Emerging Technologies: Cloud Computing, Networking Testbeds, and More

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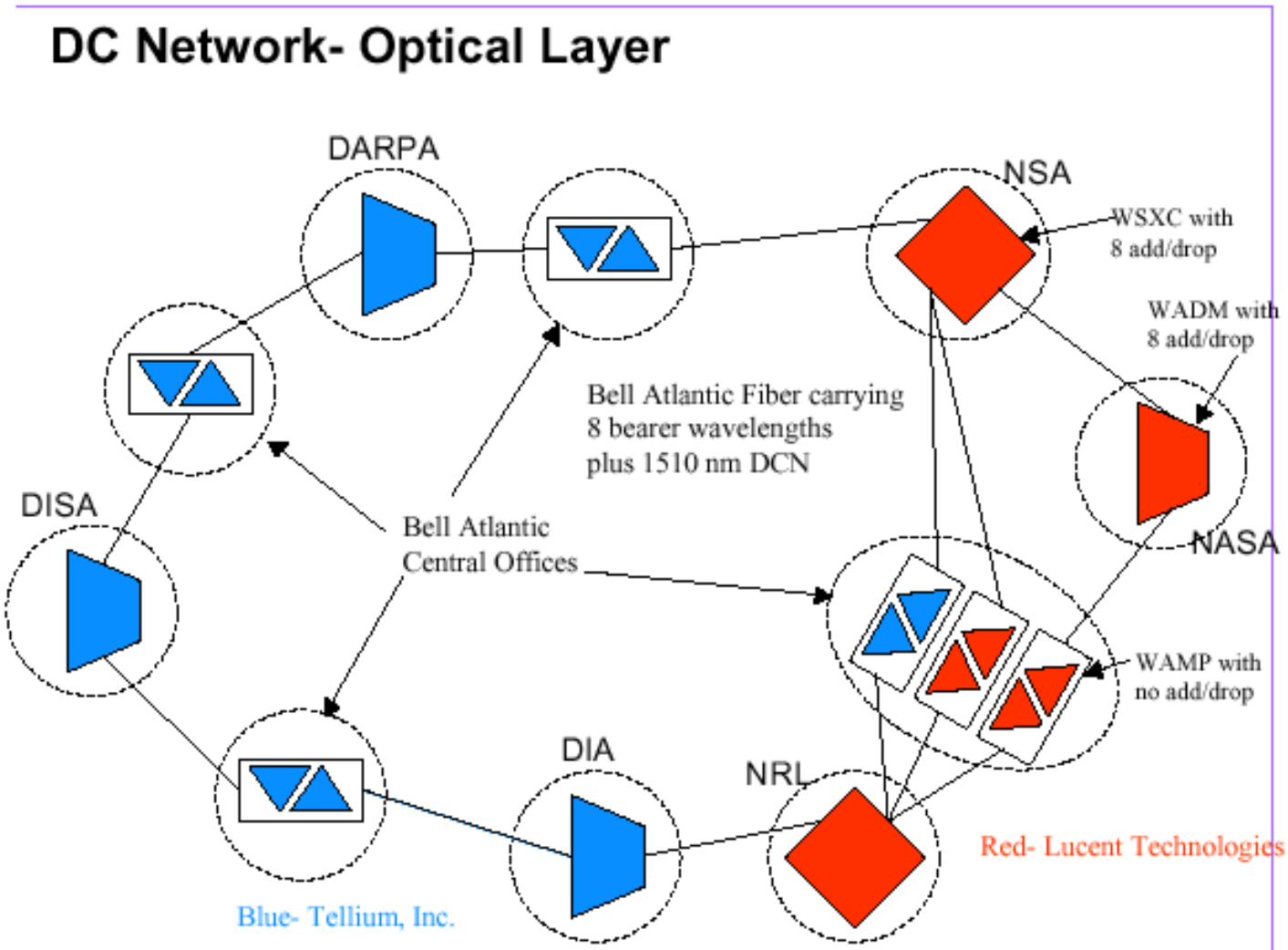
ATD-MONET DC network



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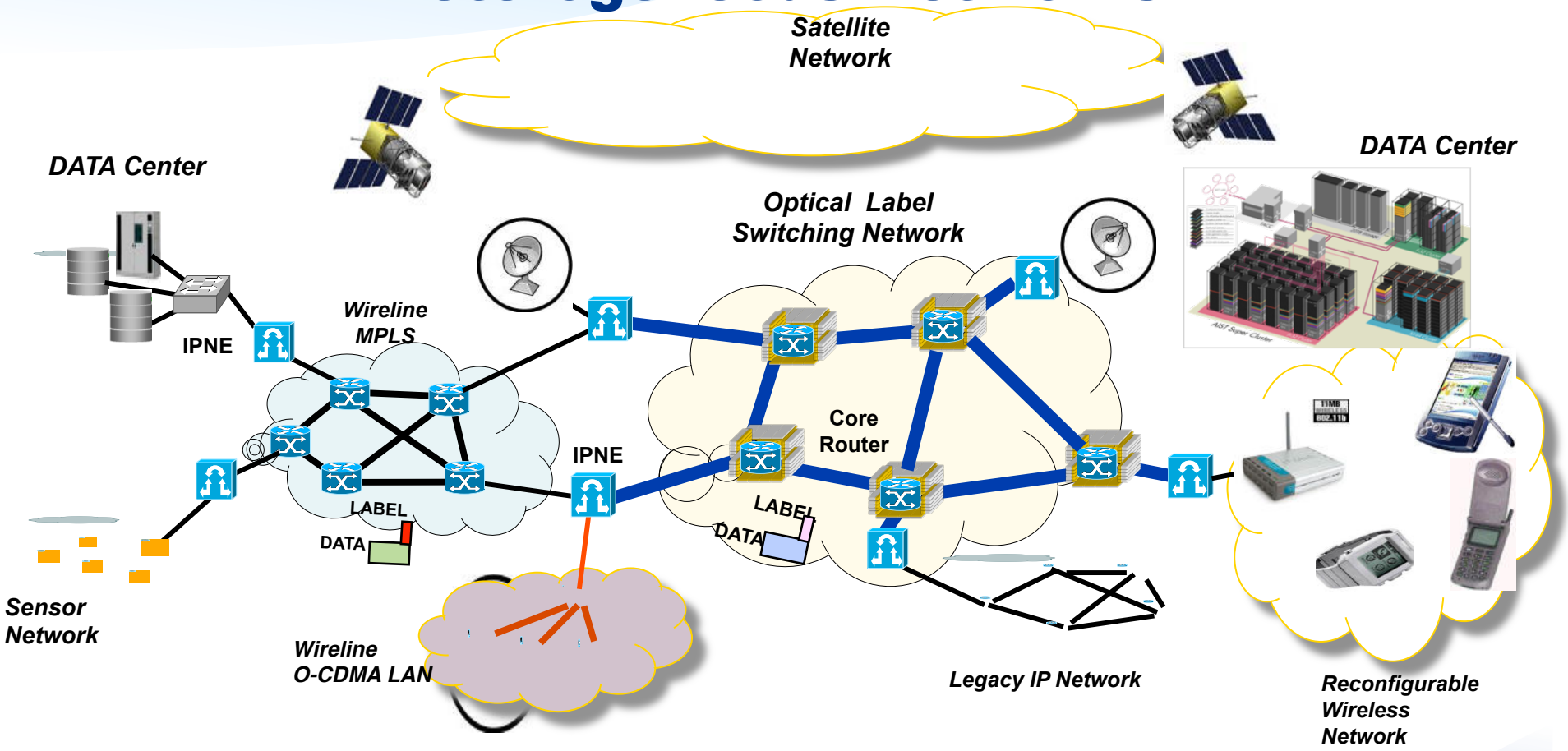
Information Communication Technology in Heterogeneous Networks



- Diverse applications over Heterogeneous Technologies
- Any-application-over-IP; IP-over-any-physical-layer; End-to-end principle
- "Faster", "Higher", "Smarter"

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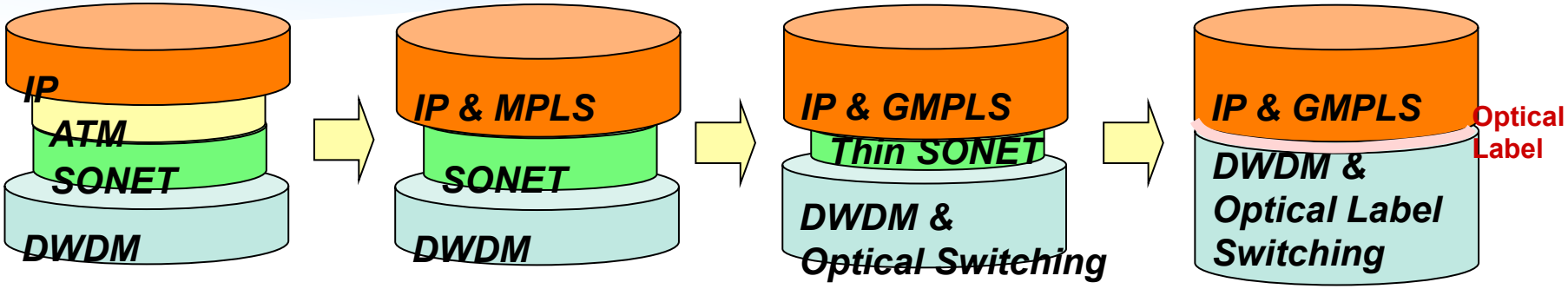
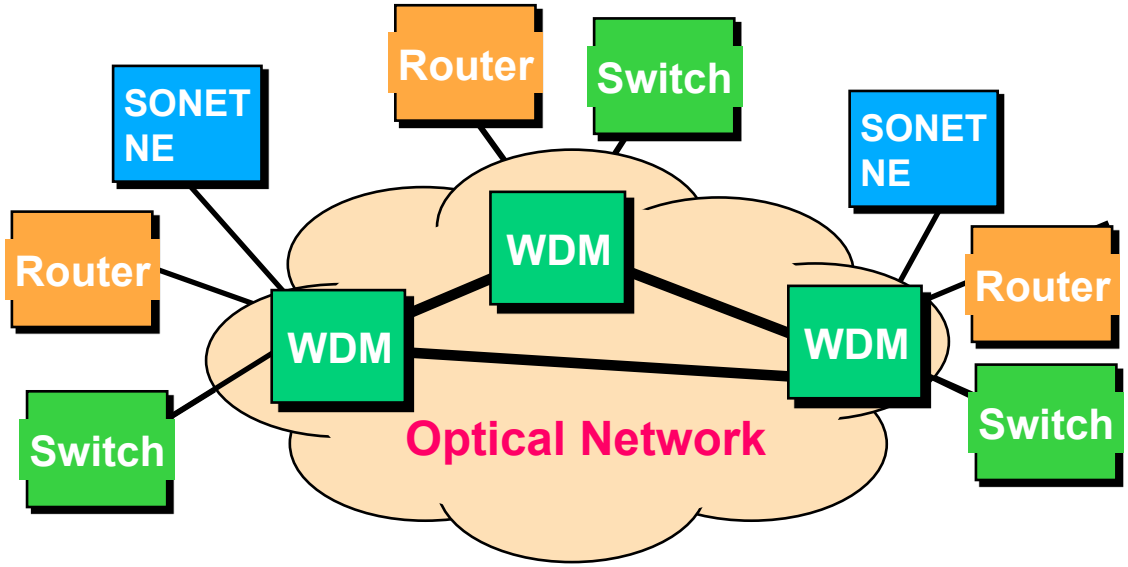
Photonic Networking Trends





Optical Internetworking

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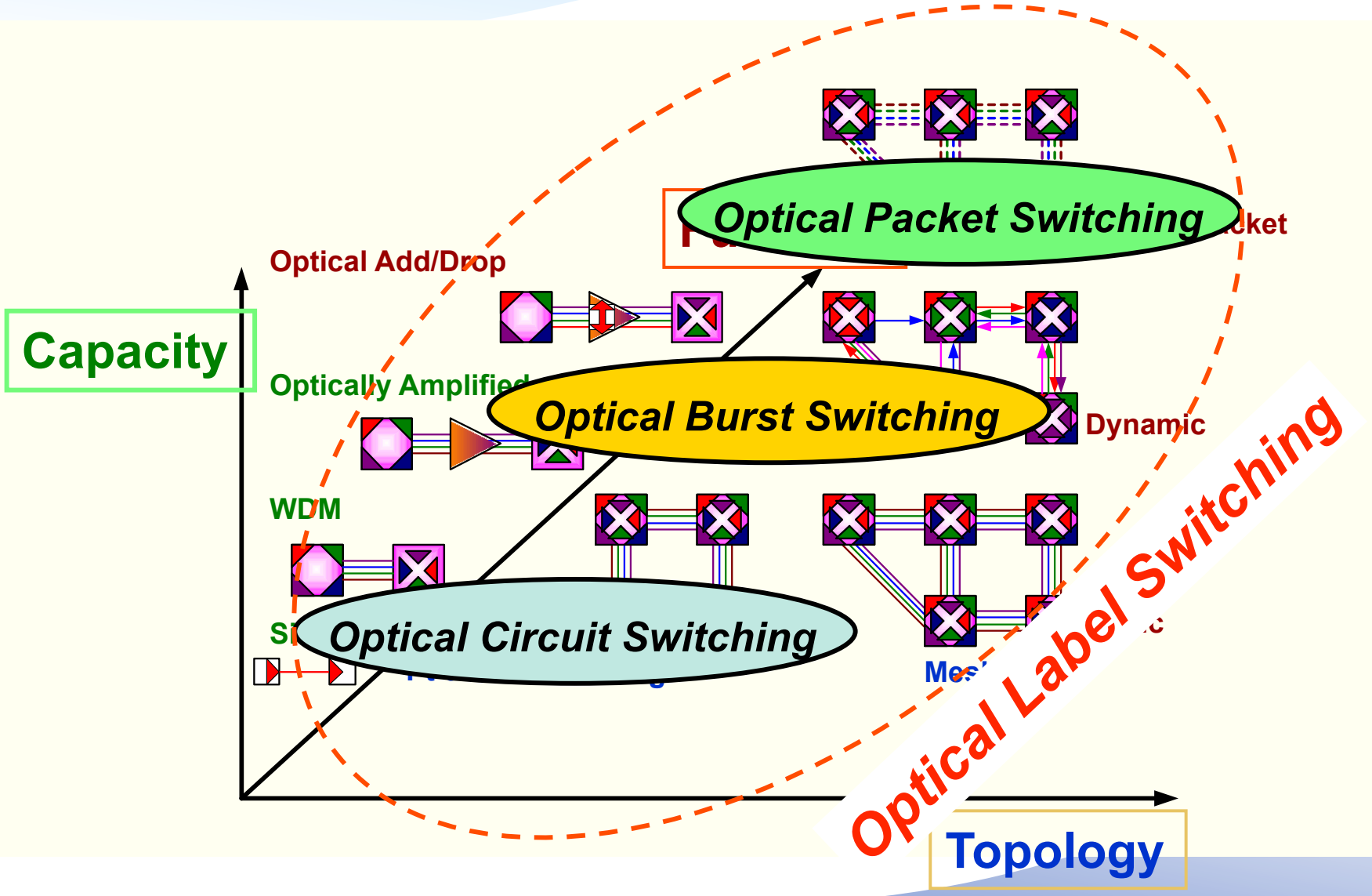
Progress in Optical Networks



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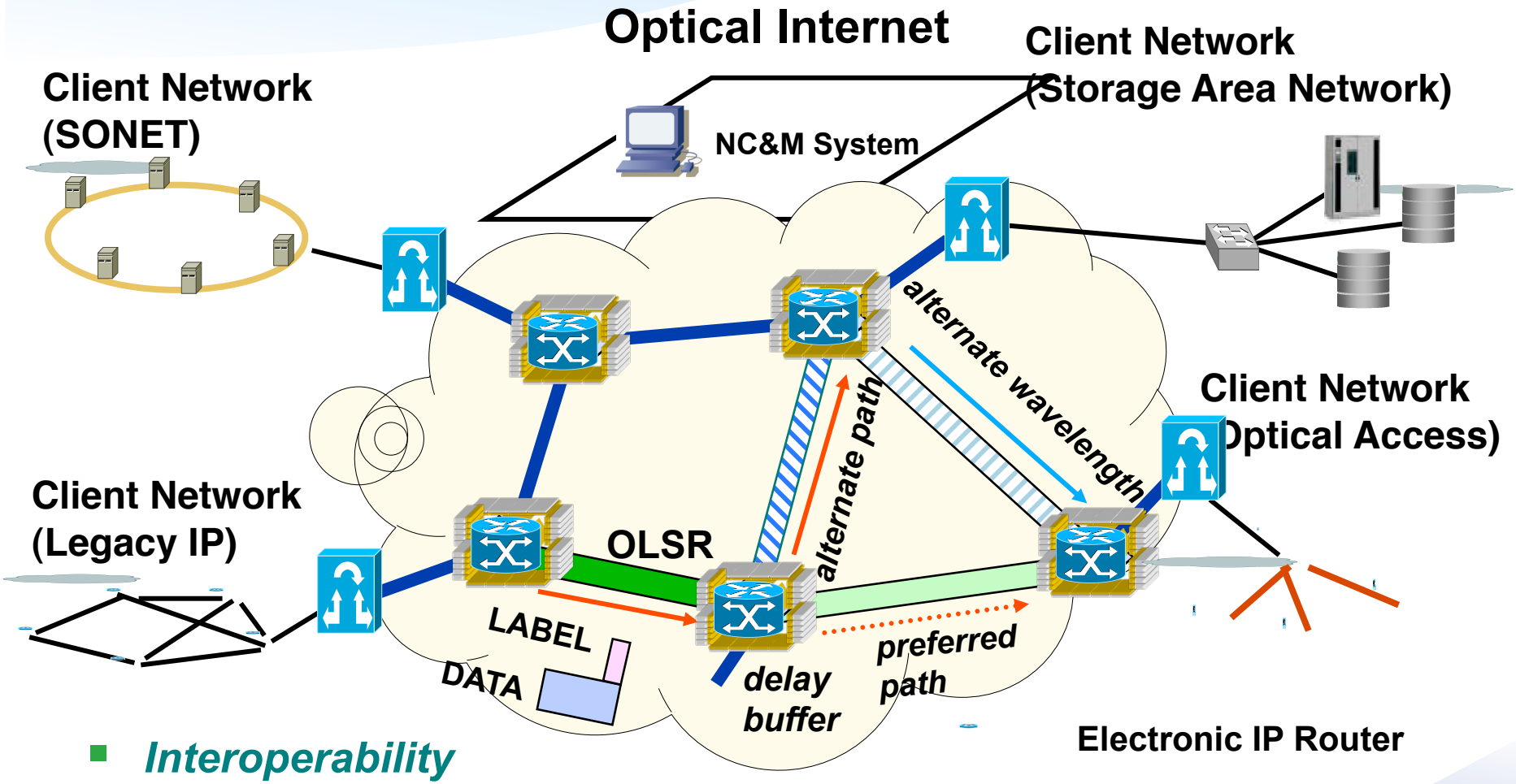
Optical-label Switching Network



- *Interoperability*
- *Transparency to Data*
- *Flexible granularity*

Electronic IP Router

Optical Label Switching Core Router

Optical Label Switching Edge Router

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Key Approaches to Optical-Label Switching

- Interoperability
  - –Multivendor NEs
  - –Circuit Switching
  - –Flow Switching
  - –Burst Switching
  - –Packet Switching
- All-Optical Data Plane and Hybrid Control Plane
- Protocol Independent Data Payload
- Minimum Buffering– low latency and jitter
- All-optical contention resolution
- Free from strict synchronization
- Support variable length packets, asynchronous forwarding
- Exploit much of the existing control plane protocol

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Optical-Label Format and Protocol (40 bit label example: can be extended or hierarchically stacked)

CLASS_A: destination oriented without TE

00	Destination	Source	Priority	Duration	Exp	QoS	ToS	OTTL

CLASS_B: destinaton oriented with TE

01	Destination	Source	Priority	Duration	TE	QoS	ToS	OTTL

CLASS_C: label based forwarding

10	Label	Priority	Duration	Exp	QoS	ToS	OTTL

CLASS_D: circuit swtching

11	Label	Priority	Set	Exp	QoS	ToS	OTTL

S. J. B. Yoo, "Optical-label switching, MPLS, MPLambdaS, and GMPLS," Special Issue on: Prospects and Challenges: Next Generation Optical Network Architectures, Optical Networking Magazine, Kluwer Academic Publishers (2002) (invited).

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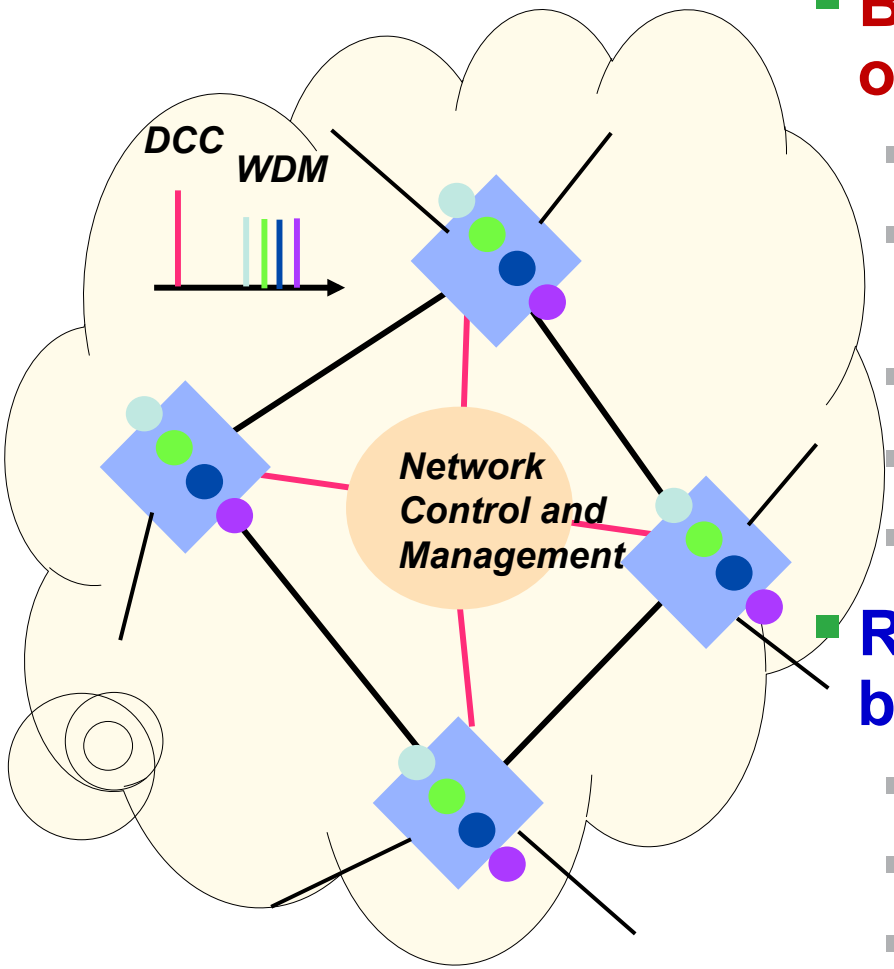
Hierarchical Control & Management



- **Brain: Interelement Control (out-of-band DCC)**
  - Slow but elaborate
  - Performance monitoring based on labels
  - Anomaly detection
  - Overall view of network (topology)
  - Listens and instructs the Reflex
- **Reflex: Distributed Control (in-band DWDM, Label based)**
  - Rapid and reflex-like
  - Packet forwarding
  - Anomaly detection
  - Communicates with the Brain

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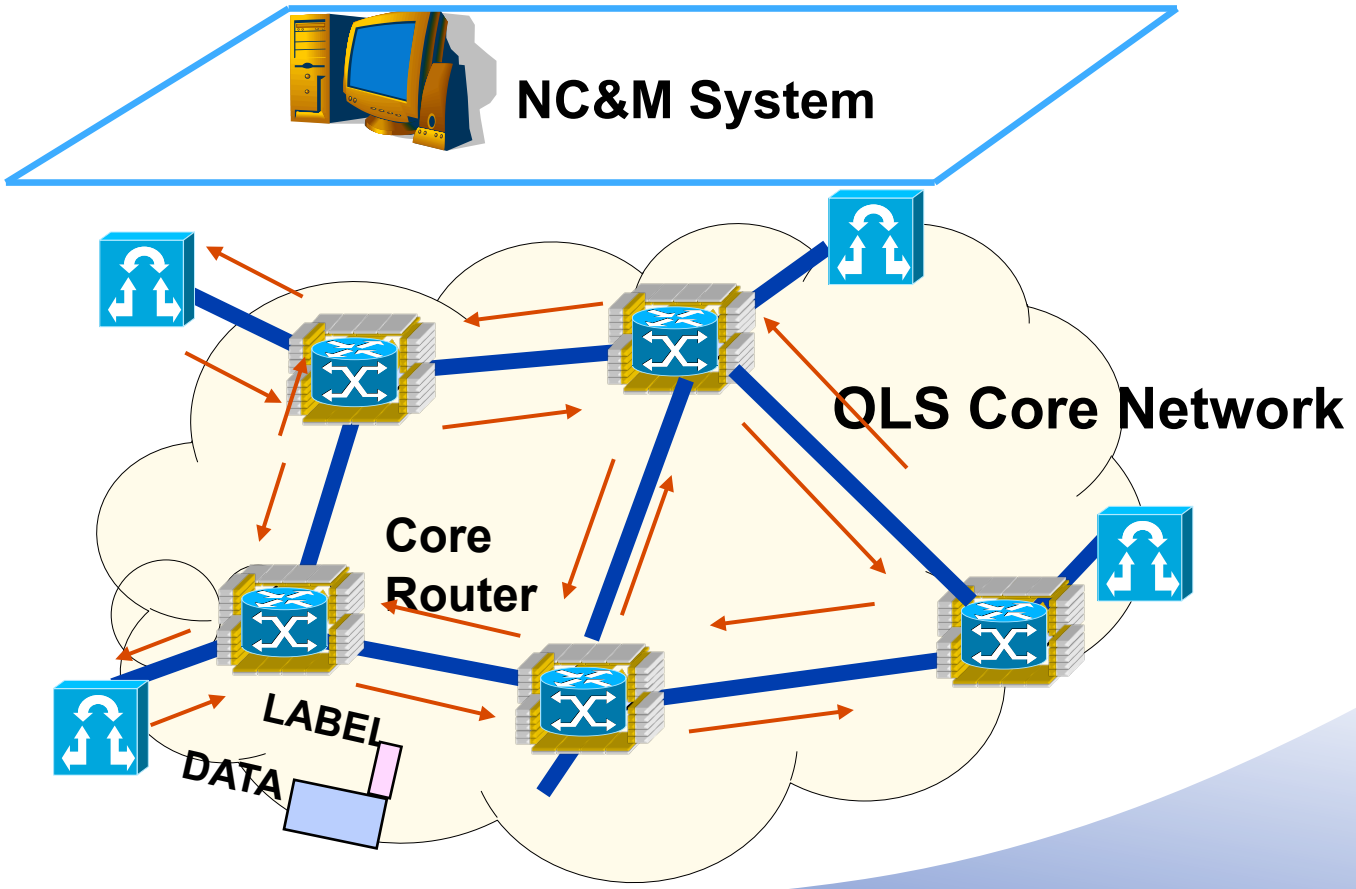
Monitoring: Getting a Big Picture

Collected Labels can tell NC&M how much sourcing and sinking are going on at each node
Identify pattern of attack (e.g. DoS) via Datamining



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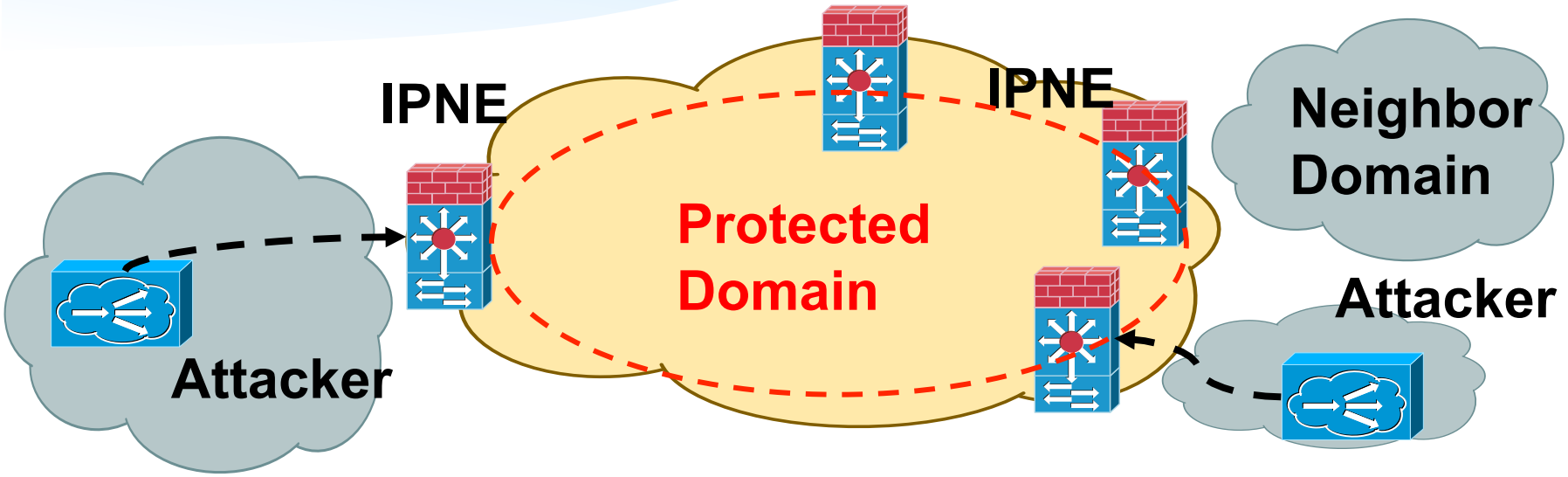
IPNE: Detect Anomaly and Intrusion



- The IPNEs surrounding a domain can detect anomalies/intrusion by monitoring traffic;
- The IPNEs will scan through data packets and mark the relevant security information;
- All network elements will “watch” each other to detect the compromised ones;

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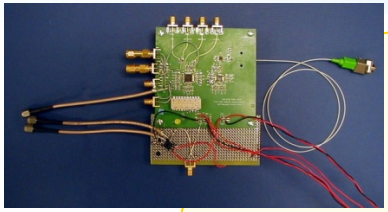
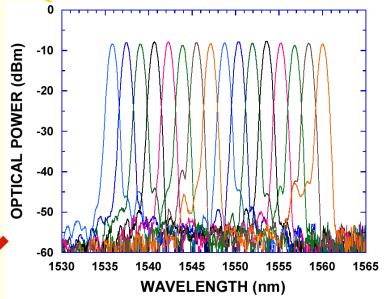
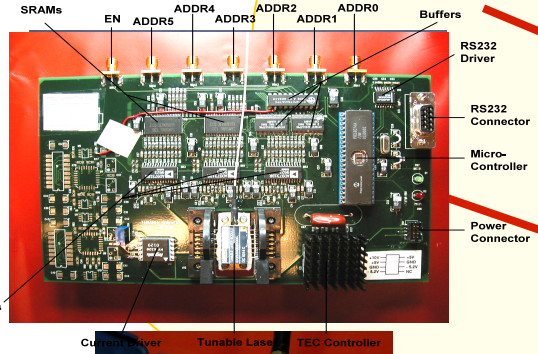
All-Optical Label Switching Router

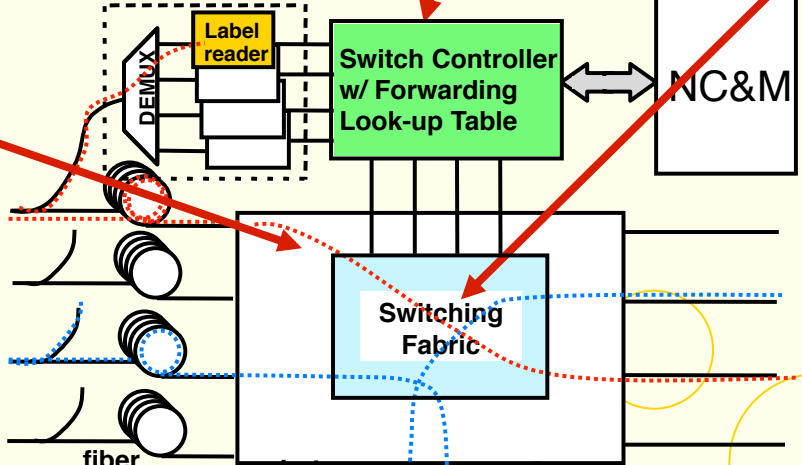
In support of agile and energy efficient networking

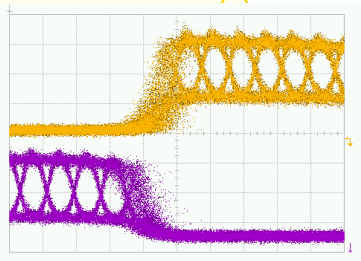






Label Processing Module-TI (LP-TI)





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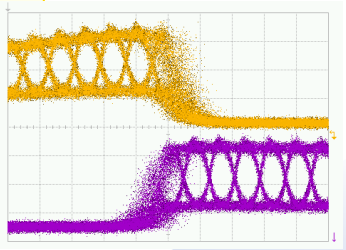

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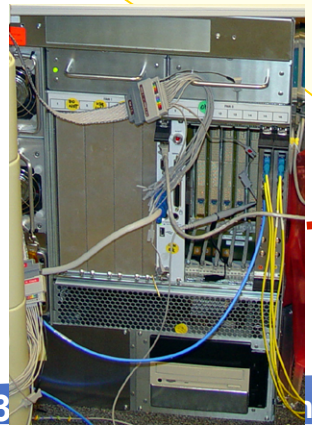
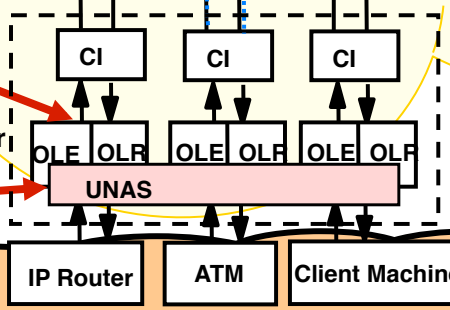
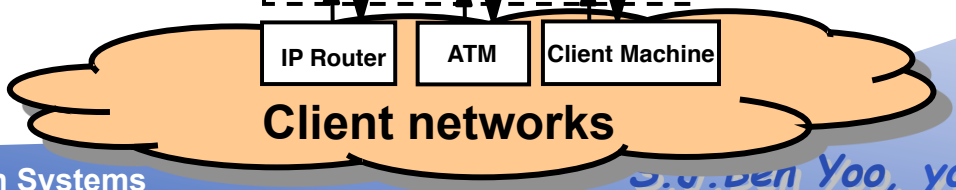




OLS Edge Router



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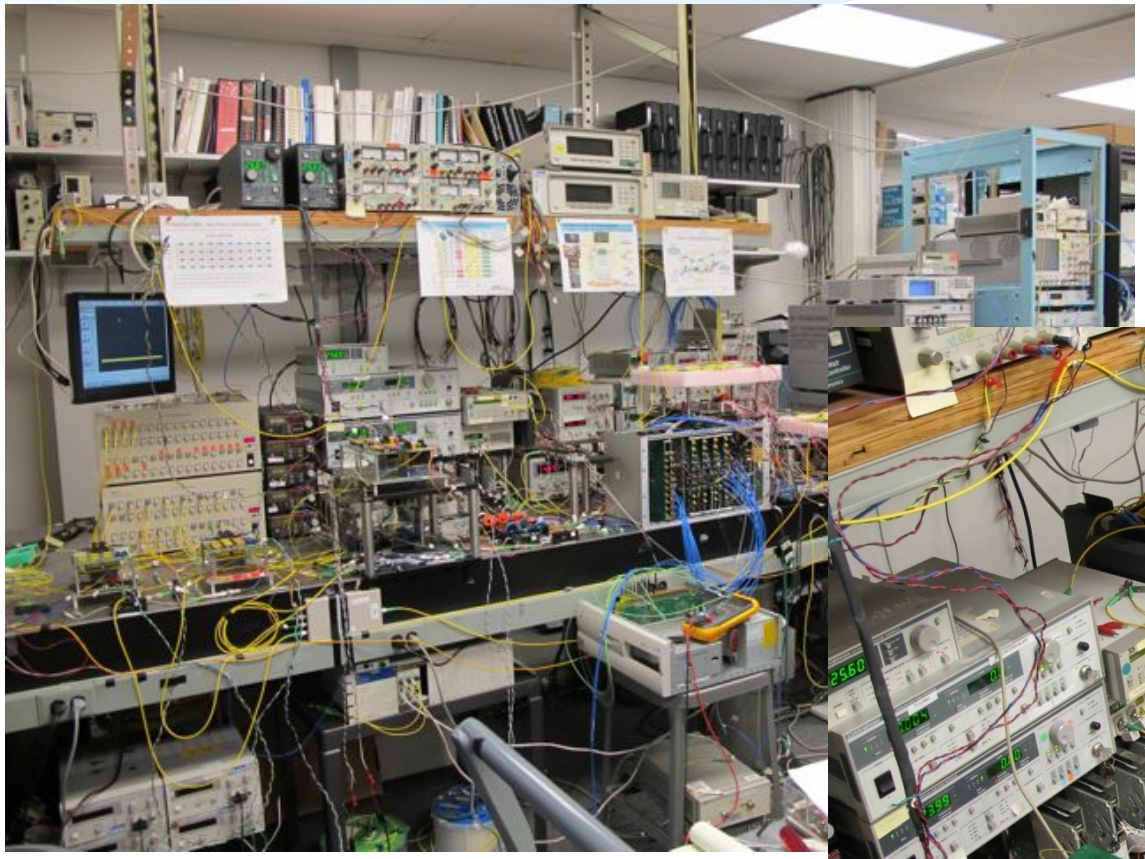
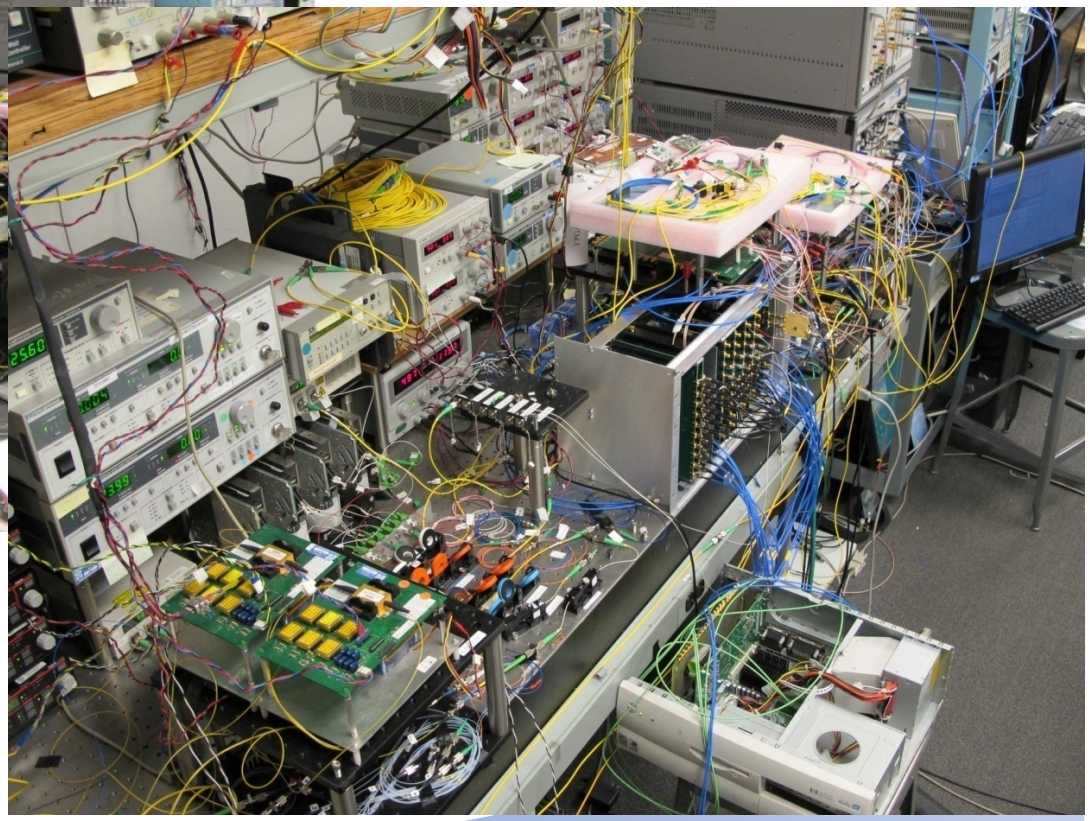
Full View of the Optical Label Switching Router Testbed Setup





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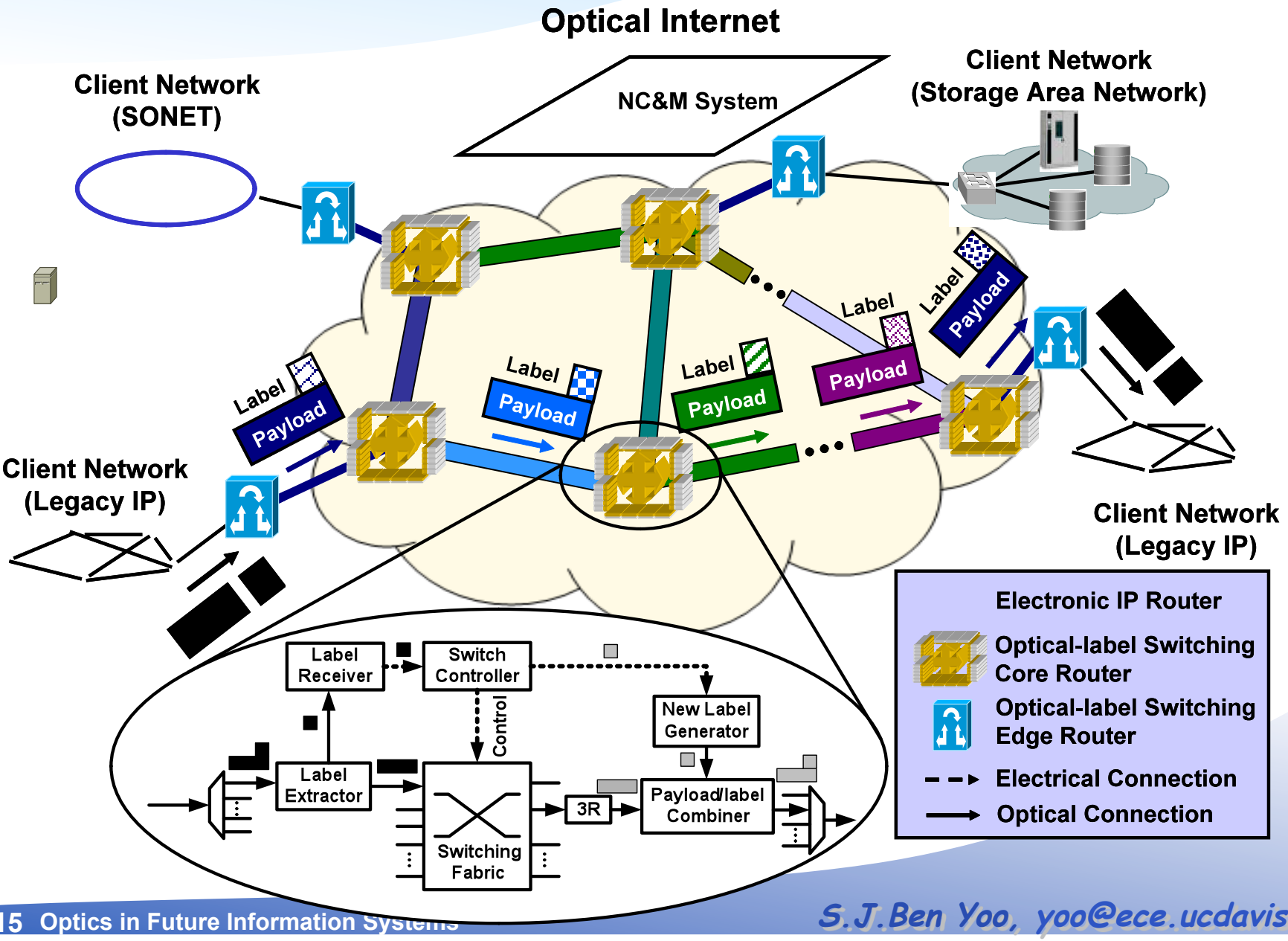
Scalability of OLS Network



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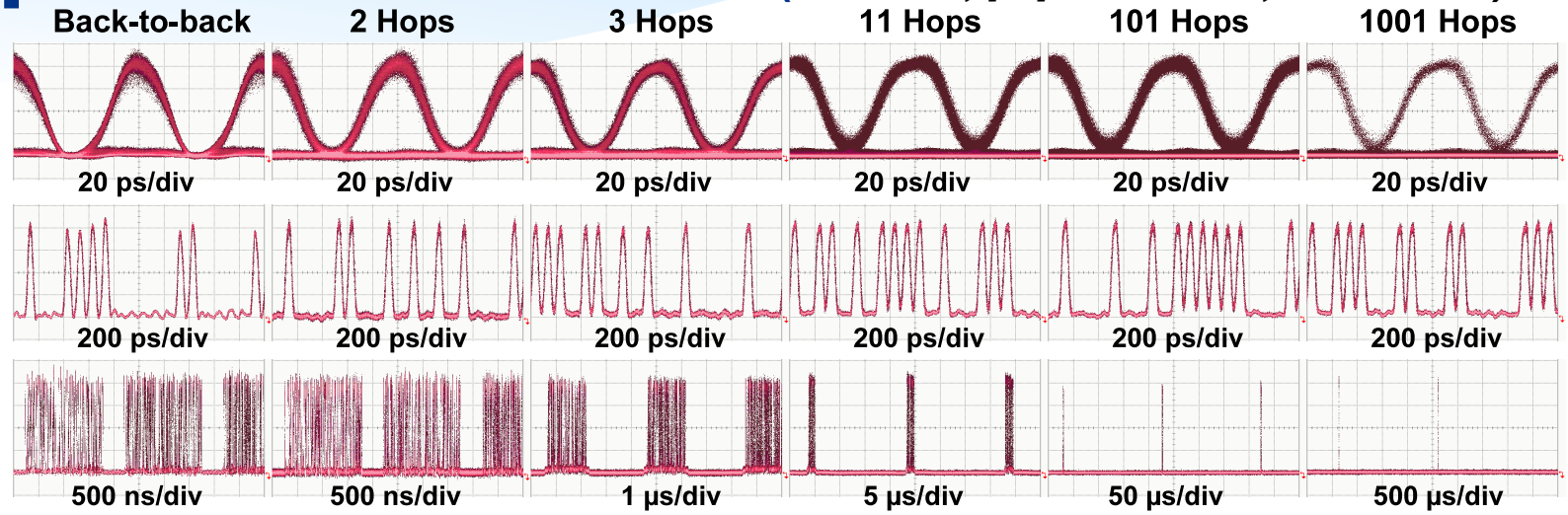
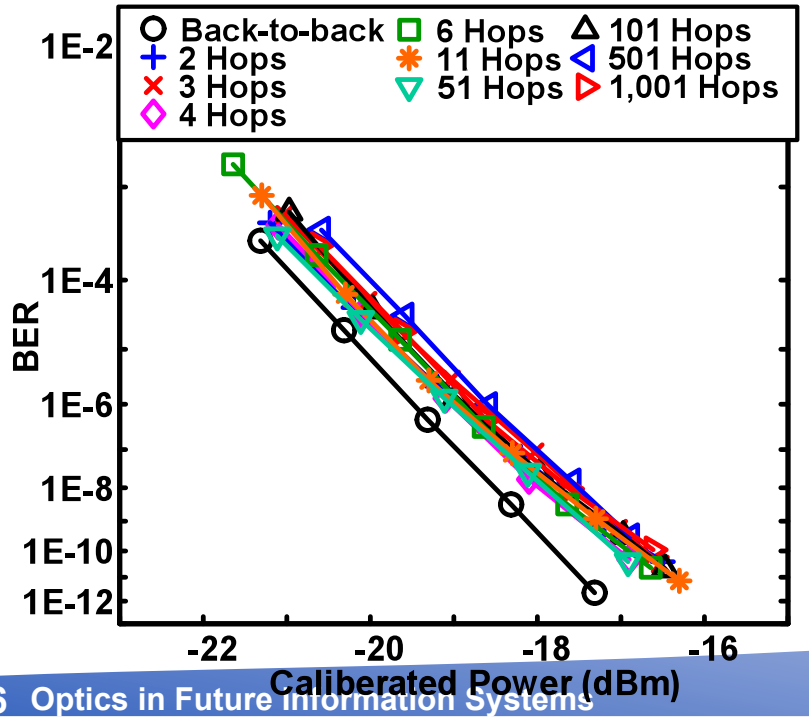
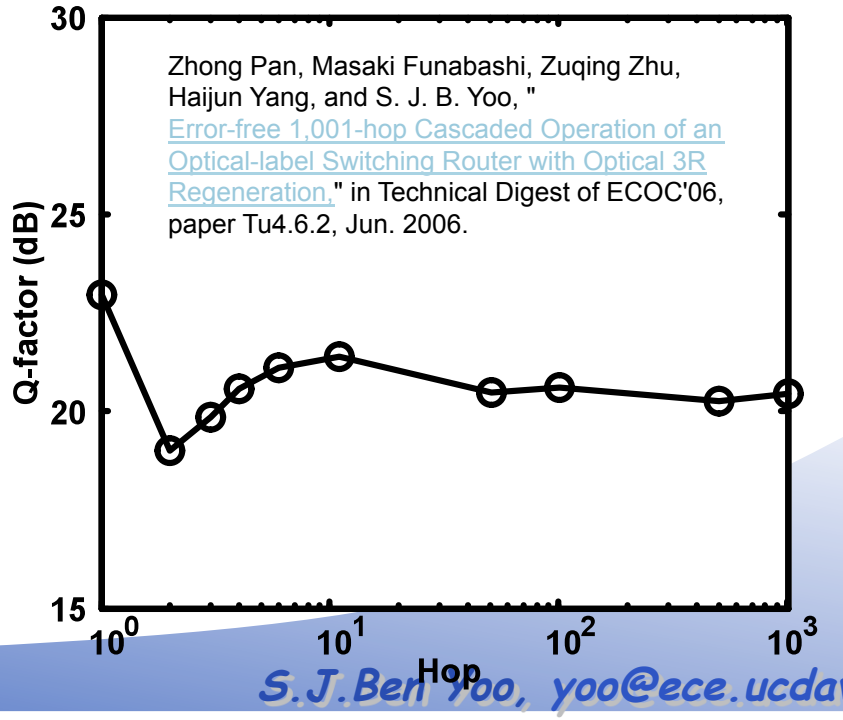
1,001 hop cascaded OLS router w/Optical 3R Experimental Results (*ECOC'06, paper Tu4.6.2, Jun. 2006.*)







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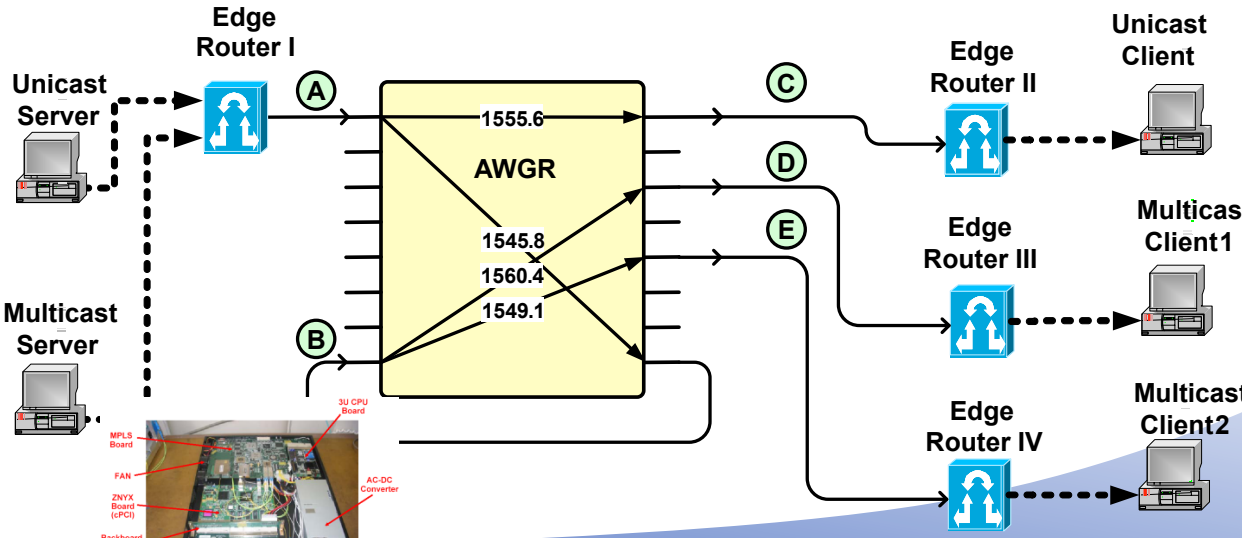
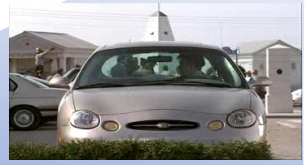
477 km Optical Label Switching Field Trial

V.J. Hernandez, et al, "First Field Trial of Optical Label Switching and Packet Dropping on a 477km NTON/ Sprint Link," OFC 2002, paper #TuY4

Video/Packet/Optical Network Testbed Demo w/ Multicast and Unicast

Packet Size (Bytes)	64	128	256	512	1024	1152	1518
PLR (%) at Unicast Client	0.01	0.01	0.01	0.04	0.09	0.04	0.07
PLR (%) at Multicast Client 1	0.01	0.01	0.01	0.00	0.00	0.04	0.02
PLR (%) at Multicast Client 2	0.01	0.00	0.07	0.04	0.02	0.00	0.05





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Slide_1

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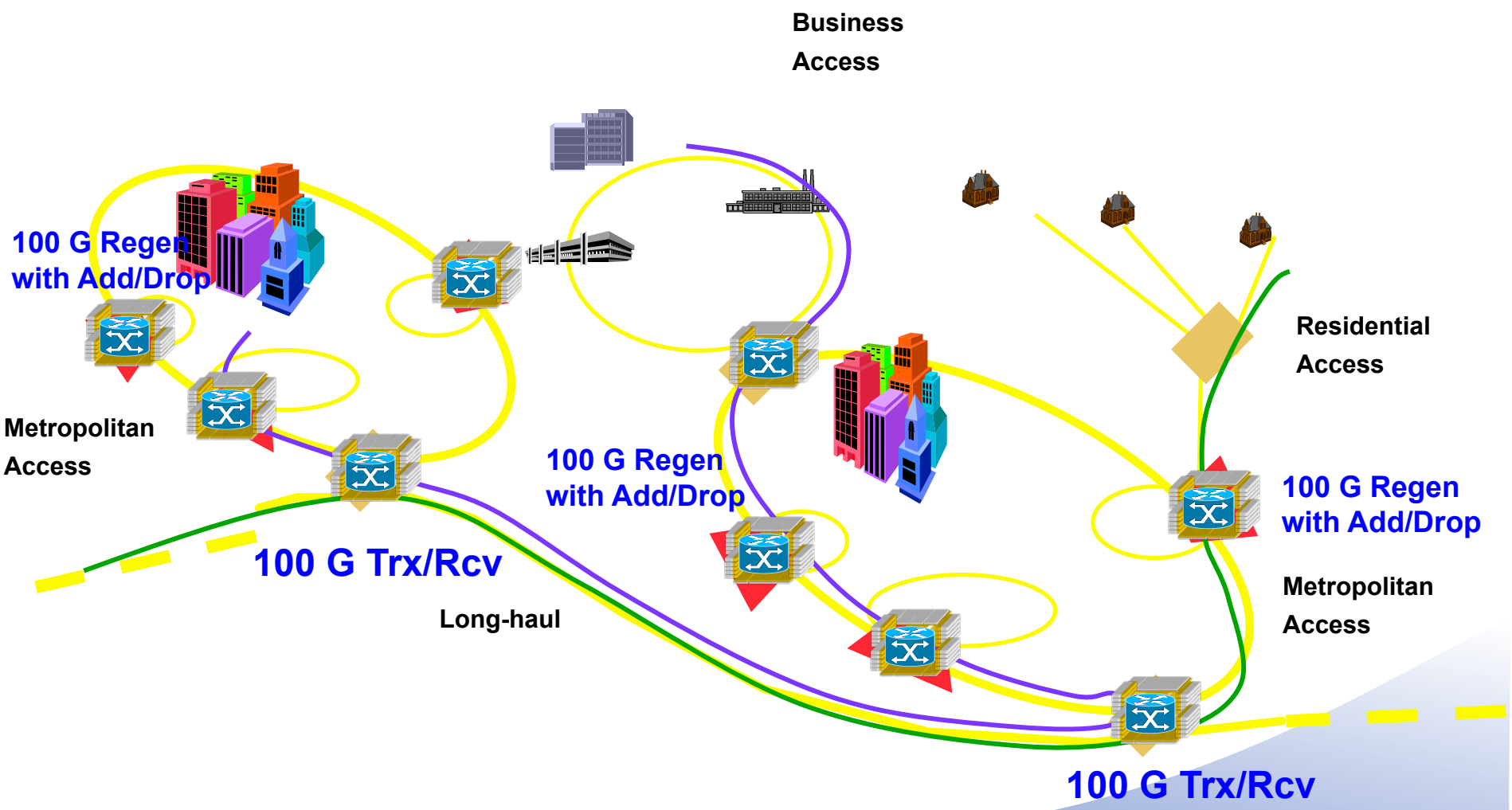
Future Multiwavelength Optical Networking with Agile 100 G Optical Trx, Rcv, Regen



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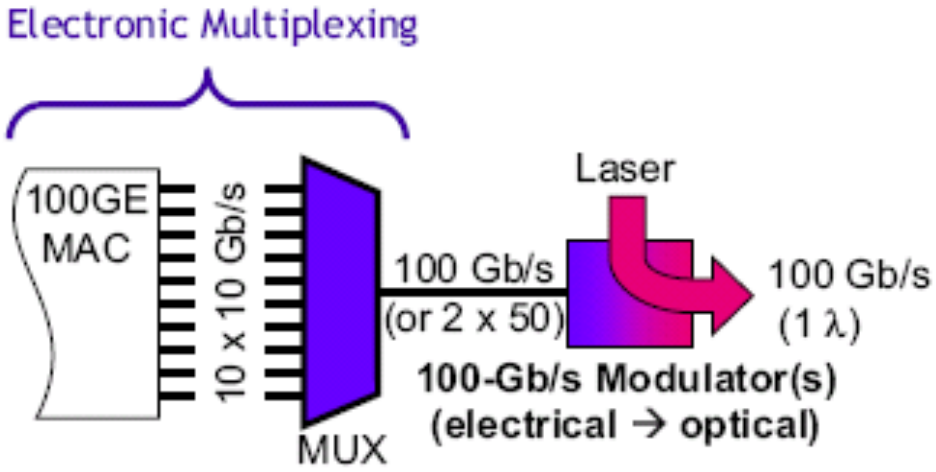
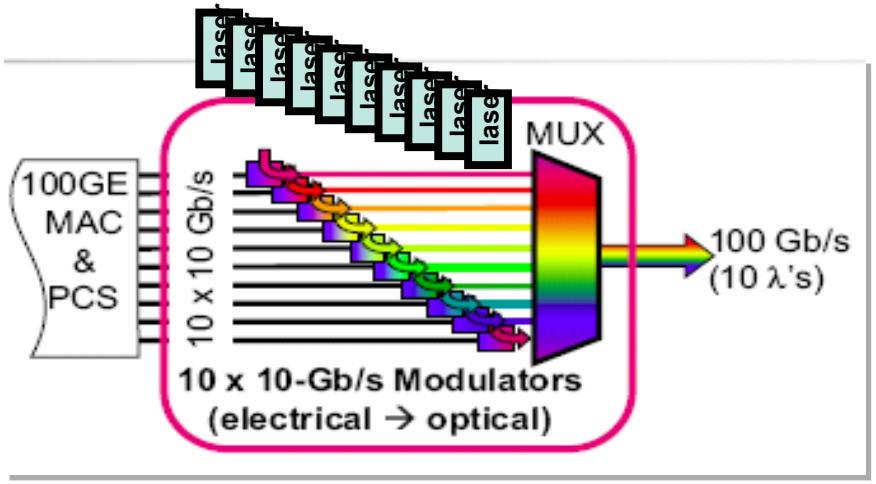
Today's Serial vs. Parallel 100 G technology

100G serial transport



- Use *single* wavelength (can be *multi-level*)
- Needs 100 G (or 2x50G) electronics
- Better spectral efficiency but more sensitive to dispersion and PMD

100G parallel transport (OTN VCAT)



- Use *multiple* wavelengths & modulators
- Needs 10 G electronics with possible synchronization
- Manageable dispersion and PMD but poorer spectral efficiency

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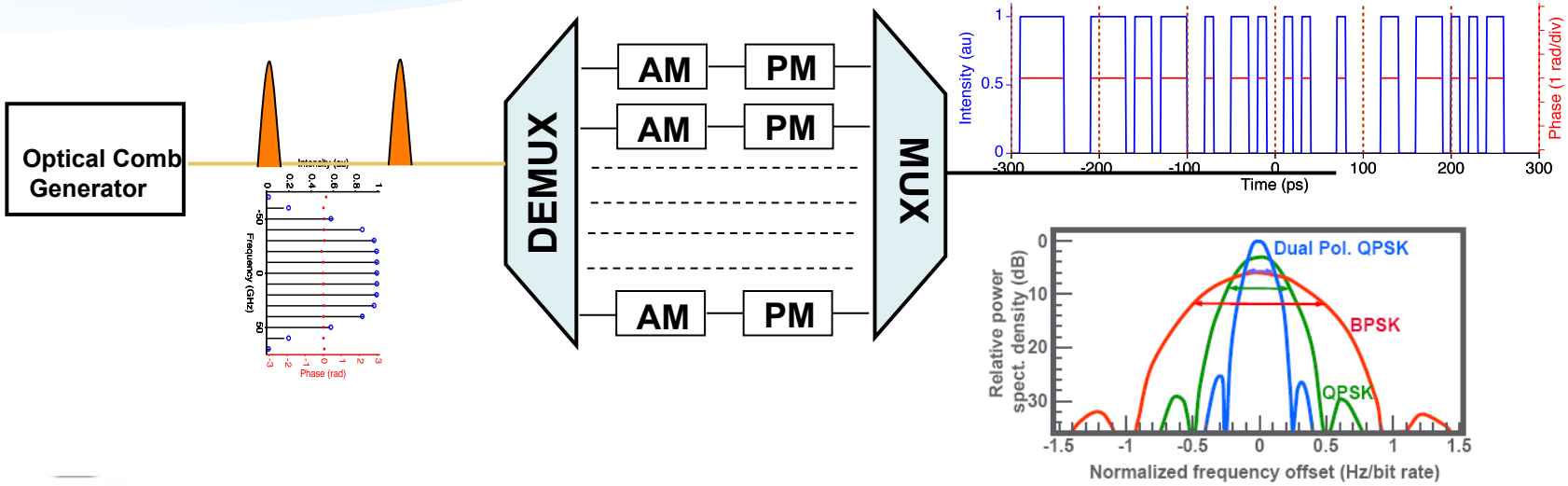
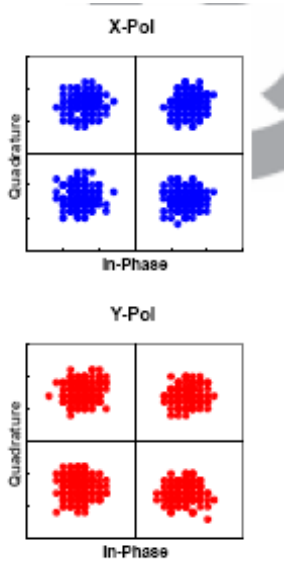
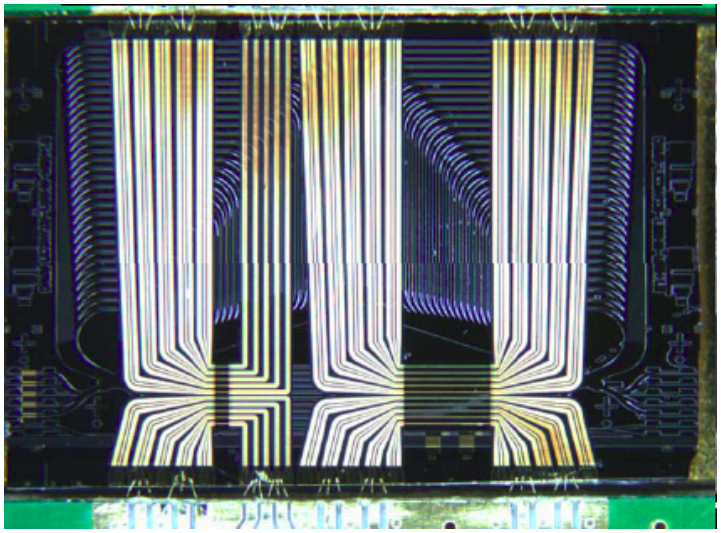
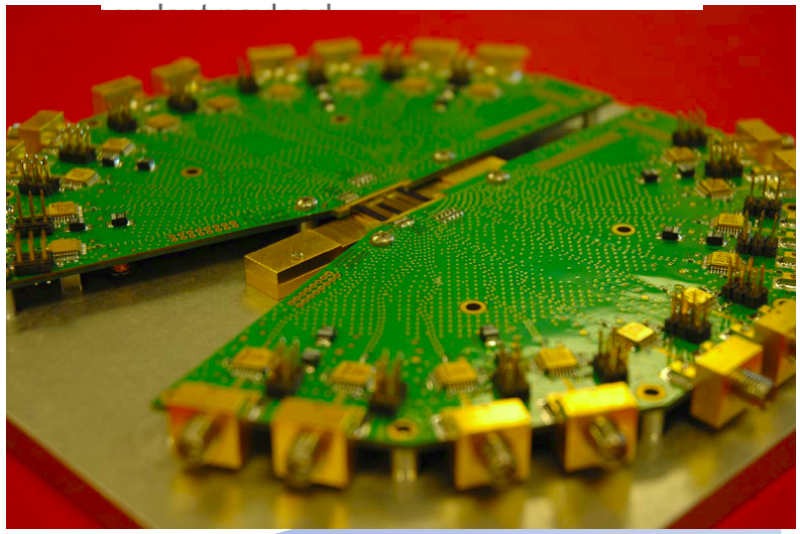
OAWG based 100 G~1Tb/s Transmission with ~10 G electronics





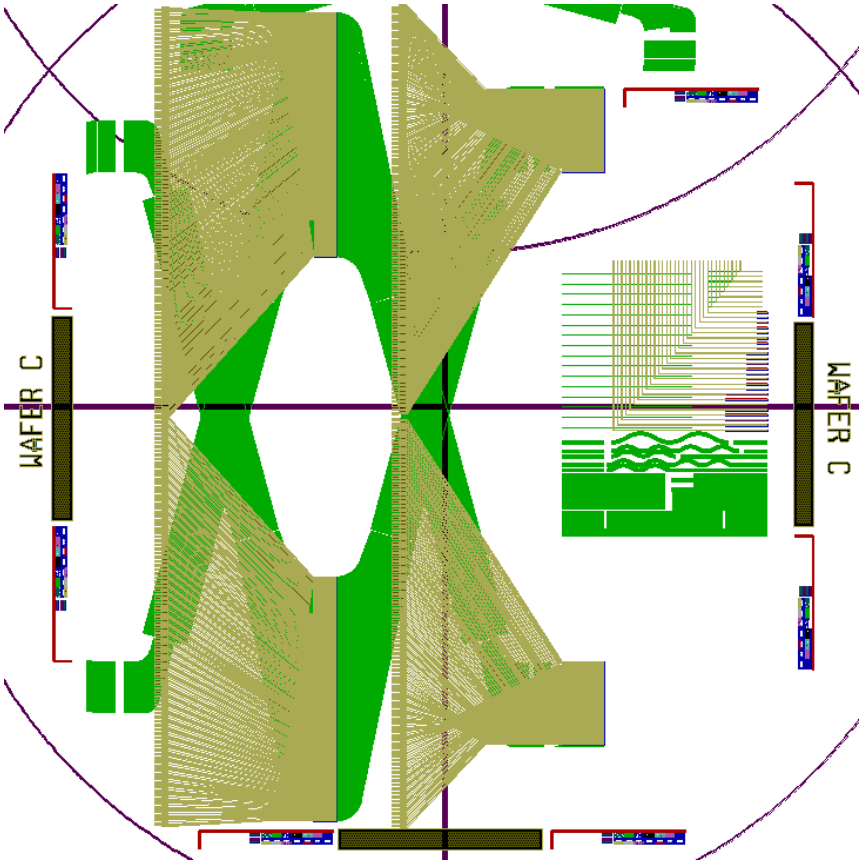




- At a glance, this is useful for parallel 40G/100G Trx/Rcv with independent ASK, PSK, DPSK, QPSK, DQPSK, etc.

1 THz (100ch x 10 GHz) OAWG encoder

Mask Layout



Fabricated Chip

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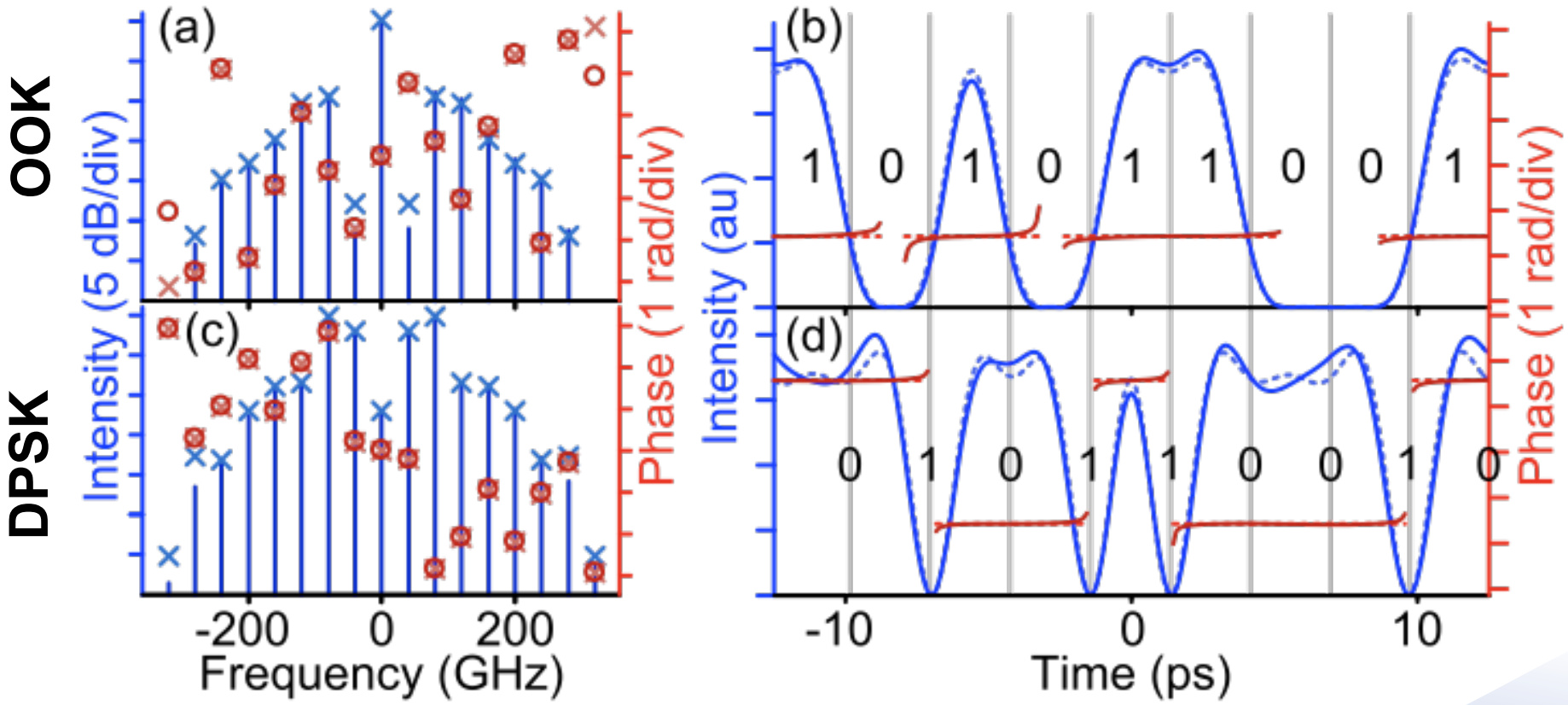
360 Gb/s PRBS Data OOK & DPSK (experiment)



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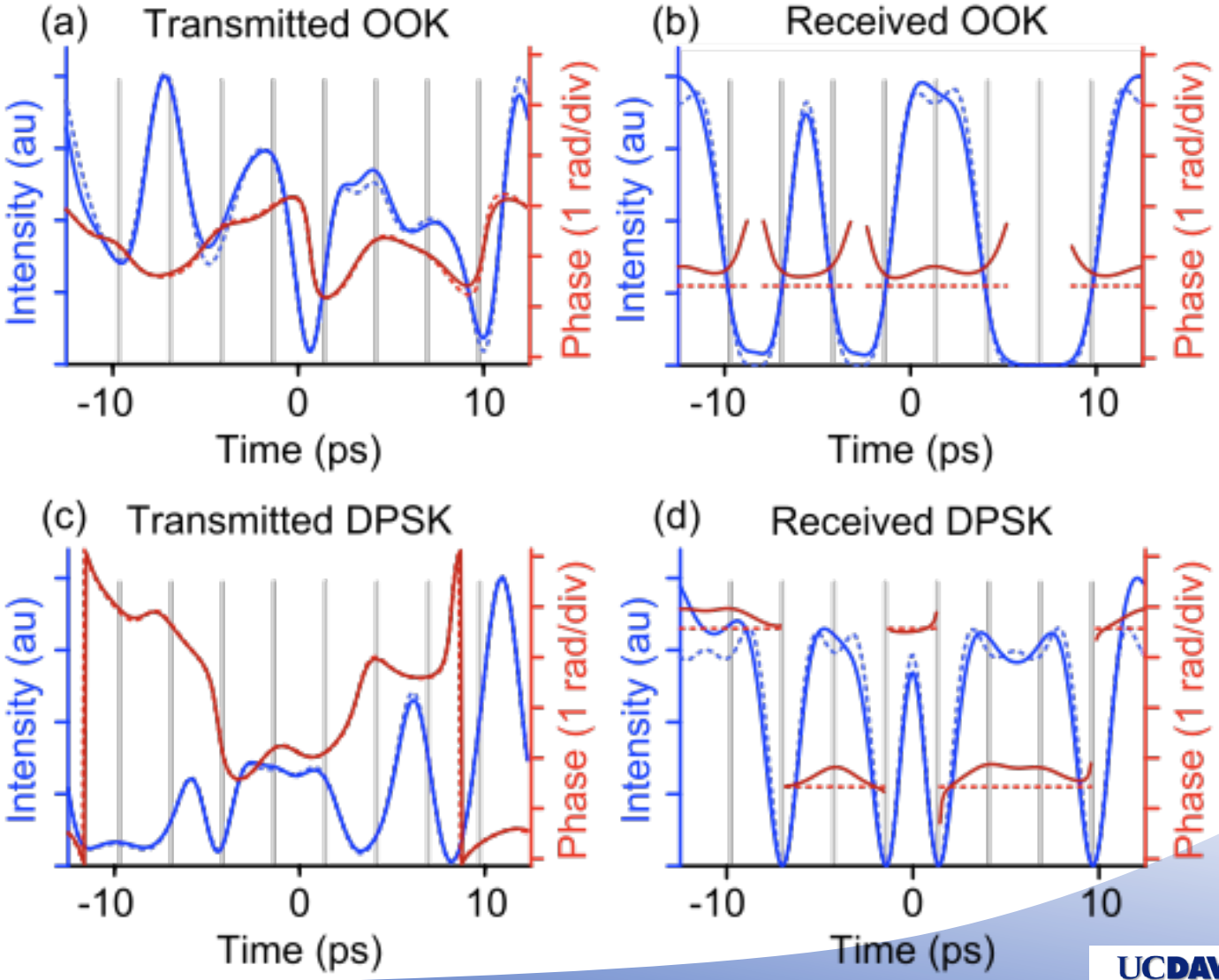
Predistorted 360 Gb/s 10 km Single Mode Fiber Transmission Results

OOK

DPSK



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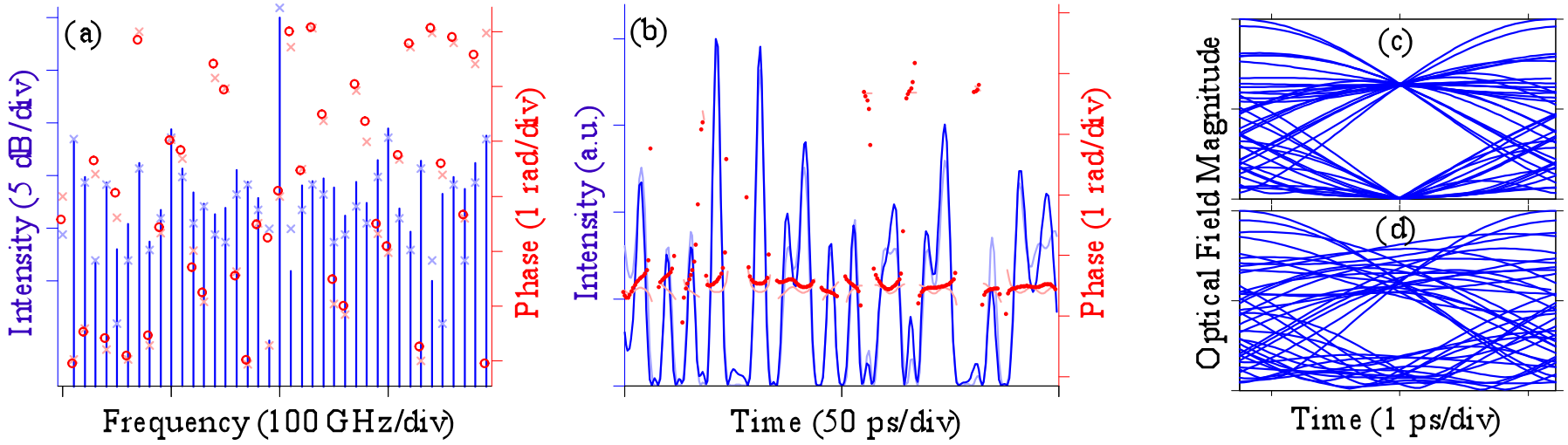
400 Gb/s NRZ-OOK PRBS generation 1 bit/s-Hz



400 Gb/s NRZ-OOK PRBS generation (40-bit-length) (a) Spectral domain (blue) intensity and (red) phase targets indicated by 'x'. (b) Time-domain optical field (blue) intensity and (red) phase. Target packet indicated by lighter shades. (c) Target and (d) measured eye diagrams.

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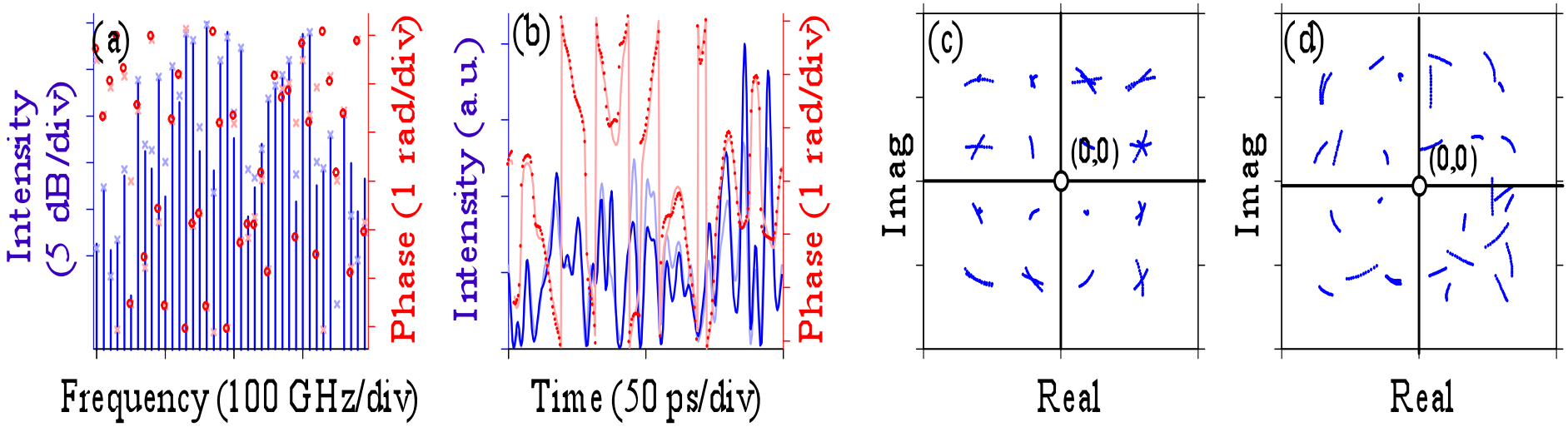
1.2 Tb/s NRZ-16QAM PRBS with 3 bit/s-Hz



120 bit 1200 Gb/s NRZ-QAM packet (a) spectral intensity (blue) and phase (red), and (b) optical field (blue) intensity, (red) phase. Target indicated by lighter shades and 'x'. (c) Target and (d) measured constellation diagrams.

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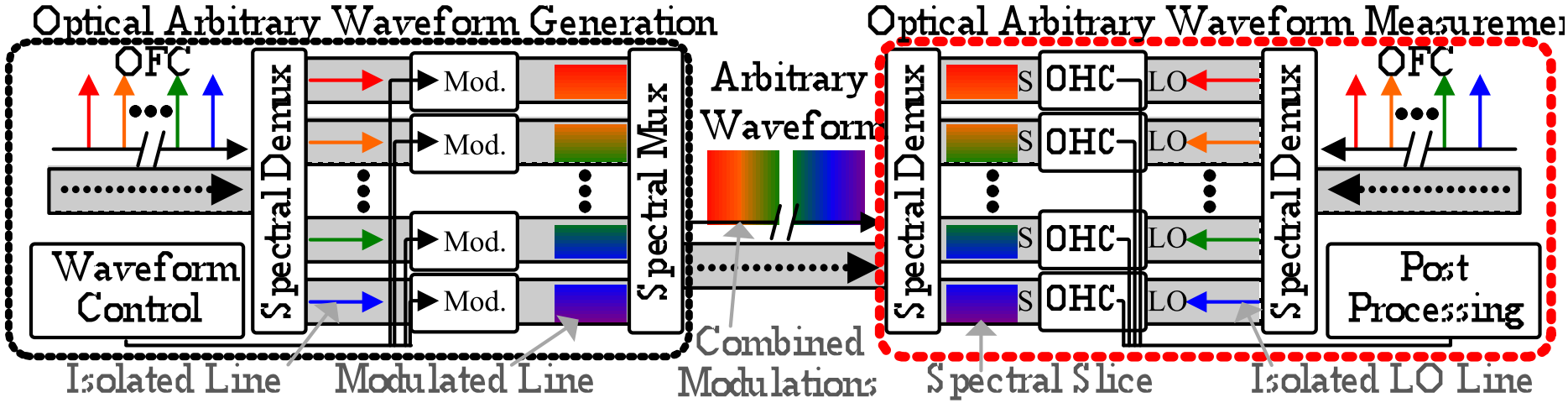
Optical Arbitrary Waveform Measurements



- Spectral slices of the signal (S) are coherently detected using a 90° optical hybrid circuit (OHC) and a single mode from the LO OFC
- Fast photodiodes (bandwidth>spectral slice width) measure the four OHC outputs
- Post processing reconstructs signal from measured outputs

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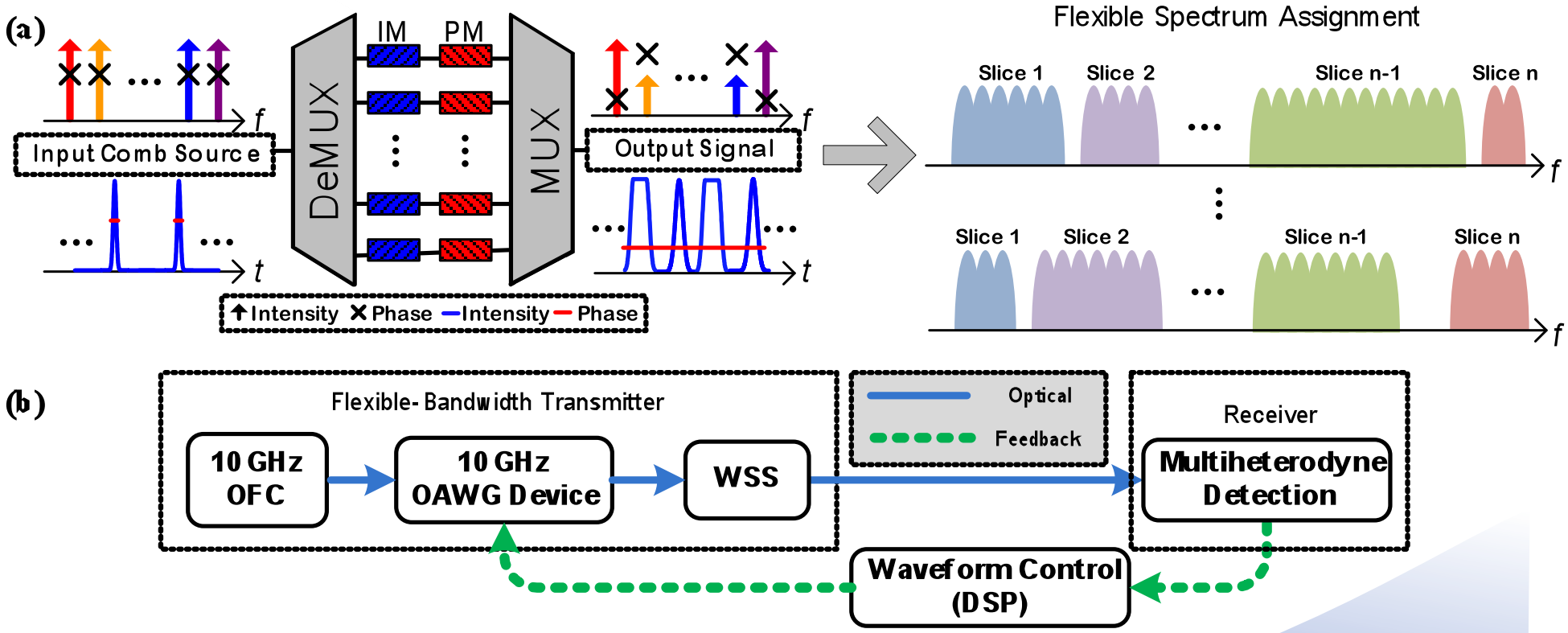
Flexible Spectral Slice Networking



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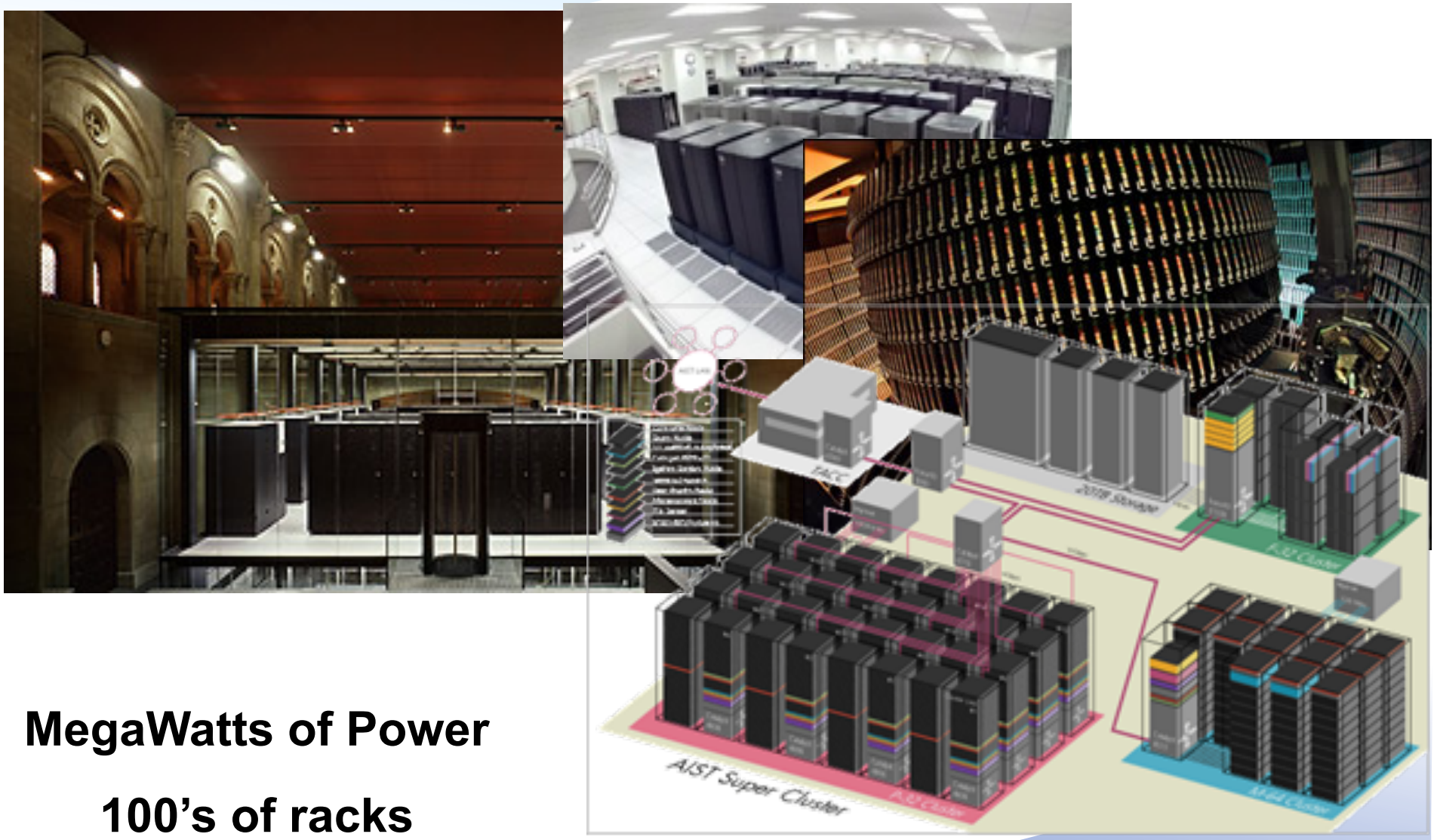
Computing of the Future

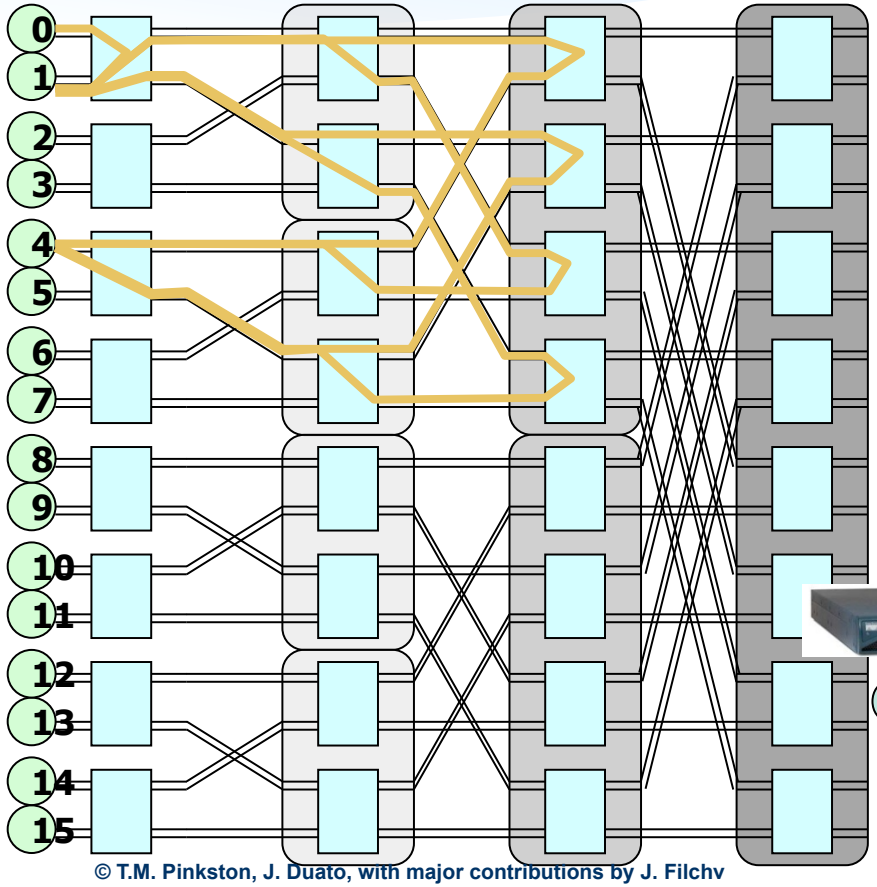


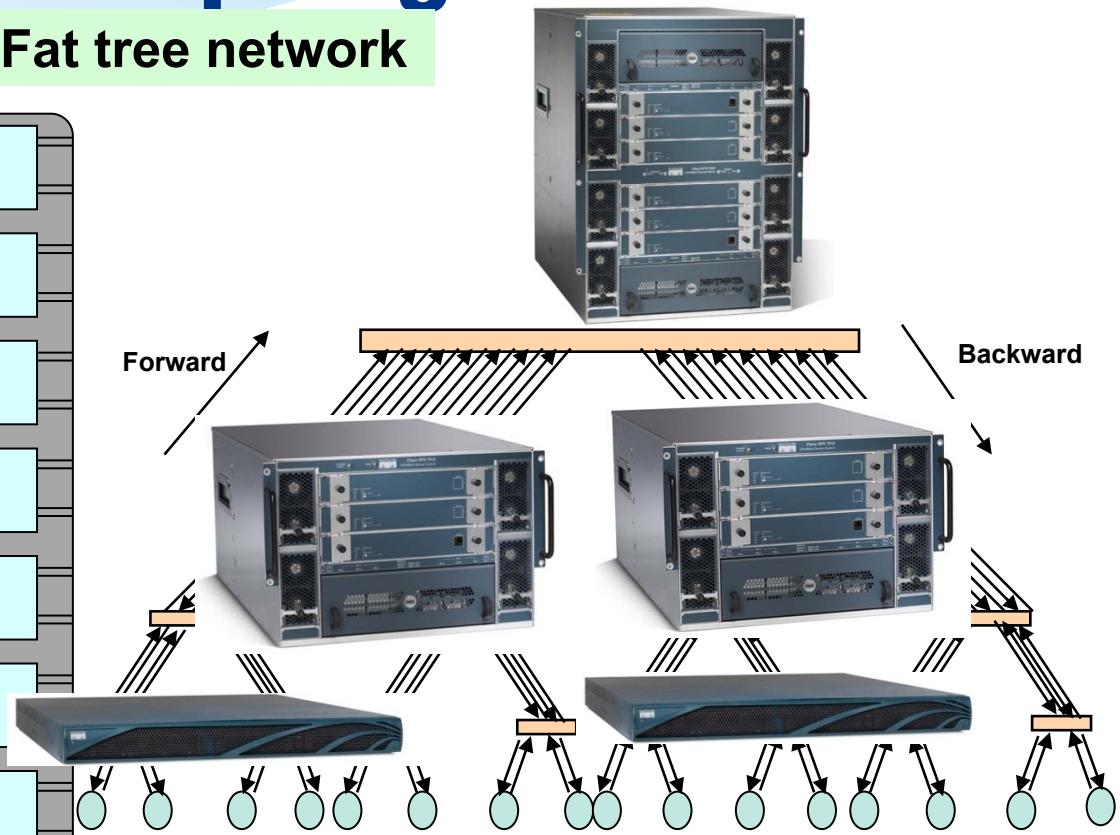
MegaWatts of Power

100's of racks

Interconnection Topologies

Folded Clos = Folded Benes = Fat tree network





- Nodes at tree leaves
- Switches at tree vertices
- Total link bandwidth is constant across all tree levels, with *full bisection bandwidth*
- Equivalent to folded Benes topology
- Preferred topology in many system area networks

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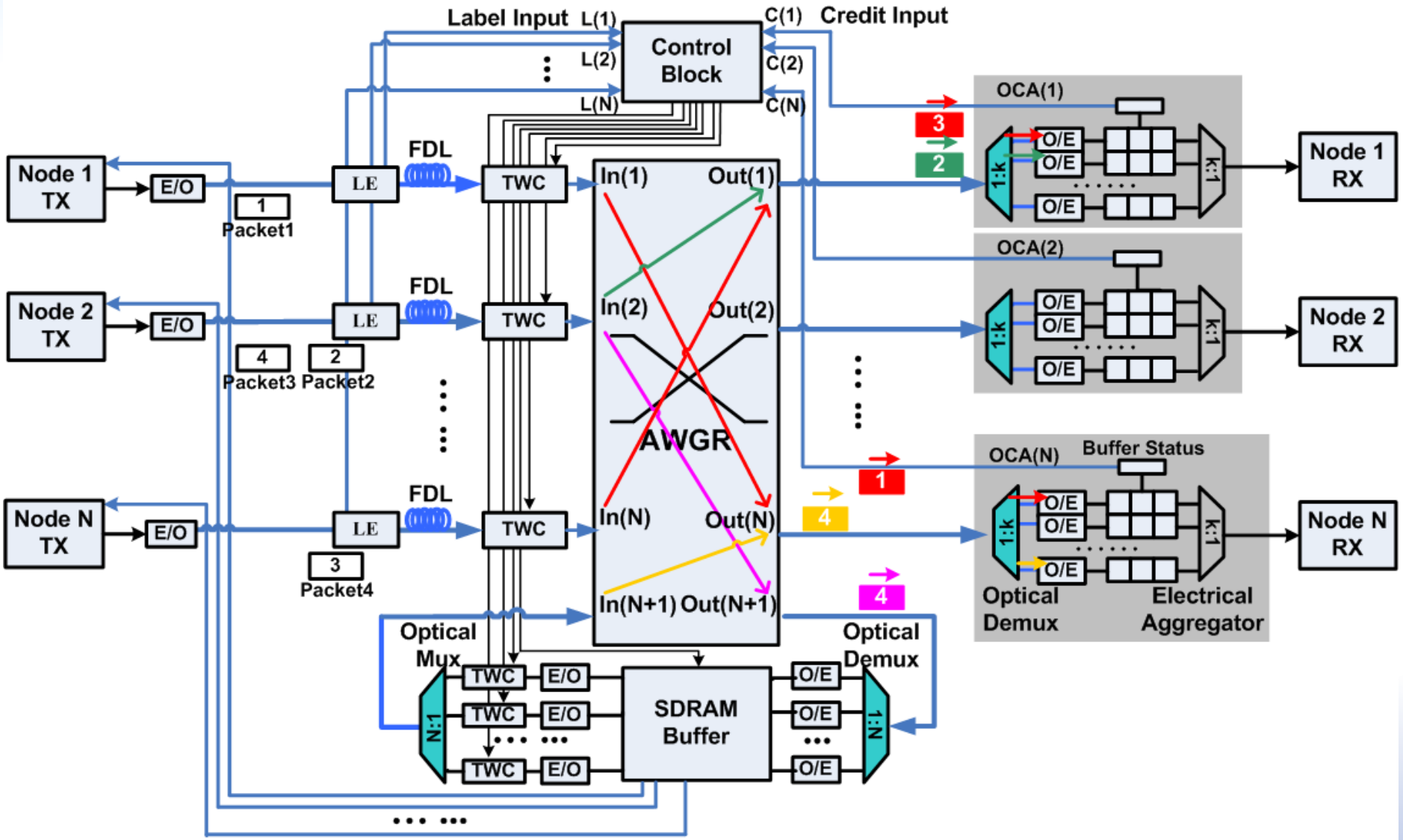
Scalable and Low Latency Optical Switch



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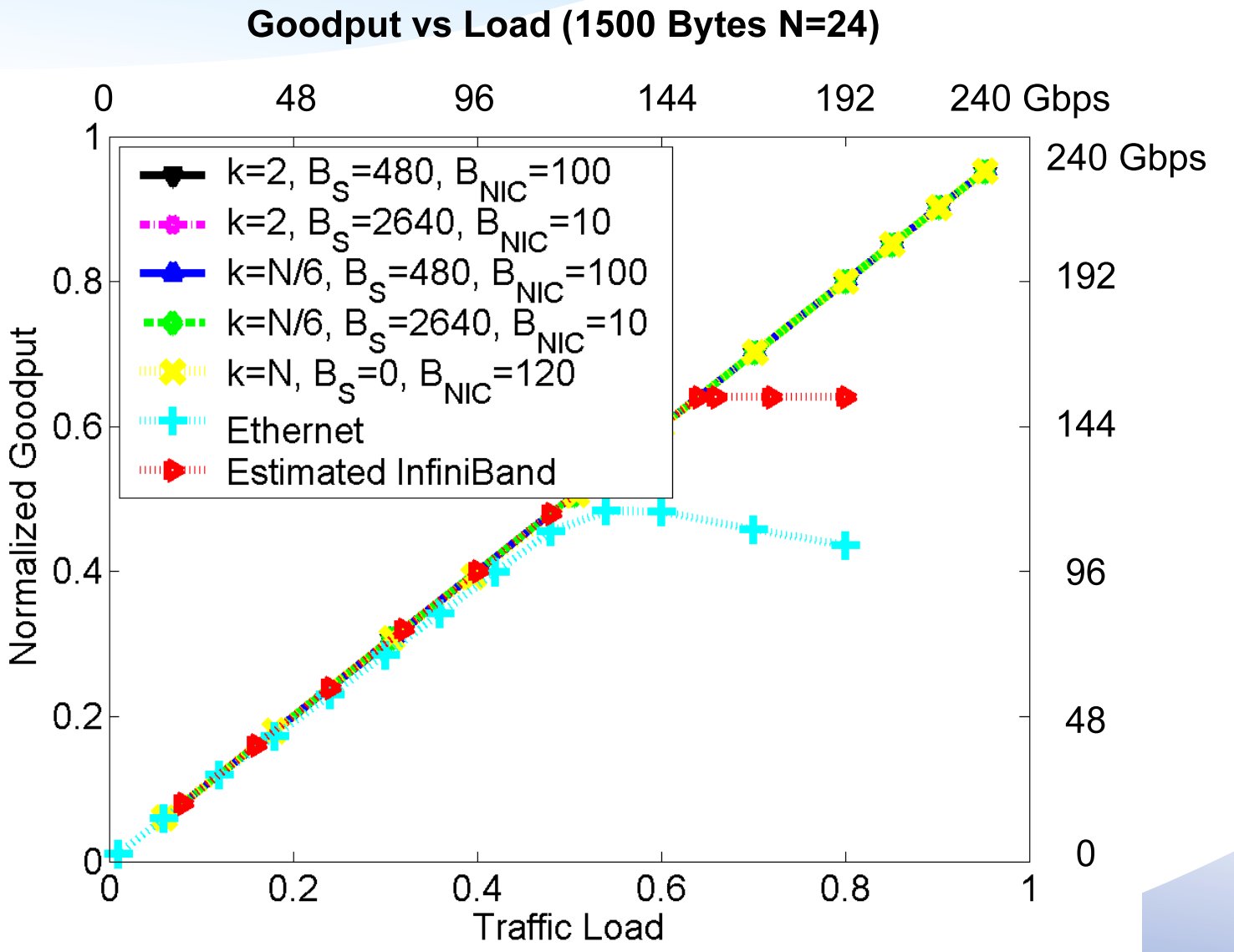
Normalized Goodput vs. Load



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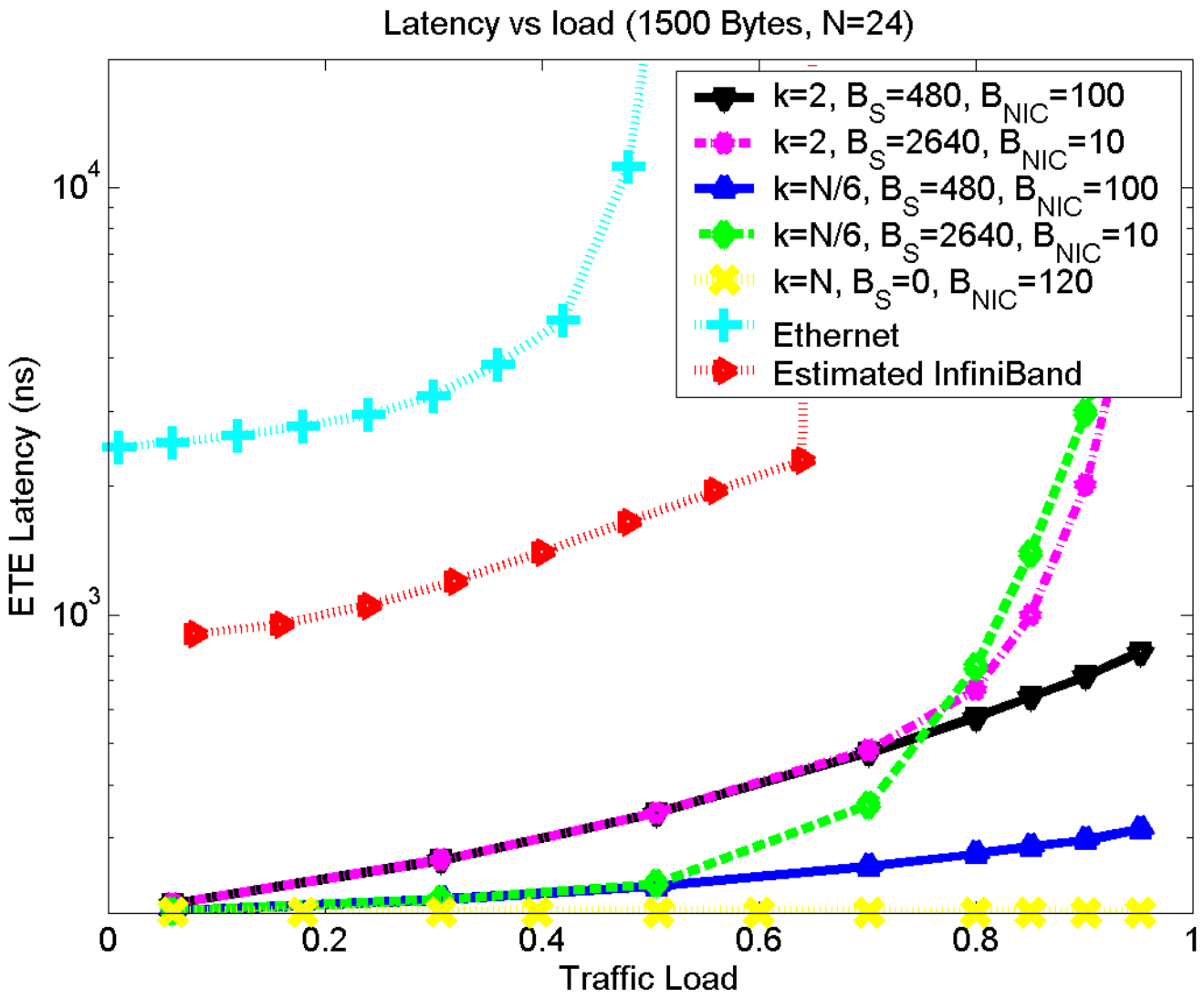
End-to-End Latency



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Key Points

- Future Internet with
  - New Architecture Exploiting Optical Parallelism, Optical Performance Monitoring, Integrated Photonics
  - Energy Efficient & High-Performance: Low Latency, High Throughput, Parallel Processing
- OLS Networking:
  - integration of Circuit, Flow, Burst, and Packet Switching
  - Pipelined Processing Store-and-Forward
  - Smart Edge and Fast Core
  - Exploit WAVELENGTH domain, and use Wavelength-Time-Space Domain contention resolution
- Computing of the future
  - Contention-free optical interconnection switch
  - Extremely low latency and high throughput
  - High Throughput and Parallel Computing

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