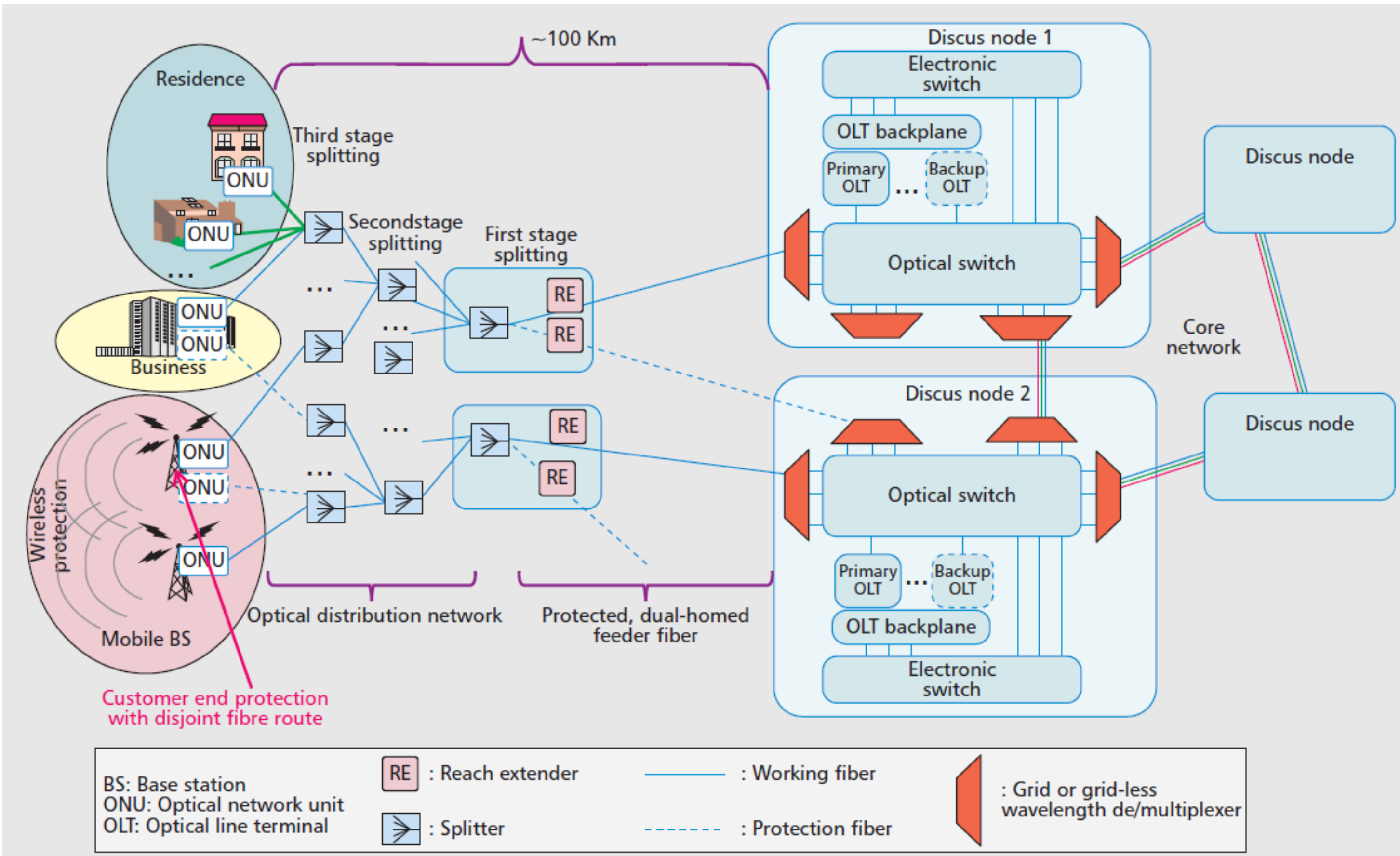
Optical Networking Evolution



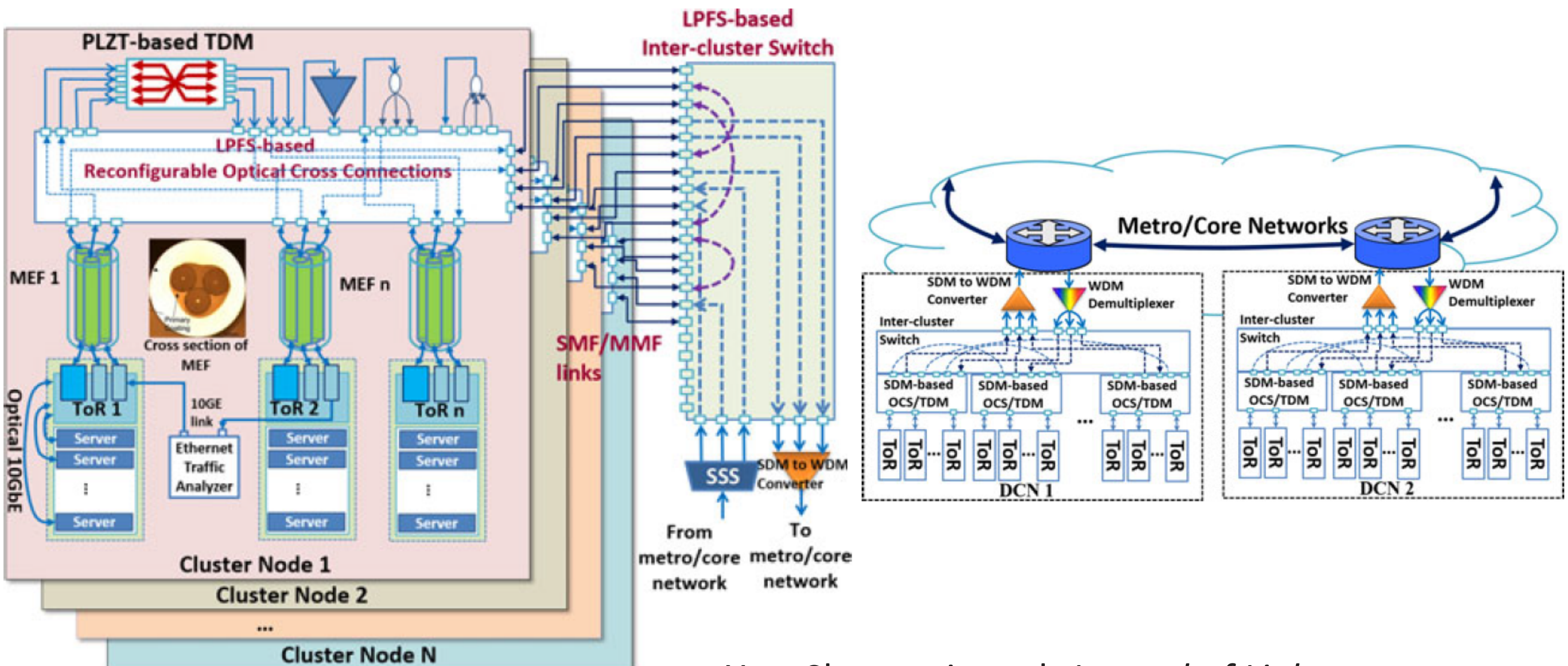
Recent Research on SDN in Cloud, Fog, Edge and DCI Networking

DISCUS: long-reach passive optical network access for backhaul mobile network and edge services



Ruffini, Marco, et al. *IEEE communications magazine* 52.2 (2014): S24-S32

Archon: a function programmable optical interconnect architecture for transparent intra/ inter data center SDM/TDM/WDM networking



Yan, Shuangyi, et al. *Journal of Lightwave Technology* 33.8 (2015): 1586-1595.

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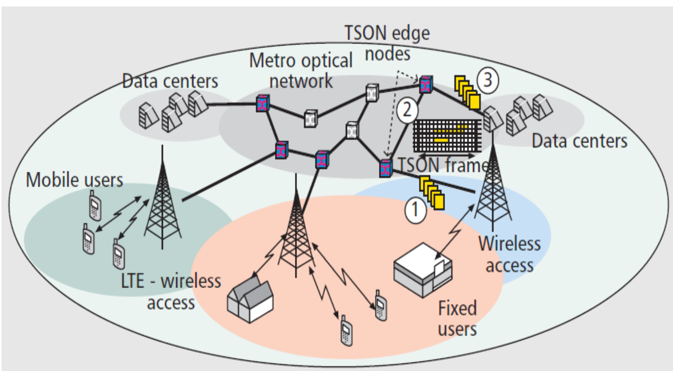
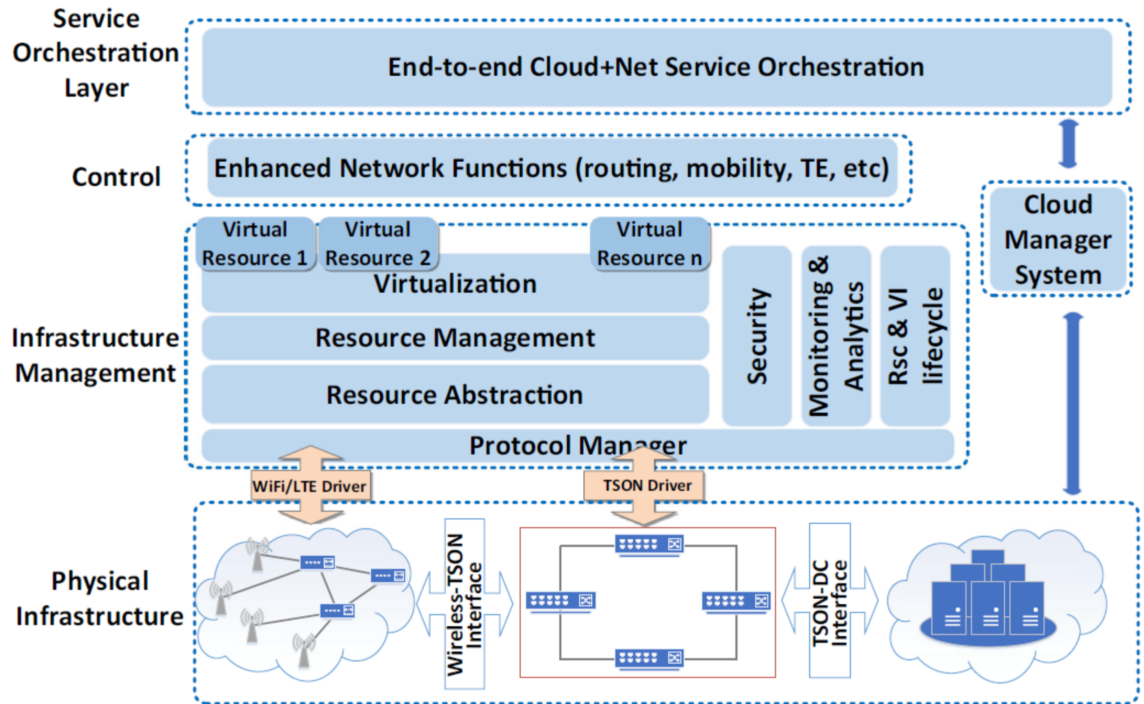
CONTENT: wireless and wired network convergence in support of cloud and mobile cloud services

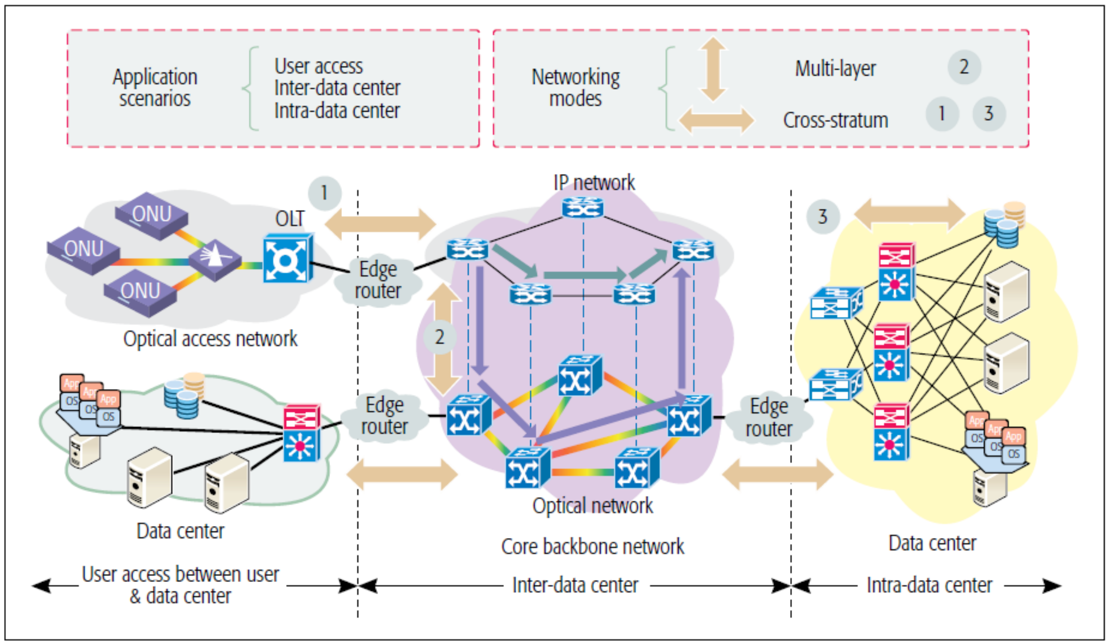


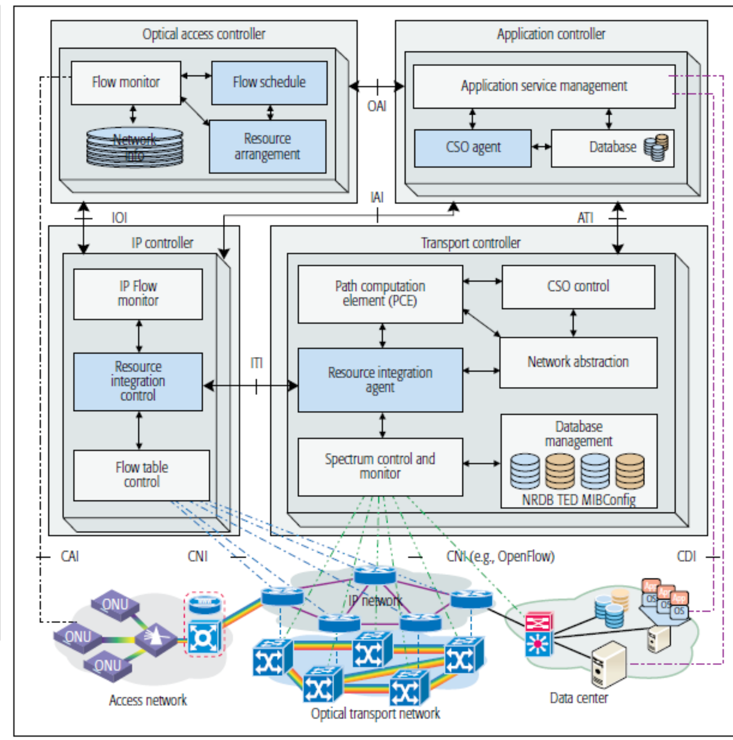


Anastasopoulos, Markos P., et al. *Photonic Network Communications* 29.3 (2015): 269-281.

Tzanakaki, Anna, et al. *IEEE Communications Magazine* 51.8 (2013): 155-161.

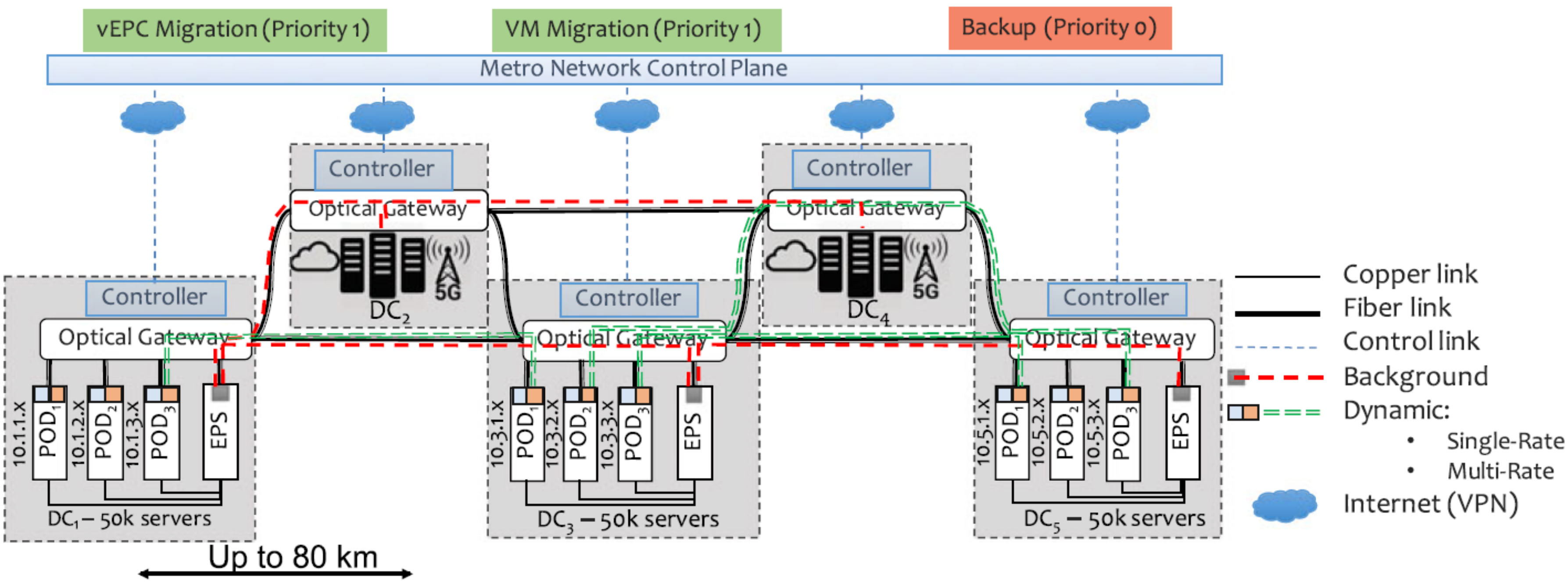
SUDOI: software defined networking for ubiquitous data center optical interconnection





Yang, Hui, et al. *IEEE Communications Magazine* 54.2 (2016): 86-95.

Flexible, converged intra- and inter-data center network architecture for geographically distributed metro data Centers



Samadi, Payman, et al. *Journal of Lightwave Technology* 35.6 (2017): 1188-1196.
Fiorani, Matteo, et al. *Journal of Optical Communications and Networking* 9.5 (2017): 385-392.

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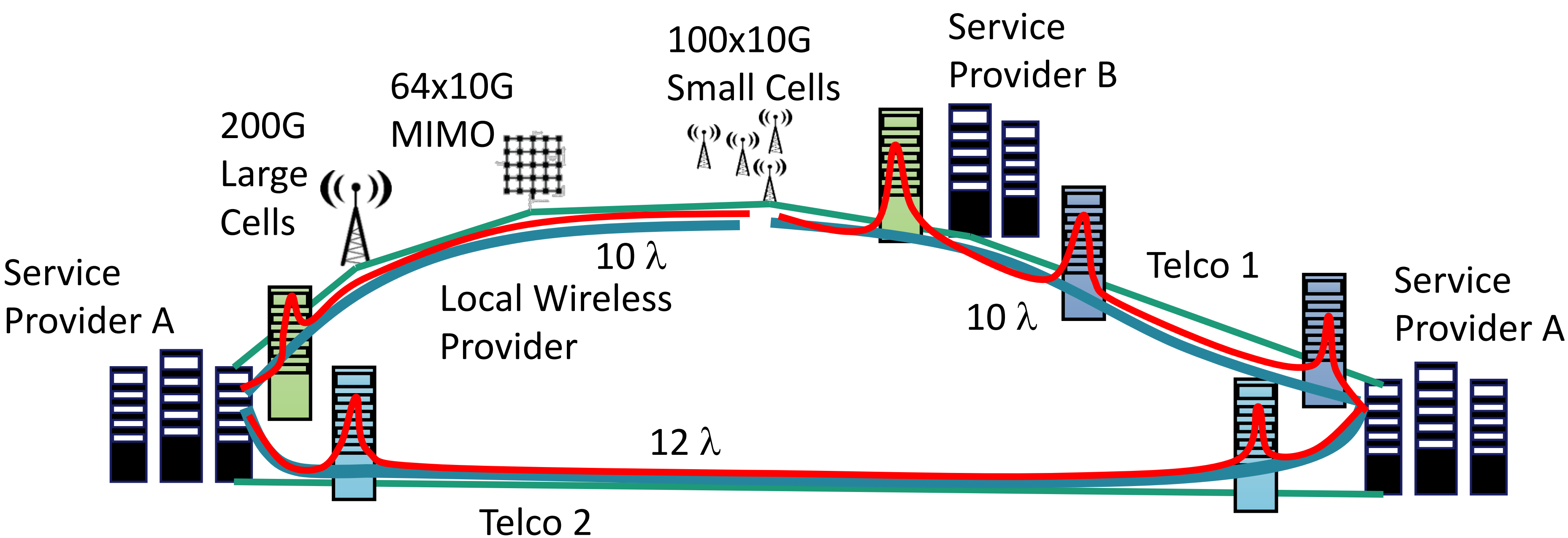
The Multi-Domain Dilemma

Moving data in and between data centers to support smart communities

- 10 Tb/s/km^2 for 5G peak densities (NGMN.ORG)
  - 10 Tb/s = 100x100Gb/s DWDM channels
- Millisecond latency (tactile)



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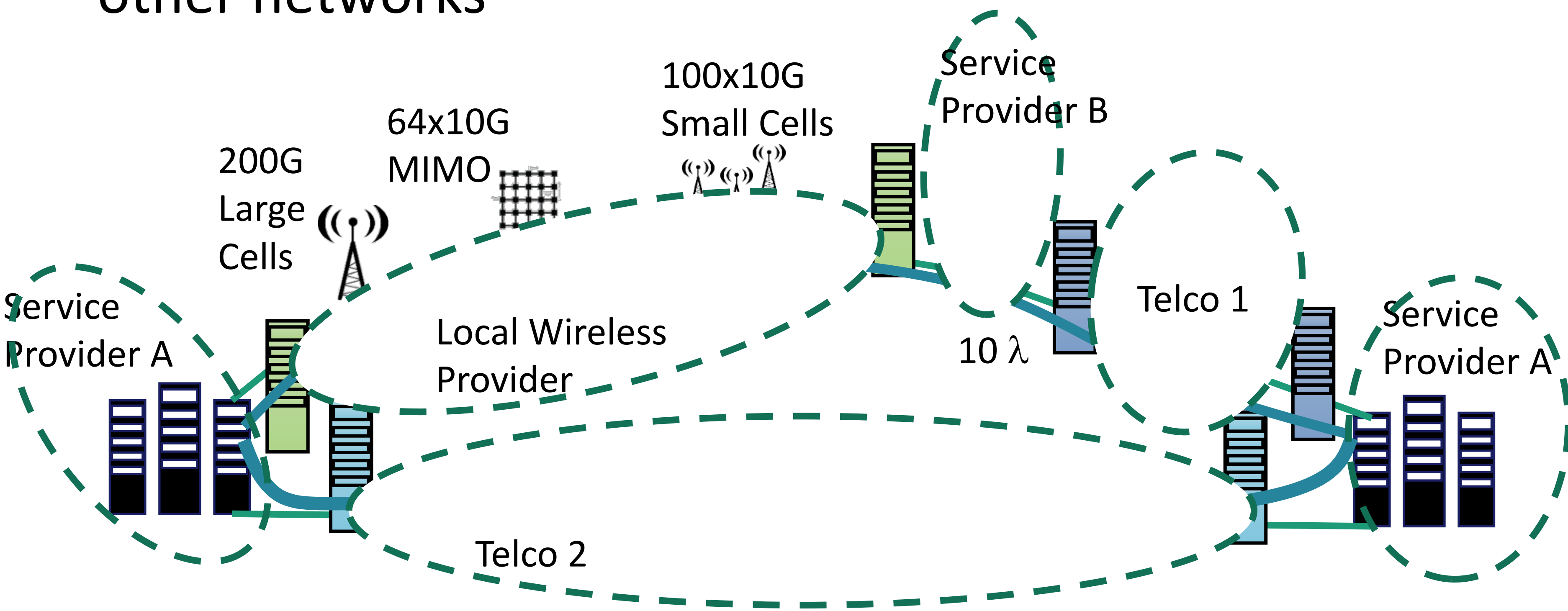
Network Domains: Autonomous Systems

- Service Provider A only sees its own network/data center and the peering points or access points in other networks



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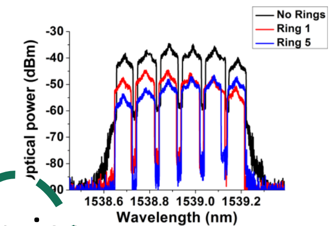
CIAN-CONNECT-IPIC-CSRI Agile Cloud

- Setup signals across autonomous domains
- Use Si Photonics/integrated phot. switches
- Optical Circuit Switching & OPM

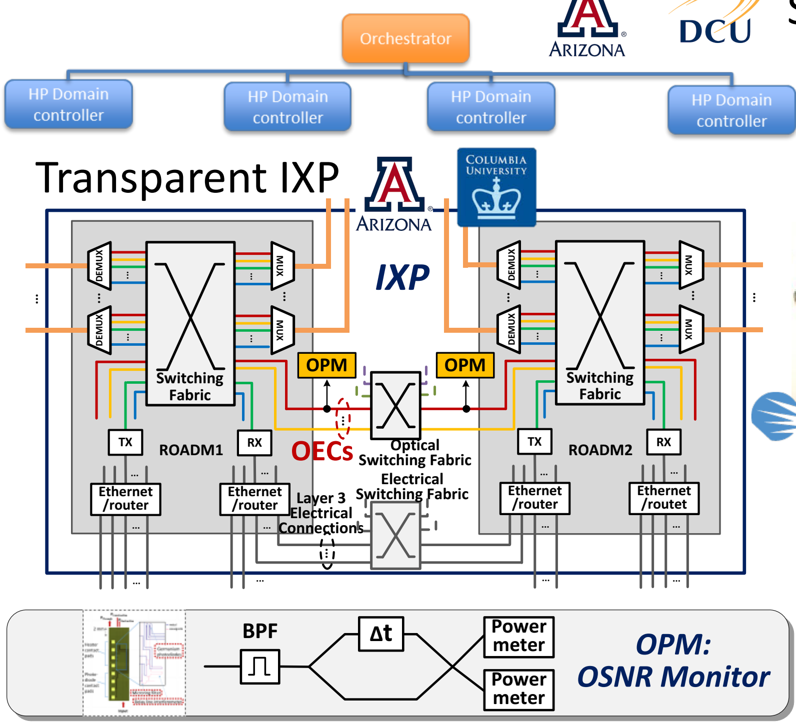
DCU Columbia University

Superchannel transmission

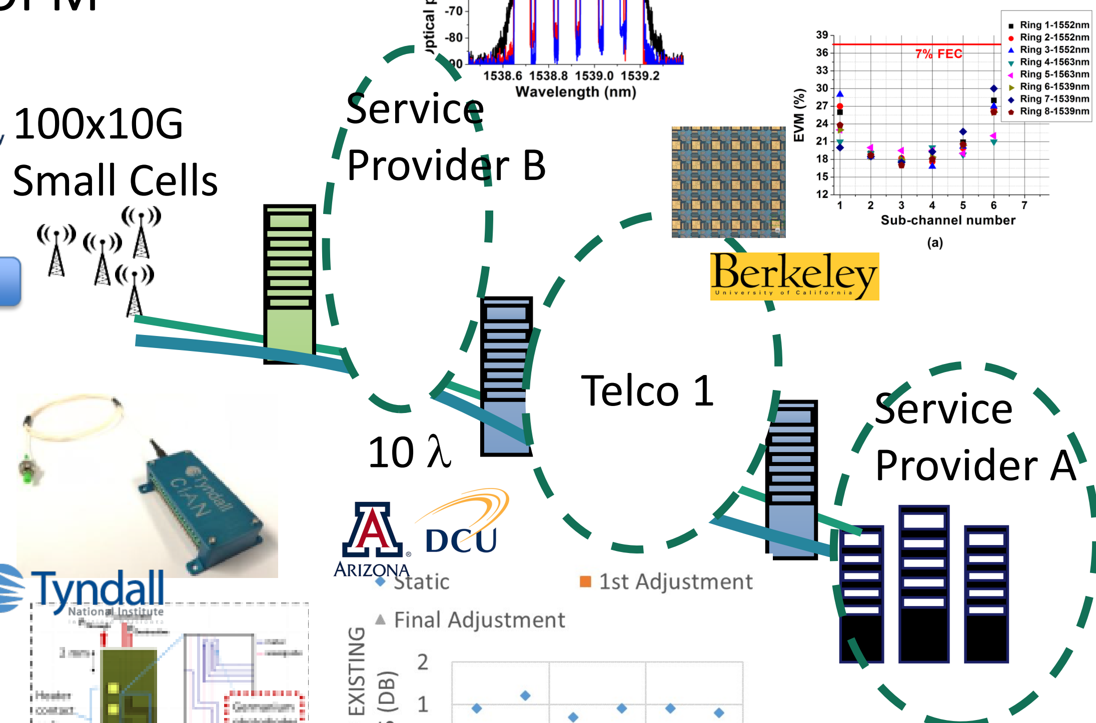


SDN/Large Scale Emulation

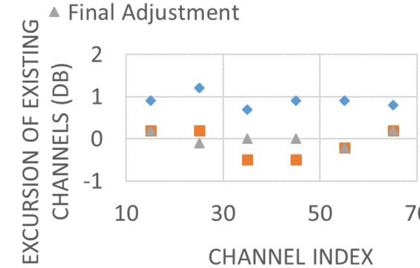
Trinity College Dublin, Ulster University, Arizona, DCU



100x10G Small Cells



Tyndall National Institute



Dual Chn Excursion-Free OCS

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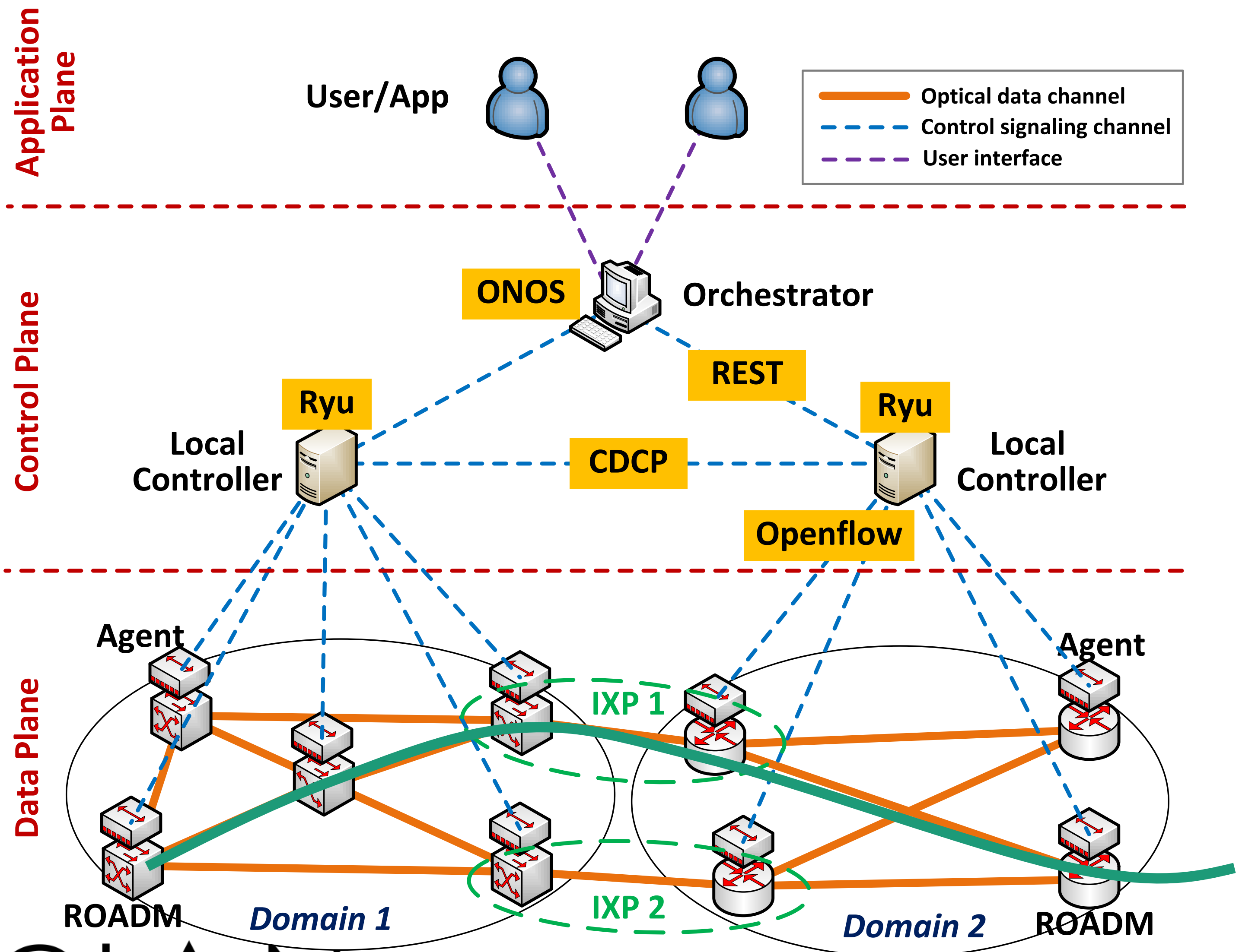
NSF
Science Foundation Ireland sfi For what's next
Department for Employment and Learning www.delni.gov.uk

Transparent Software Defined Exchange (tSDX)/Multi-Domain Transmission



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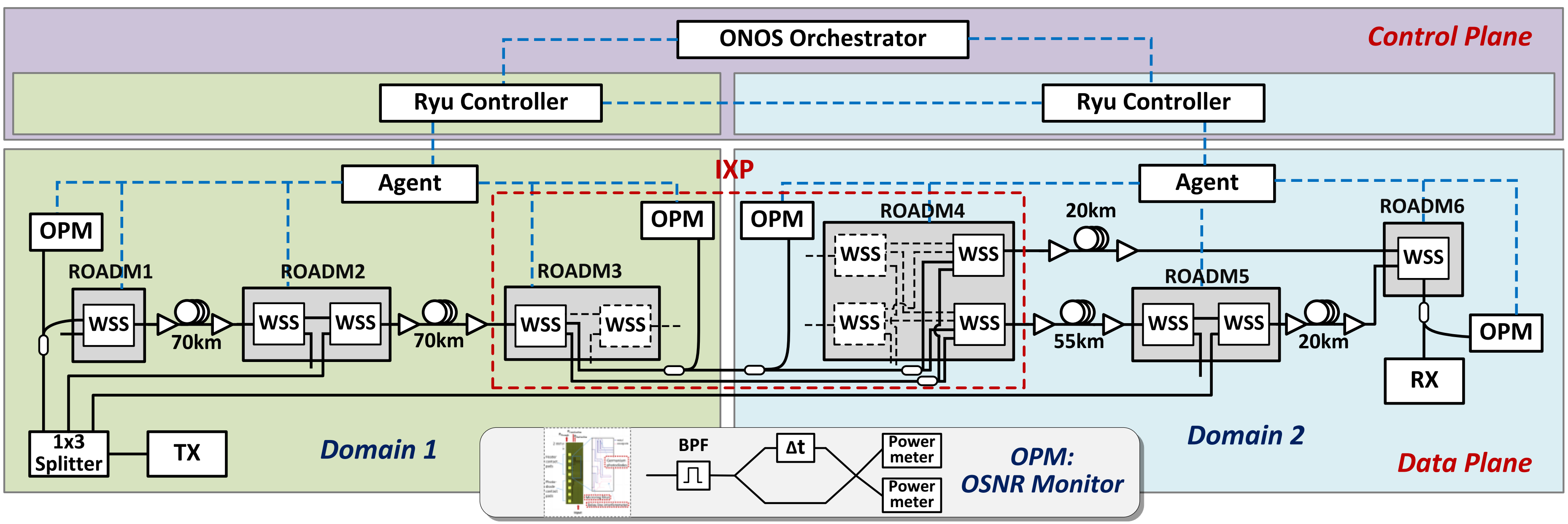
Y. Li, et. al., OFC 2017 Postdeadline

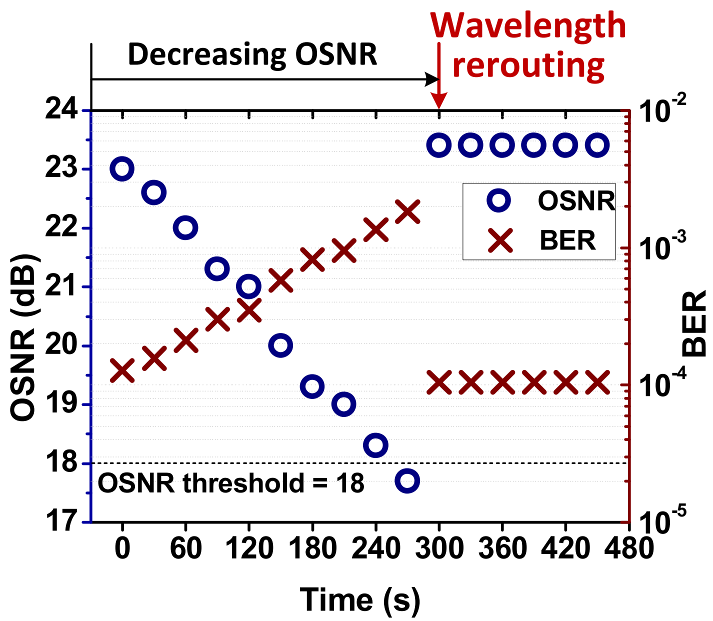
OPM Based Transparent IXP: tSDX

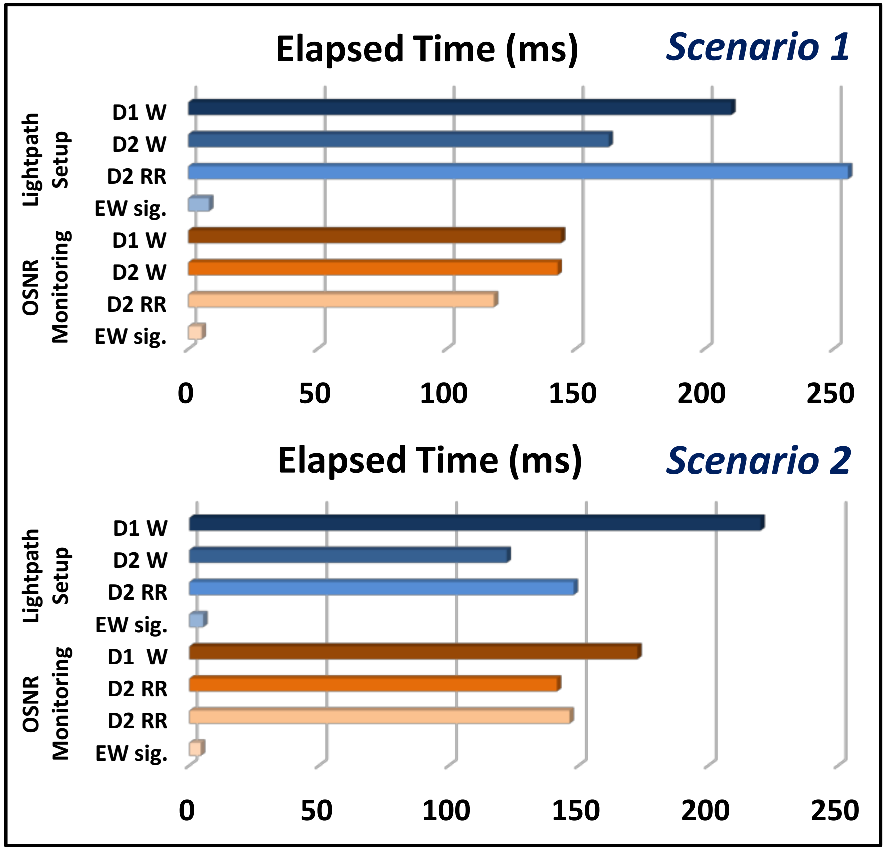
- Establish optical connections transparently through Internet peering points
- Use SDN + OPM: transparent Software Defined Exchange (tSDX)
- OPM in each domain enforces SLAs



tSDX SLA Enforcement

- Repair connection based on OPM (OSNR) monitoring across domains
- Sub-250 ms for each operation





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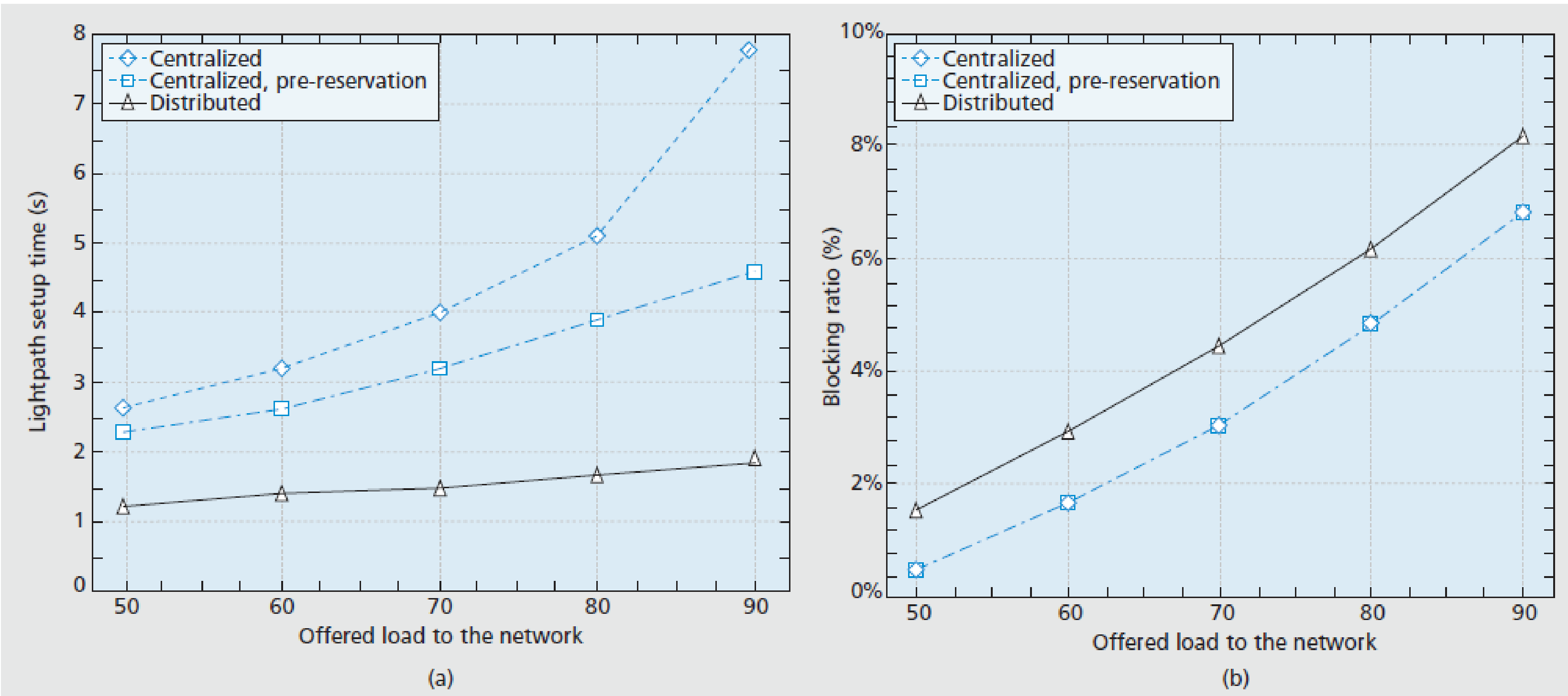
Previous Intra-Domain Path Computation and Establishment



Computation, signaling, and protocol part: ~ 1 second

CORONET: 700ms

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

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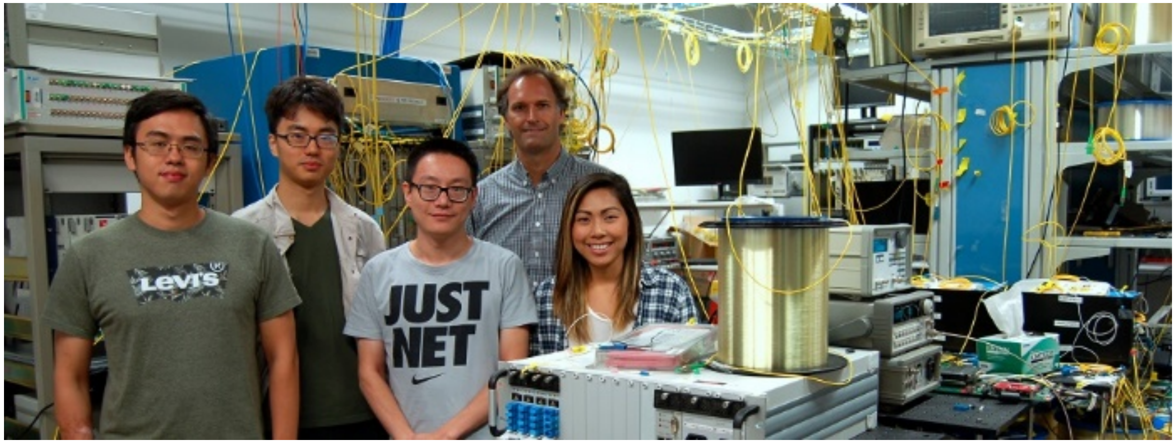
Conclusions

- Optical systems will play important role in many key application areas for data centers at the network edge: smart cities, 5G wireless, data centers, and IoT
- DCI, Fog or edge cloud networks are emerging in support of the application needs
- Industry is seeking disaggregation and software control to support this trend
- Optical communication systems still not 'programmable' performance
  - Many open questions with regard to QoT and optical physical layer control for this new application space
  - Integrated photonics will play an important role with new performance trade-offs
- Several large projects are considering edge cloud networks and their SDN control
  - Including transparent multi-domain solutions
  - Still early days….

The Team

- Dr. Yao Li
- Weiyang Mo
- Mariya Bhopalwala
- Jiakai Yu
- Shengxiang Zhu



- Nea Sample
- Sam Celaya

- Dr. Houman Rastegarfar
- Janelle Pilar

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Thank You

Our Group:
osn.webhost.uits.arizona.edu

CIAN:
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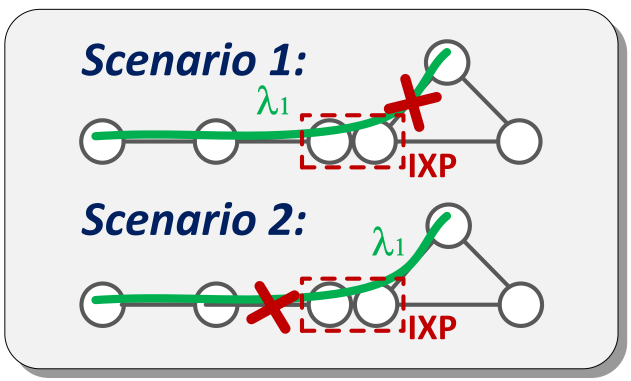
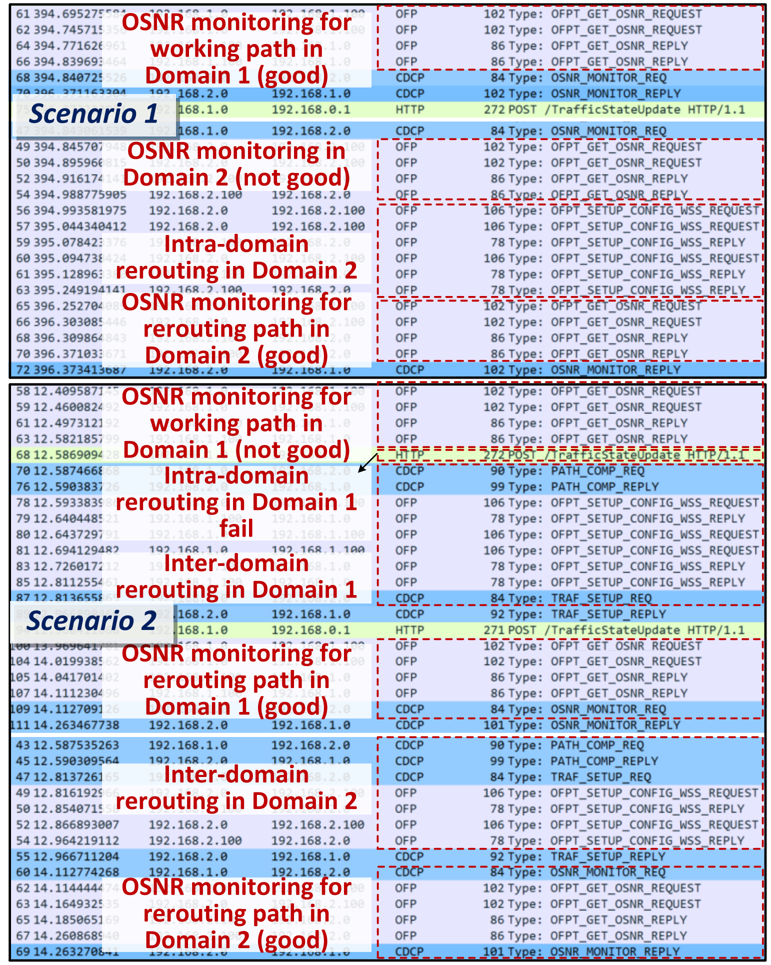
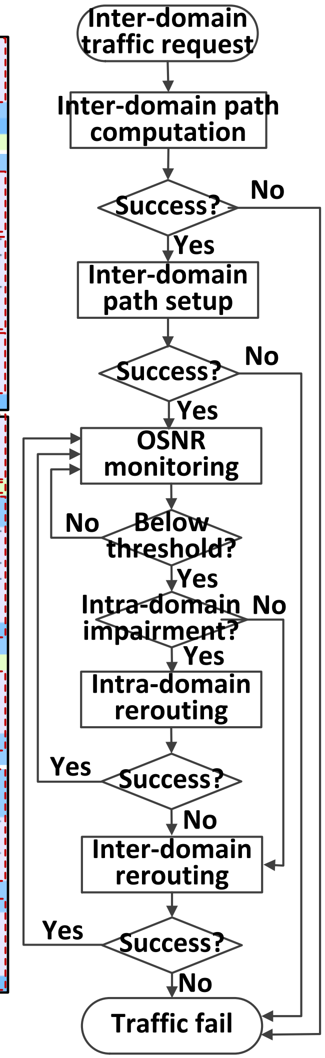
OPM Based Transparent IXP: tSDX

- Two Scenarios:
- Intra-domain re-routing
- Inter-domain re-routing

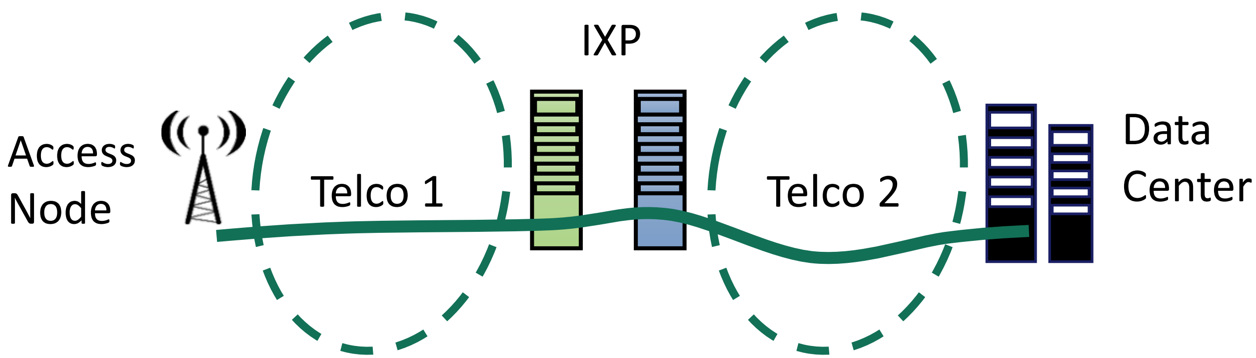






Why 'Programmable' Optics?

- Need to setup connections through Telco 1 network and Telco 2 network without knowing topology and other internal features
  - Each Telco domain needs to do this automatically and independently
- Specify performance requirements at end points and service level agreement (SLA) requirements
  - E.g. End to end OSNR, optical power, max. latency, max setup time, FEC
- Need to enforce SLA through continuous monitoring at IXP
  - Identify/localize faults
  - Assign responsibility and corrective measures



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