Photonics in Switching (PS)

July 25-28 2010, Monterey Plaza Hotel, Monterey, California, USA

The Photonics in Switching Topical Meeting addresses all research areas in which photonic technologies are applied to innovate and enhance the future networking, computing, and Internet infrastructures. Learn more.

Pre-Registration is now closed. You may still register on-site at the Monterey Plaza Hotel in the Steinbeck Foyer beginning Sunday, July 25.

Take advantage of all PS has to offer:

- Two meetings for the price of one (collocated with Integrated Photonics Research, Silicon and Nano Photonics)
- Tabletop exhibit
- Poster sessions providing one-on-one discussion time with presenters
- Renown experts presenting invited talks
- Post Deadline Session reporting critical breakthroughs
- Sunday Workshops
- Networking events

Conference Program

View the Agenda
Plan Your Conference

View the conference program and plan your itinerary for the conference

- Browse speakers and the agenda of sessions
- Browse sessions by type or day
- Use Advanced Search to search by author, title, OCIS code and more
- Plan and print your personal itinerary before coming to the conference
- Download your personal itinerary to your mobile device
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- Email your itinerary to a colleague who might be interested in attending

Download pages from the program book!

- Agenda of sessions (pdf)
- Abstracts (pdf)
- Key to Authors and Presiders (pdf)
- Postdeadline Abstracts (pdf)
- Key to Postdeadline Authors and Presiders (pdf)

Special Event Details

- Dinner at the Chateau Julien Wine Estate in Monterey, California
- Welcome Reception
- Poster Sessions
- Post Deadline Sessions
- Workshops

Sponsors:

OSA

Photonics in Switching (PS)

July 25-28 2010, Monterey Plaza Hotel, Monterey, California, USA

Program

The program for the Photonics in Switching Topical Meeting will be held Monday, July 26 through Wednesday, July 28, 2010. No events are scheduled for Sunday, July 25; however participants may register and pick up their materials on Sunday afternoon.

A number of distinguished invited speakers have been invited to present at the meeting. In addition, the organizers have planned a number of special events to make your meeting experience more enjoyable!

- Call for Papers (pdf)
- Online Conference Program
- About the meeting topics
- Workshops
- Special Events
- Invited speakers

Online Conference Program

Searchable Conference Program Available Online!

- Browse speakers and the agenda of sessions.
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- Download your personal itinerary to your mobile device.
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- Email your itinerary to a colleague who might be interested in attending.

You may search the program without creating an account; however, you will not be able to create or save a personal itinerary without first creating an account. We strongly recommend that you create a user account first.

Download pages from the program book!

- Agenda of sessions (pdf)
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About Photonics in Switching

The Photonics in Switching Topical Meeting addresses all research areas in which photonic technologies are applied to innovate and enhance the future networking, computing, and Internet infrastructures. This area includes photonic switching devices, high-throughput optical systems, efficient optical network architectures, data center networking, and computing systems with optical interconnects, optical cross-connects and interconnects, integrated photonics and system on chip, optical routers and switches. In particular, developing optical subsystems, optical processors and novel integrated circuit requires proper balancing of photonic and electronic technologies. Optical infrastructures will leverage the opportunities offered by photonics to answer the emerging needs of the next decades such as the realization of all-optical network and computing elements, the reduction of network power consumption and device footprint by integration.

Papers were considered in the following topic categories:

Optical Switching Technologies

- Optical reconfiguration in computing systems

- All optical flip-flops
- Photonic memory and optical buffers
- All-optical wavelength conversion technologies
- Hybrid wavelength conversion technologies
- Integrated photonic switching technologies
- MEMS switches
- Silicon photonic switching technologies
- Tunable laser technologies
- Nanophotonic switching technologies
- Comparisons with all-optical, electronic, and hybrid technologies

Optical Subsystems

- Optical signal processing
- Optical label swapping
- Optical-code translation and processing
- Optical-header recognition

Optical Systems

- Optics in computing systems
- Optical cross-connects
- Reconfigurable optical add-drop multiplexers
- Optical packet switching routers
- Optical burst switching routers
- Optical time domain multiplexed systems
- Optical CDMA systems
- Optical interconnects
- Optical access systems

Optical Networking

- Rapidly reconfigurable networks
- Optical network control and management
- Next-generation GMPLS, ASON, Photonic MPLS
- Optical label switching networks
- IP-over-optical architectures
- Optical access networks
- High-performance data server and computing networks with optical interconnects
- Energy-Efficiency in networks and cloud computing
- Future Internet Architectures

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Special Events

- Special Symposium on Optics in Computing
- Dinner at the Chateau Julien Wine Estate in Monterey, California (a ticketed event)
- Welcome Reception
- Poster Sessions
- Post Deadline Sessions

Photonics in Switching (PS)

July 25-28 2010, Monterey Plaza Hotel, Monterey, California, USA

Chairs & Committee Members

The Technical Program Chairs and Committee Members are integral to the success of the meeting. These volunteers dedicate countless hours to planning, including such critical activities as raising funds to support the event, securing invited speakers, reaching out to colleagues to encourage submissions, reviewing papers, and scheduling sessions. On behalf of OSA, its Board, and its entire staff, we extend enormous gratitude to the following members of the Photonics in Switching (PS) Technical Program Committee.

Program Committee

Information for Conference Chairs and Committee Members

Information for Session Chairs/Presiders

Program Committee

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- Bryan Robinson, *MIT Lincoln Lab, USA*
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- Axel Scherer, *Caltech, USA*
- Alan Willner, *Univ. of Southern California, USA*
- Ming Wu, *Univ. of California at Berkeley, USA*

If you are a member of the committee and have any questions or concerns at any point along the way, please refer to the information below or contact your program manager.

Photonics in Switching (PS)

July 25-28 2010, Monterey Plaza Hotel, Monterey, California, USA

Photonics in Switching Conference(PS) Meeting and Exhibit
Co-located with
Integrated Photonics Research, Silicon and Nano Photonics

Exhibit: July 26-28, 2010, Monterey Plaza Hotel, Monterey, California, USA

OSA Topical Meetings are unique, small sized meetings where 100-300 industry experts and top researchers and developers share their latest research and collaborate on new and future applications within their specialized fields. The meetings focus on the most advanced developments within specific topical areas of the optics and photonics industry. Exhibiting at The OSA Integrated Photonics Research, Silicon and Nano Photonics meeting offers you an extremely targeted opportunity to display your company's products that fall within these co-located topical meeting areas:

- Integrated Photonics Research, Silicon and Nano Photonics
- Photonics in Switching

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Photonics in Switching (PS)

July 25-28 2010, Monterey Plaza Hotel, Monterey, California, USA

Special Events

Joint Welcome Reception

Monday, July 26
6:30 p.m.–7:30 p.m.
Dolphins Ballroom

Please join us on Monday, July 26th, for the joint IPR/PS Welcome Reception. This reception is the perfect kick-off to this year's IPR/PS meeting. Free to all Technical Conference Attendees. Meet with colleagues from around the world. Light hors d'oeuvres will be served.

Poster Session

Tuesday, July 27
4:00 p.m.–6:00 p.m.
Dolphins Ballroom

Poster presentations offer an effective way to communicate new research findings and provide an opportunity for lively and detailed discussion between presenters and interested viewers. During the afternoon poster session, posters will be presented from the IPR and PS meetings.

Dinner at the Chateau Julien Wine Estate in Monterey, California

Tuesday, July 27
6:30 p.m.–9:00 p.m.
Chateau Julien Wine Estate

Please join us on Tuesday, July 27th, for this special event at the Chateau Julien Wine Estate. There will be a wine reception immediately followed by dinner all on the grounds of the estate. Free to all Technical Conference Attendees. Meet with colleagues from around the world and enjoy the beautiful scenery Monterey and the estate have to offer.

Get-Together Party

Sunday, July 25
6:30 p.m.—7:30 p.m.
Location to Be Announced On-Site

Join fellow attendees at an informal get-together at the start of IPR/PS. Light snacks will be provided and drink specials will be available for purchase for all attendees.

Tasting Rooms

We would like to encourage our attendees and their guests to take time out of their busy schedules and enjoy the numerous wineries and tasting rooms within the Monterey region!

The following tasting rooms are within walking distance to the Monterey Plaza Hotel and Spa:

Baywood Cellars
381 Cannery Row
Monterey, CA 93940
(831) 645-9035

Tasting Room Hours
Monday – Saturday: 1:00 PM to 6:00 PM
Last tasting begins at 5:30pm

Sundays: 1:00 PM to 5 PM
Last tasting begins at 4:30

Baywood Cellars' Tasting Room is located on historic Cannery Row and is only steps away from Monterey Bay across from the lobby of the Monterey Plaza Hotel. Enjoy tasting Baywood Cellars Award Winning wines from California's premier coastal grape growing regions, sample the gourmet vinegars, grapeseed and olive oils and browse the gallery of unique gifts.

Bargetto Winery of Cannery Row
700 Cannery Row
Monterey, CA 93940
(831) 373-4053

Tasting Room Hours
Monday-Friday: 11:00 AM - 6:00 PM
Saturday & Sunday: 11:00 AM - 6:30 PM
$5.00 tasting fee for 5 wines

The Monterey Tasting Room is a popular stop for tourists and local residents. Visit the tasting room on Cannery Row, across the lobby from the Monterey Plaza Hotel, to taste the award-winning wines and experience the breathtaking views of the Pacific Ocean.

Scheid Vineyards Inc
751 Cannery Row
Monterey, CA 93940
(831) 656-9463

Tasting Room Hours
Daily: 11:00 AM – 6:00 PM

Located on historic Cannery Row, across the lobby from the Monterey Plaza Hotel, the Wine Lounge is an elegant setting with an array of offerings from local artisans.

A Taste of Monterey
700 Cannery Row
Monterey, CA 93940
(831) 646-5446

Tasting Room Hours
Daily: 11:00 AM – 7:00 PM
$10.00 tasting fee for 6 wines

A Taste of Monterey's large Visitors' Centers on Cannery Row overlooking the Monterey Bay is a perfect location to enjoy a variety of local wines, representing over 70 regional wineries. This is a great place to taste, shop and relax.

Self Guided Tours

Let the MST Carmel Valley Grapevine Express take you on the journey without the hassles of driving or parking. Every hour MST's Grapevine Express transports passengers from downtown Monterey through Carmel Valley's wine corridor and on to Carmel Valley Village, where clustered tasting rooms invite guests to leisurely stroll from one location to another. For greater flexibility in the timing of your stay at each tasting room, buses circulate every hour to take you further on your tour or to return to downtown Monterey.

MST Carmel Valley Grapevine Express

Departing every hour
Daily – Year-round
11:00 a.m. to 6:00 p.m.
(last return trip to Monterey leaves at 7:15 p.m.)
Ride all day for only **$6.00**

Need More Help?

If you would like more assistance in planning your day, please contact the hotel's concierge at (831) 646-5310 from the hours of 11:00 AM – 7:00 PM.

Photonics in Switching (PS)

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Invited Speakers

Plenary Speakers

JMA1, **Future Computing Systems**, ***Terry Morris****; Hewlett-Packard Co., USA.*

JTuA2, **The Path to Energy Efficient Optical Networking**, ***Ken-ichi Sato****; Nagoya Univ., Japan.*

Invited Speakers

PMA1, **What is the Right Layer for Switching? Layer-1? Layer-3? Or Packet Optical?** ***Bikash Koley****; Google, USA.*

PMA2, **Optically Interconnected Supercomputing**, ***Jeffrey Kash****; IBM, USA.*

PMA3, **The Integration of Silicon Photonics and VLSI Electronics for Computing and Switching Systems**, ***Ashok Krishnamoorthy****1, R. Ho1, X. Zheng[1], G. Li[1], D. Feng[2], P. Dong[2], T. Pinguet[3], A. Mekis[3], H. Schwetman[1], J. Lexau[1], D. Patil[1], F. Liu[1], P. Koka[1], M. McCracken[1], I. Shubin[1], H. Thacker[1], Y. Luo[1], K. Raj[1], M. Asghari[2], J. G. Mitchell[1], J. E. Cunningham[1]; [1]Oracle Corp., USA, [2]Kotura Inc., USA, [3]Luxtera Inc., USA.*

PMB1, **Large-Scale Integrated Photonics for High-Performance Computer Networks**, ***Ray Beausoleil****; Hewlett-Packard Labs, USA.*

PMB2, **Optical Interconnected Computing Systems**, ***Keren Bergman****; Columbia Univ., USA.*

PMB3, **Device Requirements for Optical Interconnects to CMOS Silicon Chips**, ***David Miller****; Stanford Univ., USA.*

PMB4, **Networking Content-Rich Data Centers**, ***Donn Lee****; Facebook, USA.*

PMC1, **Silicon Photonics in High Performance Computing**, ***Michael Watts****; Sandia Natl. Labs, USA.*

PMC4, **Scaled CMOS Photonics**, ***Jason Orcutt****; MIT, USA.*

PMD3, **Flexible Use of Spectrum and Photonic Grooming**, ***Ori A. Gerstel****; Cisco Systems, USA.*

PMD6, **Optical Flow Switched Networks**, ***Vincent Chan****; Lab for Information and Decision Systems, MIT, USA.*

PTuA1, **Switching to Low-Cost Integration Technology for Switching**, ***Meint Smit****; Eindhoven Univ., Netherlands.*

PTuA4, **Silicon Photonics: The Enabling Technology for Green Optical Processing**, ***Giorgio Grasso***[1], *Marco Romagnoli[2], Andrea Melloni[3]; [1]Pirelli, Italy, [2]Independent Consulting, Italy, [3]DEI - Politecnico di Milano, Italy.*

PTuB3, **Technologies and Approaches for Improving Energy Efficiency of Network Elements**, ***Slaviša Aleksić****; Vienna Univ. of Technology, Austria.*

PTuC1, **Hybrid Optoelectronic Router Prototype for Asynchronous Optical Packet Switched Networks**, ***Tatsushi Nakahara****, Ryohei Urata, Toru Segawa, Yasumasa Suzaki, Hirokazu Takenouchi, Ryo Takahashi; NTT Photonics Labs, NTT Corp., Japan.*

PTuC4, **Recent Advances on Colored Optical Packet Switching Systems**, ***Hideaki Furukawa***[1]*, Satoshi Shinada*[1]*, Szilárd Zsigmond*[2]*, Hiroaki Harai*[1]*, Naoya Wada*[1]*;* [1]*NICT, Japan,* [2]*Budapest Univ. of Technology and Economics, Hungary.*

PTuD3, **Impact of Switching Technologies on Resilience Mechanisms in Transparent and Translucent Networks**, *Dimitri Staessens, Maarten De Groote, Matthias Gunkel, Didier Colle,* ***Mario Pickavet****, Piet Demeester; Ghent Univ., Belgium.*

PTuD6, **OOO Switches in Future Core Network Architectures**, ***Jeff Jian Chen****, Kristin Rauschenbach; BBN, USA.*

PWA1, **Ultra-Fast All Optical Signal Processing and Switching Based on PPLN Waveguides**, ***Antonella Bogoni***[1,2]*, Xiaoxia Wu*[2]*, Jieng Wang*[2]*, Alan E. Willner*[2]*;* [1]*Natl. Lab of Photonic Networks, CNIT, Italy,* [2]*Univ. of Southern California, USA.*

PWA4, **Monolithic Photonic Integrated Circuits for Modulating and Routing Optical Signals**, ***Chris Doerr****; Bell Labs, Alcatel-Lucent, USA.*

PWB3, **Scaling Optical Switches to 100 Tb/s Capacity**, ***Shifu Yuan****, Chris Lee; Calient Networks Inc., USA.*

PWB6, **Monolithic SOA Switch Fabric**, ***Ian White****, Richard V. Penty, Adrian Wonfor; Univ. of Cambridge, UK.*

PWC1, **All-Optical Terabit/s OFDM Signal Processing**, ***Juerg Leuthold****; Univ. of Karlsruhe, Germany.*

PWC4, **Terabit Optical Ethernet**, ***Daniel Blumenthal****; Univ. of California at Santa Barbara, USA.*

PWD3, **Fourier-Transform, Integrated-Optic Spatial Heterodyne Spectrometers on Planar Lightwave Circuits**, ***Katsunari Okamoto****; AiDi Corp., Japan.*

PWE1, **Extremely-Low-Power Nanophotonic Devices Based on Photonic Crystals**, ***Kengo Nozaki***[1]*, A. Shinya*[1]*, T. Tanabe*[1]*, S. Matsuo*[2]*, T. Sato*[2]*, T. Kakitsuka*[2]*, E. Kuramochi*[1]*, H. Taniyama*[1]*, M. Notomi*[1]*;* [1]*NTT Basic Res. Labs, Japan,* [2]*NTT Photonics Labs, Japan.*

PWE4, **Fast and Energy Efficient Optical Switches and Modulators Based on Photonic Crystals**, ***Jelena Vučković****, Bryan Ellis, Arka Majumdar, Gary Shambat, Andrei Faraon, Dirk Englund; Edward L. Ginzton Lab, Stanford Univ., USA.*

PWF3, **Next Mobile Network Based on Optical Switching**, ***Masami Yabusaki****, Hendrik Berndt, Joerg Widmer; Docomo Communications Labs Europe GmbH, Germany.*

PWF6, **Experiments of IP Optical Multi-layer Network in Japan National Testbed**, ***Kohei Shiomoto***[1]*, Akeo Masuda*[1]*, Akinori Isogai*[1]*, Yoshihiro Nakajima*[2]*, Testuo Kawano*[2]*, Mitsuru Maruyama*[2]*, Eiji Ohtsuki*[3]*, Kazumasa Kobayashi*[3]*, Shinji Shimojo*[3]*;* [1]*NTT Network Service Systems Labs, Japan,* [2]*NTT Network Innovation Labs, Japan,* [3]*NICT, Japan.*

Workshops

Sunday, July 25
2:00 p.m–6:30 pm (coffee break from 4:00 pm–4:30 pm)
Cypress III

Workshop 1: Energy Efficient Networking and Systems

This workshop will promote discussions on energy efficient networks and systems. New networking architectures, protocols, routing/protection algorithms as well as new systems architectures will be covered in this workshop. The role of optics vs. electronics, and hybrid use of optical and electrical technologies in networks or systems are also of our interest.

June-Koo (Kevin) Rhee, *KAIST, S. Korea,* **Co-Chair**
Antonella Bogoni, *CNIT, Italy,* **Co-Chair**
Dominique Chiaroni, *Alcatel-Lucent, France,* **Co-Chair**

Session 1:

Antonella Bogoni, *CNIT, Italy,* **Moderator**

2:00 p.m.–2:15 p.m.
Opening Remarks
Antonella Bogoni, *CNIT, Italy*
June-Koo (Kevin) Rhee, *KAIST, S. Korea*

2:15 p.m.–2:30 p.m.
Network Equipment Energy Use and Public Policy, Steven Lanzisera, *Lawrence Berkeley Lab, USA.* The talk will cover an estimate of the USA and world wide consumption of network equipment, a campus LAN energy use case study, measuring the energy use of network equipment, and an overview of public policy in this area.Slides. (pdf)

2:30 p.m.–2:45 p.m.
A Researcher's Perspective to the Energy Issue, Alan Willner, *Univ. of Southern California, USA.*
For a majority of people, it is usually quite difficult to compare power consumption between electronic and photonic approaches. However, there are still a set of possible questions to pose that can help a researcher in photonics decide the potential energy-savings value of pursuing a given project. This presentation will highlight such questions, as well as use nonlinear optical signal processing as an example. Slides (pdf)

2:45 p.m.–3:00 p.m.
Energy Footprint and Opportunities of ICT Networks, Loukas Paraschis, *Cisco, USA.* The access network currently dominates energy consumption, which has otherwise been contained benefiting by IC and optical advancements, despite the multi-year > 50% CAGR of traffic.

3:00 p.m.–3:15 p.m.
Energy Efficiency and Green Networking, Mauro Macchi, *Juniper, USA.* The presentation will analyze the current status of energy consumption in telecom network and provide strategies for energy savings. Different aspects will be evaluated such as innovative network design as well as basic technology choices. Finally an historical track of power consumption reduction will be provided as well insights for future enhancements.

3:15 p.m.–3:30 p.m.
Energy Efficiency of Access Nertworks in a Life Cycle Perspective, Stefan Dahlfort , *Ericsson, Sweden.* This presentation discuss the Life Cycle Assessment of Telecom in general and in particular of mobile and fixed broadband access: how much do the various parts of the broadband network and network operations contribute to the energy consumption. Focusing on fixed broadband, the presentation makes use of a theoretical model of fixed access networks to illustrate potential areas of power savings. Slides (pdf)

3:30 p.m.–4:00 p.m.
Panel Discussion
Steven Lanzisera, Alan Willner, Loukas Paraschis, Mauro Macchi, Stefan Dahlfort

4:00 p.m.–4:30 p.m.
Coffee Break

Session 2:

June-Koo (Kevin) Rhee, *KAIST, S. Korea,* **Moderator**

4:30 p.m.–4:45 p.m.
Energy Efficiency in Telecom Optical Networks, Pulak Chowdhury, *Univ. of California at Davis, USA.* Due to the rapid growth of energy consumption in telecom networks, lot of attention is being devoted towards "green" networking solutions. In this presentation, we provide a summary of various research approaches for minimizing the energy consumption in telecom optical networks. The approaches are classified over different network domains. Slides.

4:45 p.m.–5:00 p.m.
Hybrid Optoelectronic Router for Optical Packet Switching, Tatsushi Nakahara, *NTT, Japan.* We describe a hybrid optoelectronic router for optical packet switched networks. The router optimally utilizes both optical and electrical technologies within a new node architecture to reduce power and latency while maintaining functionality to implement various services (multicast, QoS, etc.). A prototype router and its key device and subsystem technologies will be described. Slides (pdf)

5:00 p.m.–5:15 p.m.
Electronic vs All-optical Processing: Flexibility vs Power Consumption, Nikola Alic, *CAL-IT2, Univ. of California at San Diego, USA.* Routing flexibility and power consumption are conflicting requirements in fiber optic transmission, when relying on the existing and widely adopted signal processing techniques. Power consumption alone, however, clearly calls for a careful joint optimization of both of these prerequisites. In this presentation, we shall give an overview of the recent CALIT2/UCSD Photonics Systems Group demonstrations paving a path for all-optical and electronic processing for the first time properly addressing flexible transport and exceedingly low power consuming ultra high speed transport.

5:15 p.m.–5:30 p.m.
Reduction of the Energy Footprint in Optical Networks, Dimitri Staessens, *Univ. of Ghent, Belgium.* This presentation will focus on the current footprint of communication networks and provide strategies to reduce this footprint considerably in the coming decade. First an estimation is given for the energy consumption and carbon footprint of ICT worldwide and the share of communication networks in particular. From this current vantage point an estimation is made for future networks. Then some solution approaches and research initiatives to alleviate this footprint will be presented. We present the potential energy savings of FTTH in the access network, and introducing transparency in the core. Slides.

5:30 p.m.–5:45 p.m.
Energy and Spectrally Efficient Elastic Optical Path Network, Masahiko Jinno, *NTT, Japan.* I will present an energy and spectrally-efficient elastic optical path network where the required minimum spectral resources are adaptively allocated to an optical path according to various network conditions. I will focus on the direct accommodation of wide range of client traffic in the optical domain without any power-consuming electrical aggregation layer. Slides.

5:45 p.m.–6:00 p.m.
Optical Packet and Circuit Integrated Network for New Generation Energy Efficient ICT, Takaya Miyazawa, *NICT, Japan.* This presentation will introduce our R&D on optical packet and circuit integrated network. The R&D is a part of AKARI architecture design project which NICT of Japan has been promoting for approximately 4 years. Firstly, our concept, a node architecture and an experimental setup of optical integrated network will be presented. After that, a potential for energy saving by the optical integration technique will be discussed. Slides.

6:00 p.m.–6:30 p.m.
Panel Discussion
Pulak Chowdhury, Nikola Alic, Dimitri Staessens, Masahiko Jinno, Takaya Miyazawa

Sunday, July 25
2:00 p.m–6:30 pm (coffee break from 4:00 pm–4:30 pm)
Cypress

Workshop 2: Integrated Photonic Technologies and Systems: Current Status, Future Prospect, and Enabling Applications

This workshop will promote discussions on current status, future prospects, and enabling applications of Integrated Photonic Technologies and Systems. The workshop will highlight recent advancements in the area, both from research and utilization points of view, and also discuss trends in and motivations for future development and commercialization. In order to broaden the discussion and make it interactive, panels will be organized throughout the workshop, which all of the contributors will participate in.

Two major questions will be at the focus of this discussion: how do we make integrated photonics products and what do we intend them for? Accordingly, the workshop is divided in two sessions, the first – to address generic integrated photonics technologies and approaches to commercialization of such via a generic foundry model, and the second – current and future applications of integrated photonics.

It is one intention of the workshop organizers to, maybe in somewhat of a provocative manner, raise the question of what is so unique about photonic integration from a practical component or system design point of view that keeps the technology development alive and well for more than 40 years, while successful commercialization of this technology thus far has been very limited? New and innovative applications enabled by photonic integration, such as optical interconnects, high-capacity communications with advanced modulation formats and biomedical devices for personal healthcare/wellness – all are of great interest from this perspective, as well as new approaches to design and manufacturing of the integrated photonics products, e.g. fabless and foundry modes. The workshop sessions and panel discussions will, hopefully, provide some answers.

Session I: Generic Integrated Photonics Technologies and Foundry Approaches

Valery Tolstikhin, *OneChip Photonics, Inc., Canada,* **Moderator**

2:00 p.m.–2:15 p.m.
Introduction to the Workshop, Valery Tolstikhin, *OneChip Photonics, Inc., Canada*

2:15 p.m.–2:30 p.m.
Silicon / III-V Hybrid Integrated Photonics, John Bowers, *Univ. of California at Santa Barbara, USA*

2:30 p.m.–2:45 p.m.
A Generic Foundry Approach for InP Photonics, Meint Smit, *TU Eindhoven, The Netherlands*

2:45 p.m.–3:00 p.m.
Towards a Foundry Approach for Silicon Photonics and III-V/Silicon Photonics, Geert Morthier, *Univ. of Ghent, Belgium*

3:00 p.m.–3:15 p.m.
Circuit Design Approach to Integrated Photonics: A Generic Design Platform for Generic Foundry, Andrea Melloni, *Politecnico di Milano, Italy*

3:15 p.m.–3:30 p.m.
Status of the Silicon Photonics Fabless Ecosystem, Michael Hochberg, *Univ.of Washington, USA*

3:30 p.m.–4:00 p.m.
Panel Discussion
John Bowers, Meint Smit, Geert Mortier, Andrea Melloni, Michael Hochberg

4:00 p.m.–4:30 p.m.
Coffee Break

Session II: Current and Future Applications of Integrated Photonics

Takuo Tanemura, *Univ. of Tokyo, Japan,* **Moderator**

4:30 p.m.–4:45 p.m.
InP Integrated Photonics, Larry Coldren, *Univ. of California at Santa Barbara, USA*

4:45 p.m.–5:00 p.m.
Integrated Photonics in Telecom Systems, Fred Kish, *Infinera, USA*

5:00 p.m.–5:15 p.m.
Integrated Photonics: from Telecom to Biomed, Jian-Jun He, *Zhejiang Univ., China*

5:15 p.m.–5:30 p.m.
InP-Based Photonic Integrated Circuits for Transmission and Switching, Toru Segawa, *NTT, Japan*

5:30 p.m.–5:45 p.m.
Chip-Scale Integrated Photonic Systems, S. J. Ben Yoo, *Univ. of California at Davis, USA*

5:45 p.m.–6:00 p.m.
Supercomputing on an Integrated Photonic-Electronic 'Chip', Jeff Kash, *IBM, USA*

6:00 p.m.–6:30 p.m.
Panel Discussion Larry Coldren, Fred Kish, Jian-Jun He, Toru Segawa, S.J. Ben Yoo, Jeff Kash

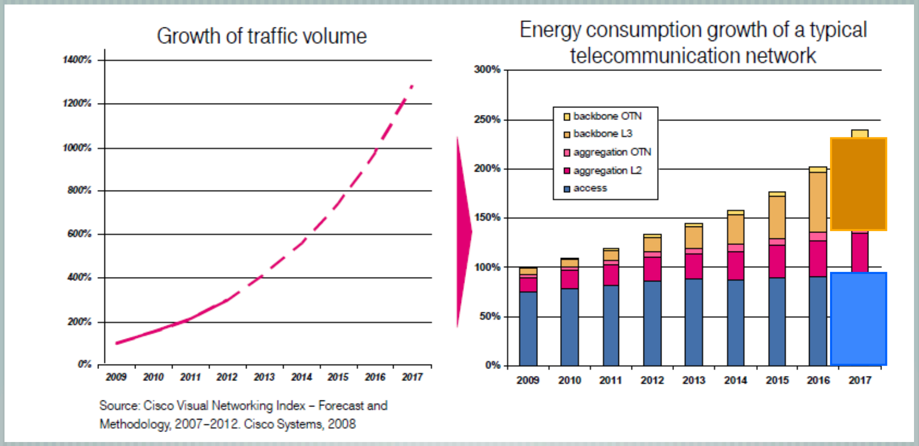
Energy Efficiency in Telecom Optical Networks

Pulak Chowdhury
University of California, Davis

Workshop on Energy Efficient Networking and System
Photonics in Switching ‘10
July 25, 2010

Y. Zhang, P. Chowdhury, M. Tornatore, B. Mukherjee, “Energy efficiency in telecom optical networks,” IEEE Communications Surveys and Tutorials, 2010.

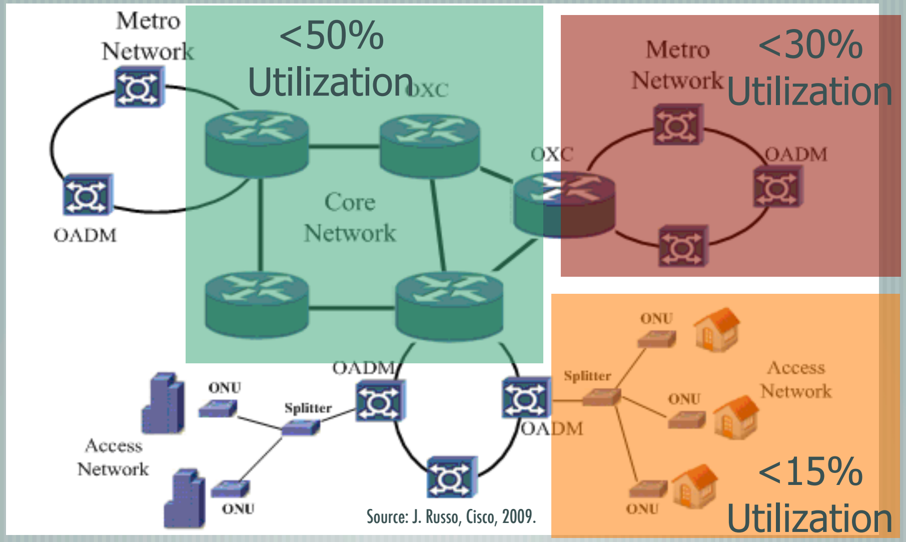
Energy Consumption of Broadband Networks



Source: Cisco Visual Networking Index – Forecast and Methodology, 2007–2012. Cisco Systems, 2008

Source: C. Lange, “Energy consumption of telecommunication networks - a network operator’s view,” OFC/NFOEC’09, San Diego, Mar. 2009.

Network Domains



<50% Utilization

<30% Utilization

<15% Utilization

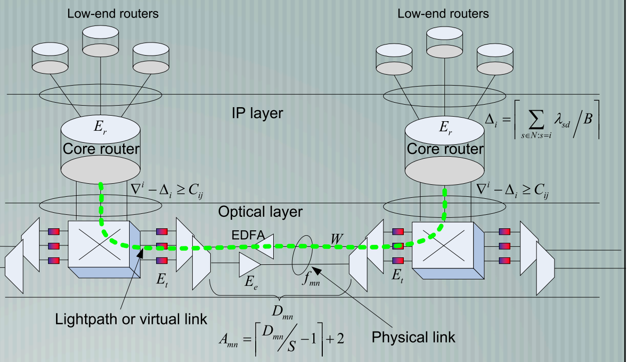
Source: J. Russo, Cisco, 2009.

Energy Efficiency in Core Networks

- Energy-Efficient Network Design
  - IP-over-WDM Network Design
  - Mixed-Line-Rate Network Design
- Energy-Efficient Network Operations
  - Shutting Down Idle Network Elements
  - Green Routing
  - Energy Efficient Traffic Grooming

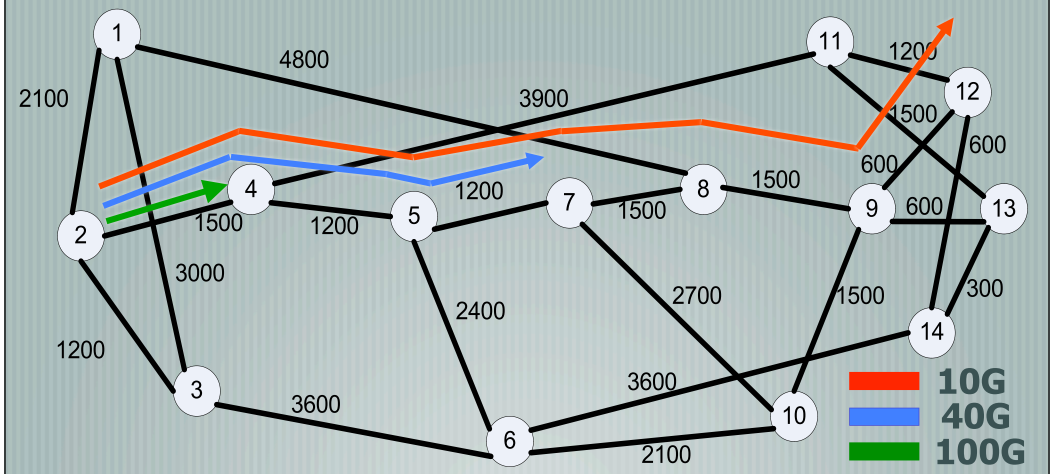
Energy-Efficient IP-over-WDM Network Design

- Energy consumption of IP routers, EDFAs, and transponders is jointly minimized.



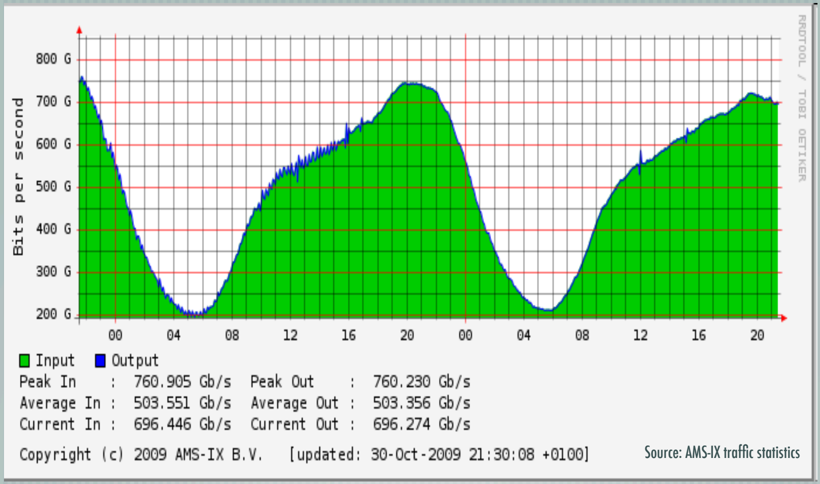
Source: G. Shen and R. S. Tucker, "Energy-minimized design for IP over WDM networks," IEEE/OSA Journal of Optical Communications and Networking, vol. 1, no. 1, pp. 176–186, June 2009.

Energy-Efficient Mixed-Line-Rate (MLR) Network Design



Source: "On the Energy Efficiency of Mixed-Line-Rate Networks," P. Chowdhury, M. Tornatore, and B. Mukherjee, OFC/NFOEC'10, San Diego, CA, March 23-25, 2010.

Internet Traffic Profile



```
Peak In    :  760.905 Gb/s  Peak Out    :  760.230 Gb/s
Average In :  503.551 Gb/s  Average Out :  503.356 Gb/s
Current In :  696.446 Gb/s  Current Out :  696.274 Gb/s

Copyright (c) 2009 AMS-IX B.V.   [updated: 30-Oct-2009 21:30:08 +0100]
```

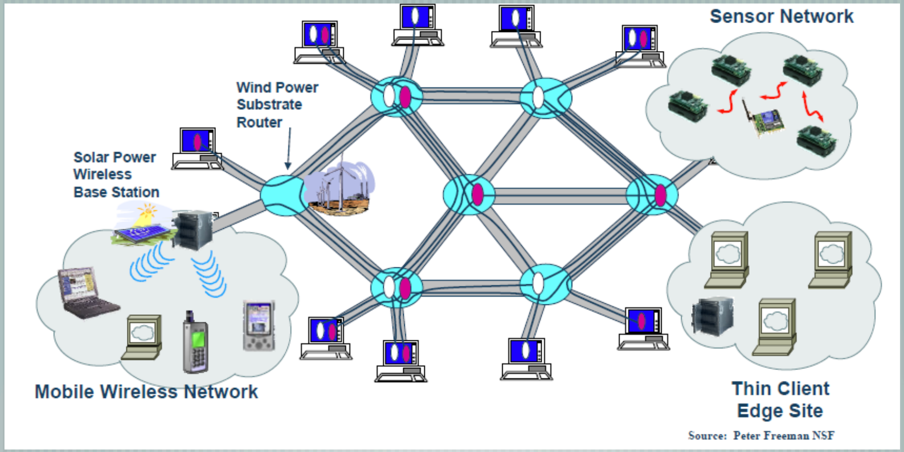
Source: AMS-IX traffic statistics

Shutting Down Idle Network Elements

- Some links are at low load during various hours of a day.
- Low-load links can be shut down to save energy.
- Traffic can be consolidated to minimal number of links.

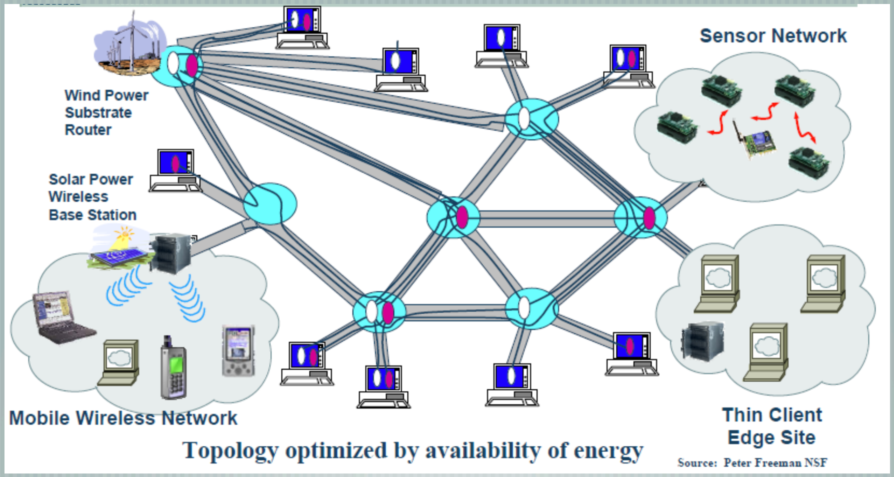
Sources:
(1) Y. Zhang, M. Tornatore, P. Chowdhury, and B. Mukherjee, "Time-aware energy conservation in IP over WDM networks," Photonics in Switching, July 2010.
(2) L. Chiaraviglio, M. Mellia, and F. Neri, "Reducing power consumption in backbone networks," IEEE ICC'09, Dresden, Germany, June 2009.

Green Routing (1)



Source: B. St. Arnaud, "CANARIE: Research networks to help reduce global warming," OFC/NFOEC'09, San Diego, Mar. 2009.

Green Routing (2)

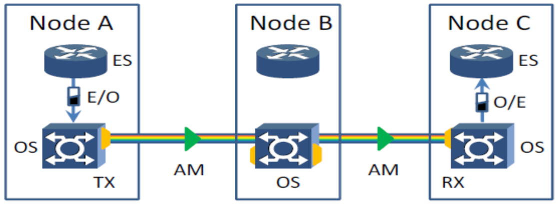


Topology optimized by availability of energy

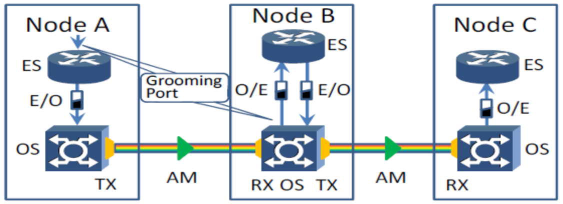
Source: Peter Freeman NSF

Source: B. St. Arnaud, “CANARIE: Research networks to help reduce global warming,” OFC/NFOEC’09, San Diego, Mar. 2009.

Energy-Efficient Traffic Grooming



(a) Direct lightpath.



(b) Two lightpaths with traffic grooming.

Source: M. Xia, M. Tornatore, Y. Zhang, P. Chowdhury, C. Martel, and B. Mukherjee, "Green provisioning for optical WDM Networks," IEEE Journal on Selected Topics in Quantum Electronics, Special Issue on Green Photonics, 2010.

Energy Efficiency in Access Networks

- Energy-Efficient Passive Optical Networks (PON)
- Energy-Efficient Next Generation Access Networks
  - Wireless-Optical Broadband Access Network (WOBAN)

Energy Efficiency in PON

- Shed power in the User Network Interface (UNI)
- Slow down UNIs
- Shed power in Access Network Interface (ANI)
- Shed speed in ANI

Sources:
(1)F. J. Effenberger, “Opportunities for power savings in optical access,” http://www.itu.int/dms- pub/itu- t/oth/ 09/05/T09050000010006PDFE.pdf, Feb. 2008.

Energy Efficiency in PON

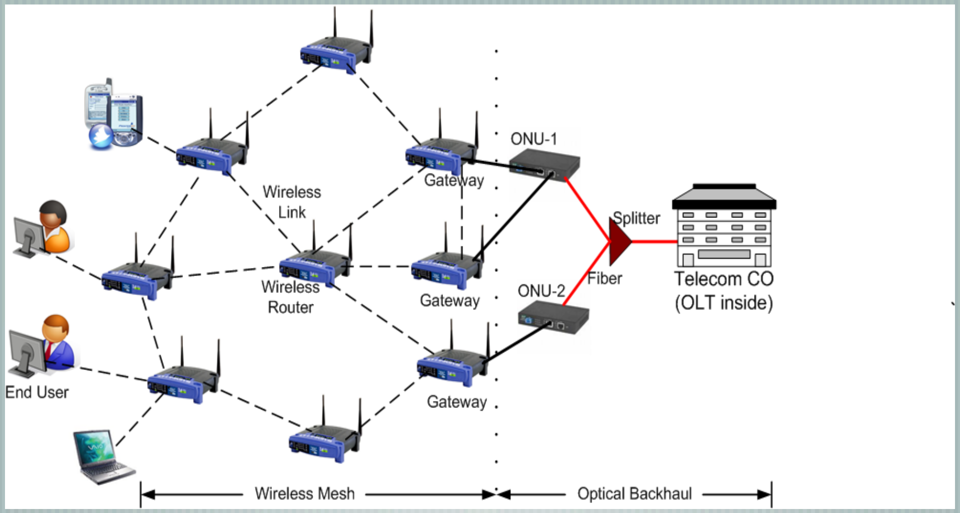
- Power saving modes for TDM-PON ONU
- Coordinated scheduling of ONU shutdown

Sources:

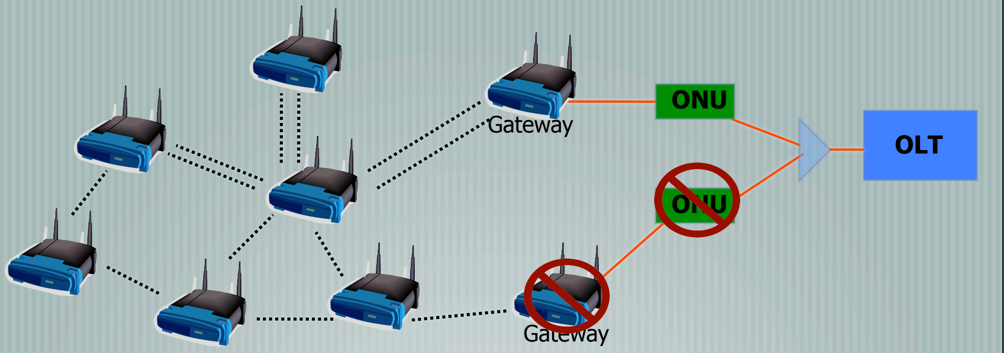
(1) J. Mandin, “EPON powersaving via sleep mode,” IEEE P802.3av 10GEPON Task Force Meeting, www.ieee802.org/3/av/public/2008-09/3av 0809 mandin 4.pdf, Sept. 2008.

(2) S.-W. Wong, L. Valcarenghi, S.-H. Yen, D. R. Campelo, S. Yamashita, and L. G. Kazovsky, “Sleep mode for energy saving PONs: Advantages and drawbacks,” IEEE GLOBECOM Workshops’09, Honolulu, HI, pp. 1–6, Dec. 2009.

WOBAN Architecture



Energy Efficiency in WOBAN



Source: P. Chowdhury, M. Tornatore, S. Sarkar, and B. Mukherjee, "Building a green wireless-optical broadband access network (woban)," IEEE/OSA Journal of Lightwave Technology (JLT), Special Issue on Very High Throughput Wireless over Fiber Technologies and Applications, 2010.

More Research Topics

- Topics not covered but can be found in the survey -
  - Standardization Efforts
  - Metro Networks
  - Data Centers
  - Grids and Applications

Reference: Y. Zhang, P. Chowdhury, M. Tornatore, B. Mukherjee, "Energy efficiency in telecom optical networks," IEEE Communications Surveys and Tutorials, 2010.

Reference: Y. Zhang, P. Chowdhury, M. Tornatore, B. Mukherjee, “Energy efficiency in telecom optical networks,” IEEE Communications Surveys and Tutorials, 2010.

Thank You

Network Equipment Energy Use and Public Policy

Steven Lanzisera

Lawrence Berkeley National Laboratory

OSA Photonics Switching Symposium

Energy Efficient Networking and Systems

25 July 2010

Electronics Energy Use (USA)

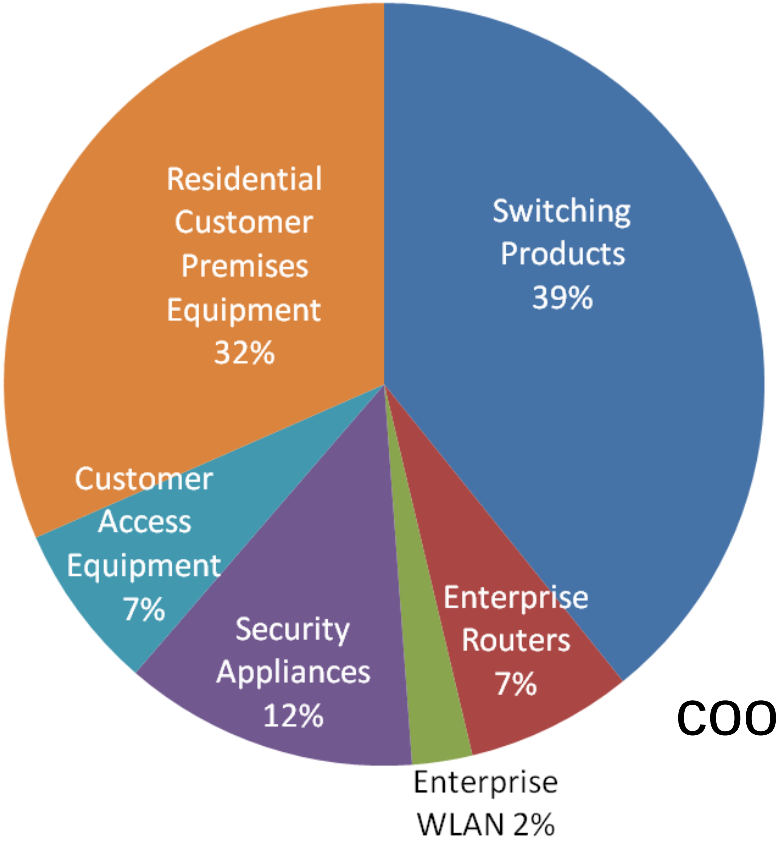
- Over 7% of total electricity used
  - Nearly 300 TWh/year
  - Costs about $30 billion/year
- Non-electronics?
  - Everything else: Lighting, Heating/Cooling, Appliances, etc.

USA Network Equipment Energy Use

18 TWh (~$2B) in 2008

11 Million Tons CO_2

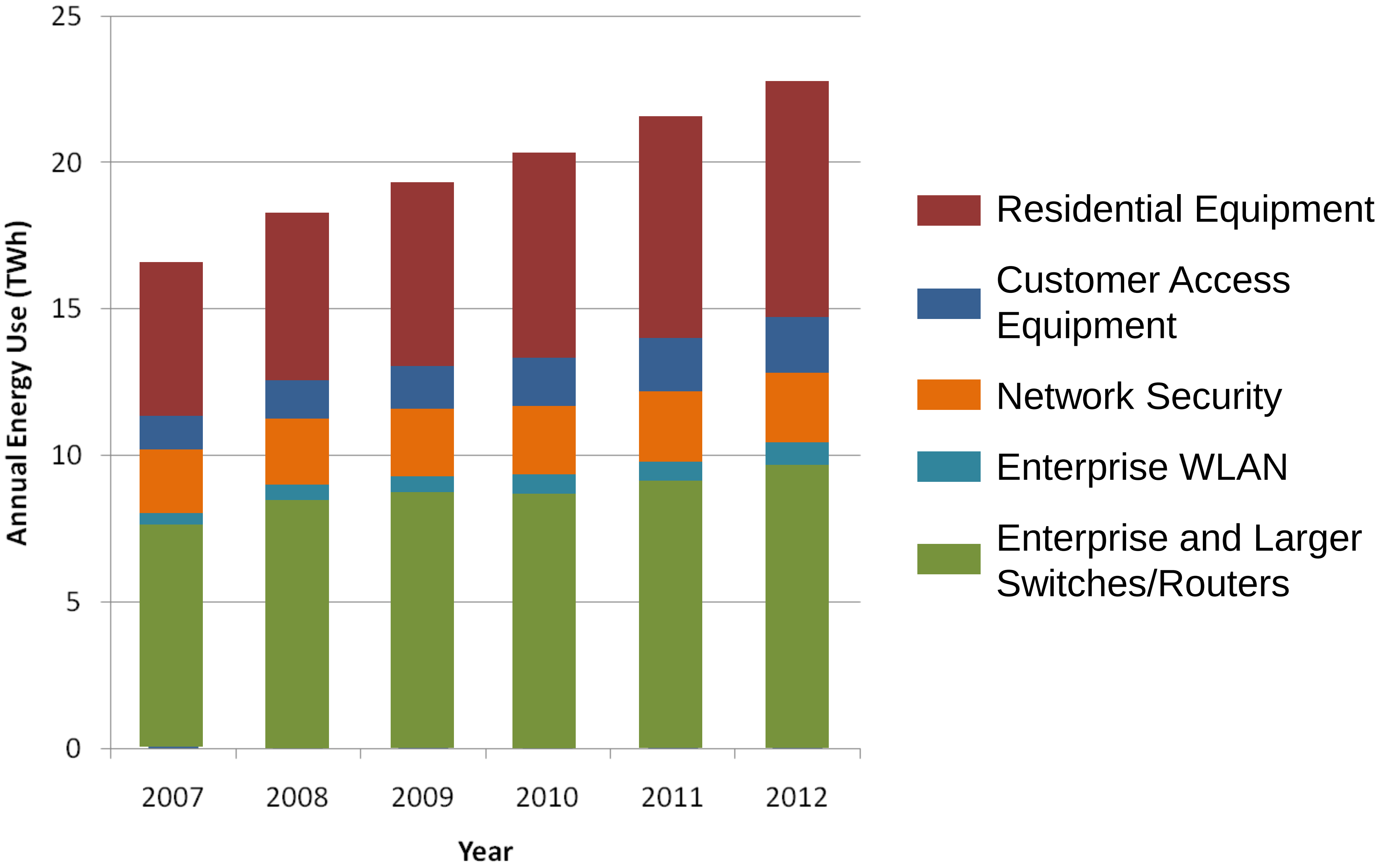
1% of total USA electricity use



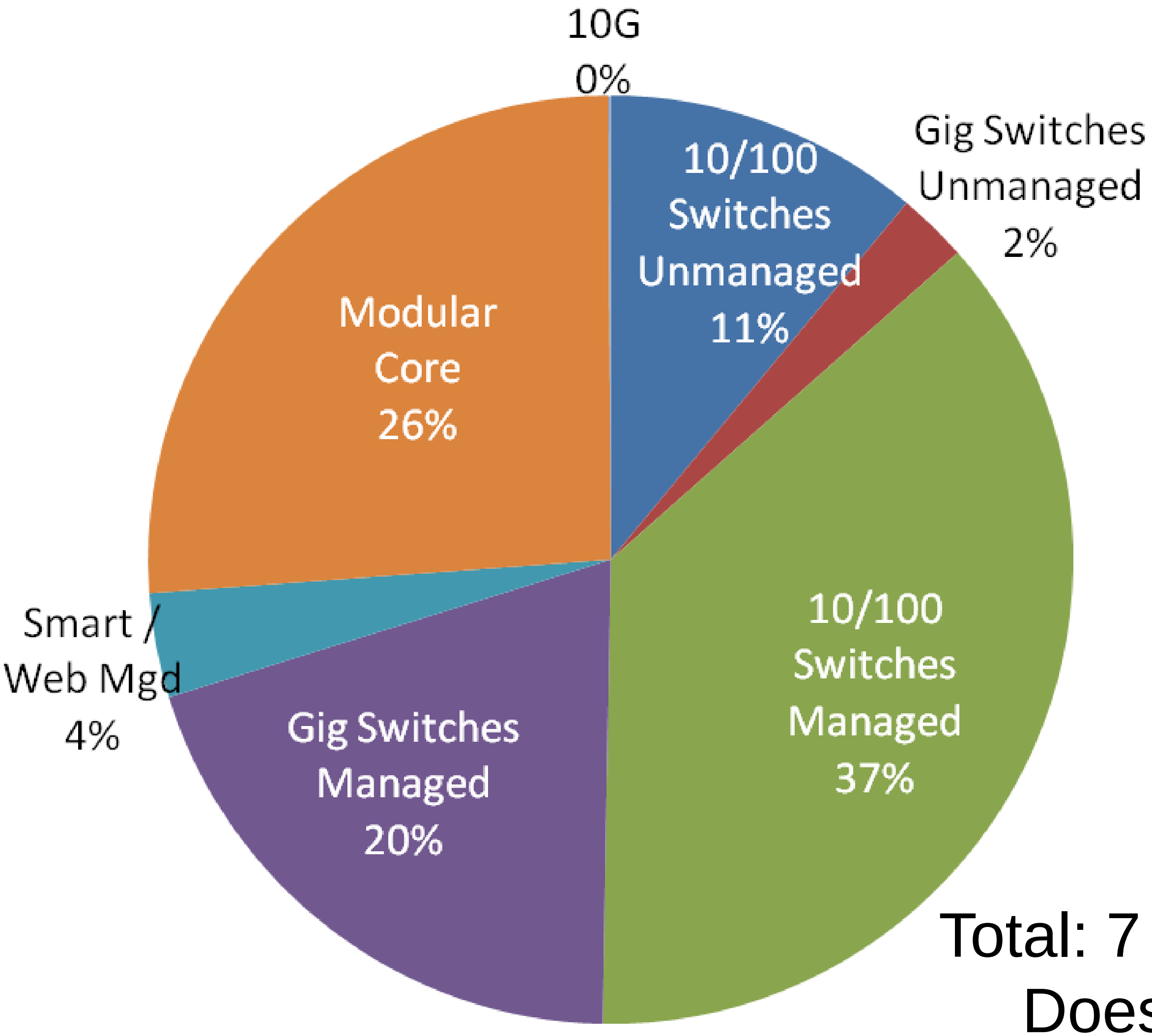
Does not include cooling, lighting or other infrastructure

Lanzisera, Nordman, Brown, “Data Network Equipment Energy Use and Savings Potential in Buildings,” ACEEE Summer Study on Buildings, Aug 2010.

USA Energy Use Growth

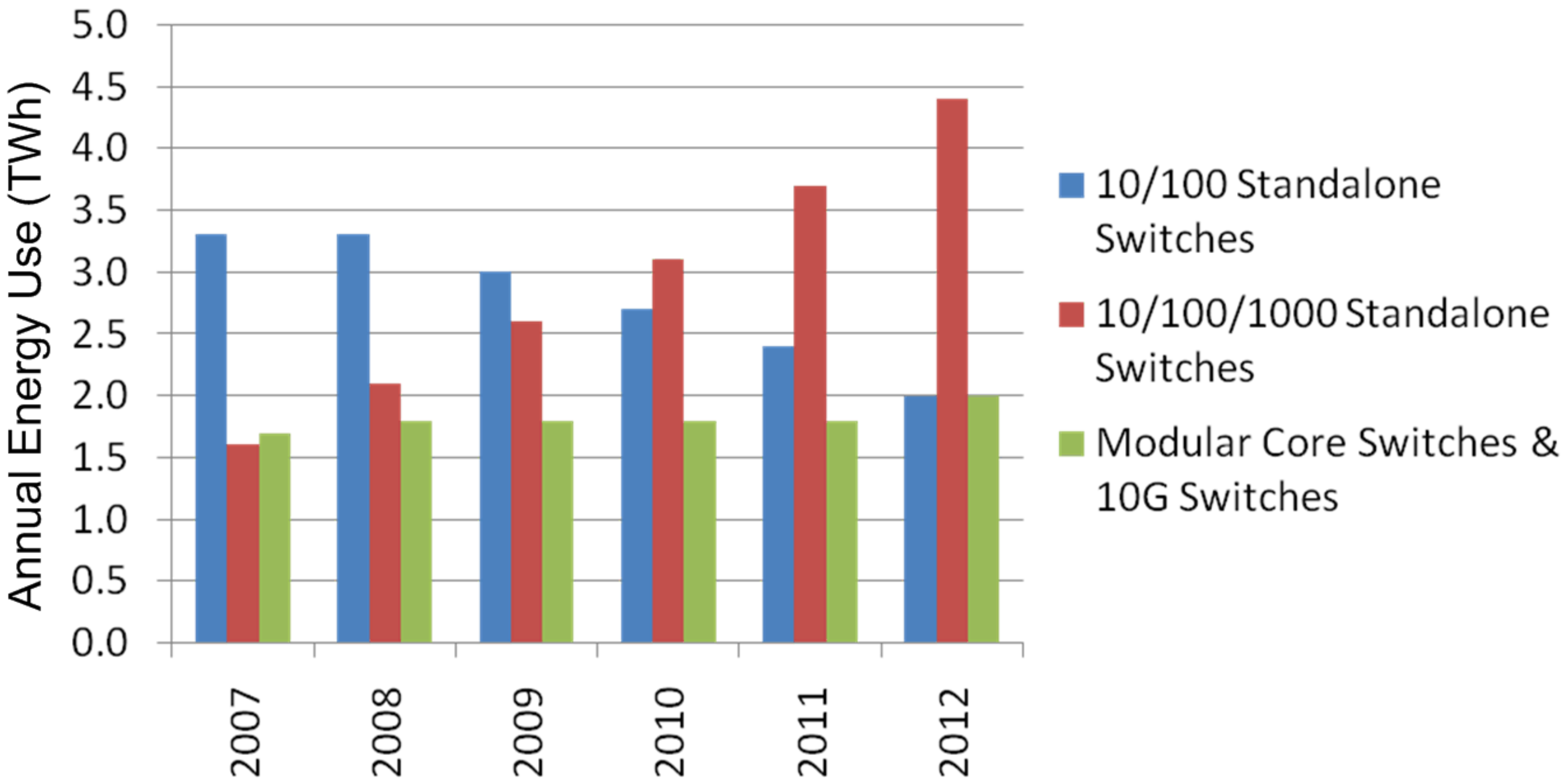


2008 USA Switches



Total: 7 TWh or $700M
Does not include cooling, etc.

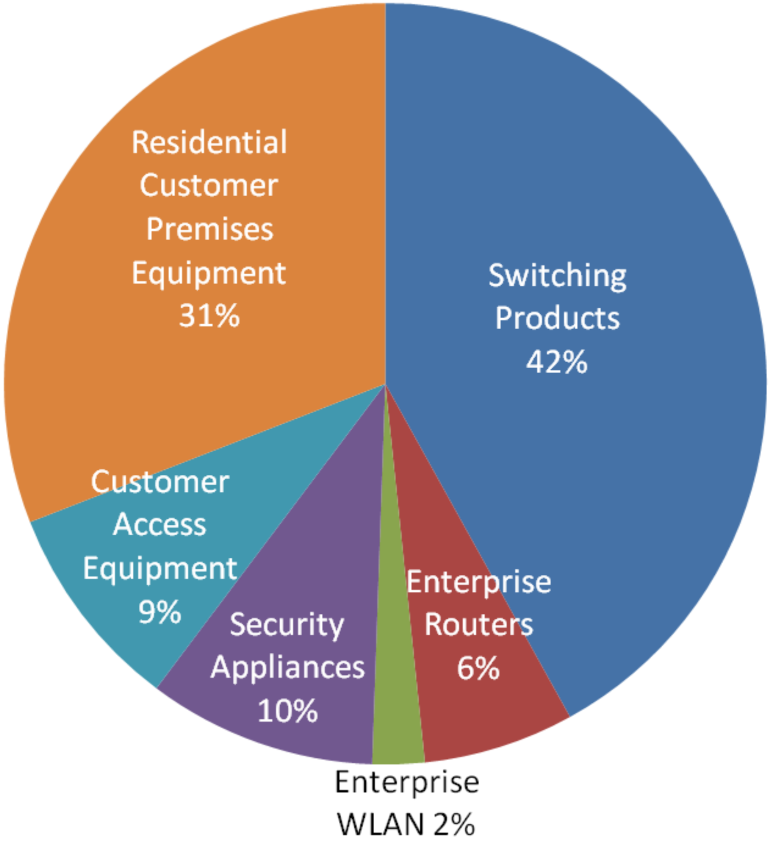
Faster Edge, Core Stays the Same



World Network Equipment Energy Use

51 TWh in 2008

30 Million Tons CO_2



Lanzisera, Nordman, Brown, “Data Network Equipment Energy Use and Savings Potential in Buildings,” ACEEE Summer Study on Buildings, Aug 2010.

Campus LAN Example

76 building, 4000 employee campus LAN
11k managed ports, 3.5k unmanaged ports

Equipment Type	Annual Energy (MWh)	Percent of Total
Managed Switches and Routers	310	82%
Security Appliances	27	7%
Enterprise APs	23	6%
Unmanaged Desktop Switches	20	5%
Total	380	100%

94 kWh/year for each employee

Energy Savings Opportunities (USA)

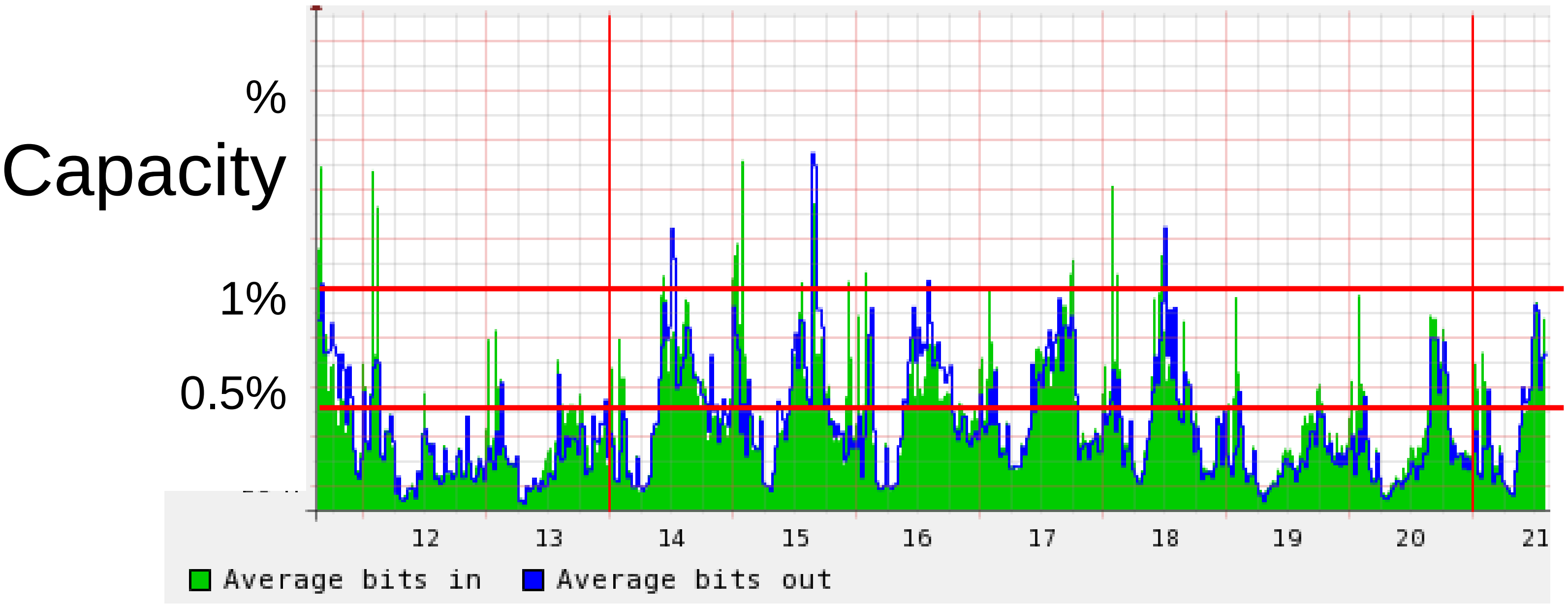
- EEE can provide 10% savings with full adoption
- Power supply efficiency another 10% (e 75%→85%)
- Adaptive capacity (slow) 25% savings
- Adaptive capacity (real time) 30% savings
- Combined for up to 50% savings
  - About 9 TWh or $1B
  - Vast majority is near the edges where utilization is lowest

Energy Use Induced by Networks

- Induced vs direct consumption
  - Direct: Switches, NICs, etc.
  - Induced: PCs awake for updates
- Induced >> Direct Consumption
- **The edge consumes more than the core**
  - Lower performance but many more devices
  - Savings opportunities are large

Testing Network Equipment

- Evaluate equipment like it is used
  - Not all ports supporting a link (<50% used in survey)
  - Low average utilization



Uplink utilization (10 days)

Modular switch with 144 GigE, 2x10GigE

Reporting Energy Use

- ATIS TEER: Unitless ratio scaled from 1-1000
- Others propose W/Gbps type metric
  - Comparisons across classes?
  - Only considers peak throughput
  - Not a miles-per-gallon rating
- Report power at different utilization levels
  - Test without all ports supporting a link
  - Weighted average power
  - Annual energy consumption
  - Report other metrics if you wish (e.g. W/Gbps)

Goal of Energy Public Policy

- Obtain energy savings that also save money
  - Address market failures
  - Environmental & energy security goals
- Many tools
  - Mandatory, voluntary programs
  - Rebates and incentives
  - Consumer education

Public & Industrial Efficiency Efforts

Policy

- Energy Star
- EU Code of Conduct
- EUP Standby (Lot 6 & Lot 26)
- METI Top Runner (Japan)

Efficiency efforts

- IEEE EEE
- ATIS test procedures
- Many others…

Public Policy (Energy Star)

- Energy Star is developing a "Small Network Equipment" Specification
  - Roughly 10 wired Ethernet ports or less
  - Includes all APs
  - Specification finalized end of 2010
- Large Network Equipment
  - Will include standalone & stackable switches
  - May include modular switches
  - May include routers, security, etc
  - Launch stakeholder interaction in 2011?

Conclusions

- USA Network equip used 18TWh ($2B) in 2008
- Consumption is growing 6% per year
- Networks probably save more than they use

- Measure equipment the way it is used
- Report actual numbers rather than ratios
- Public policy efforts are underway
  - Focus is on the edges rather than the core

Photonics in Switching 2010
Workshop on Energy-Efficient Networking and System

Energy and Spectrally Efficient Elastic Optical Path Network:

Introducing Elasticity and Adaptation into Optical Domain

2010.7.25

NTT Network Innovation Laboratories
Masahiko Jinno

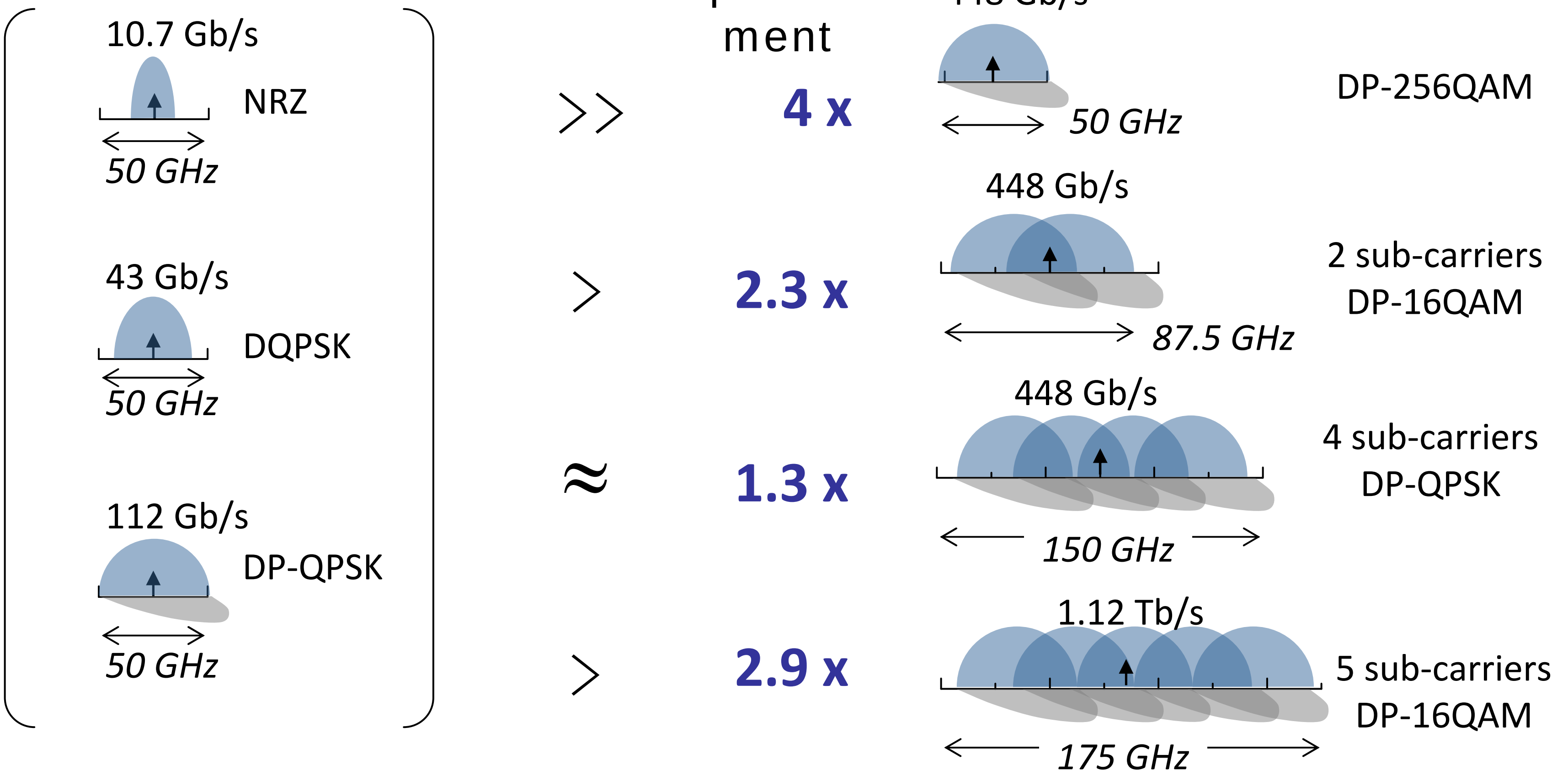
Outline

1. Drivers
    - Adaptive spectrum allocation
    - Shifting grooming and multiplexing functionalities directly to optical domain

   in 100G era and beyond
2. SLICE concept and enabling technology
    - Spectrum-sliced elastic optical path network
3. Energy and spectrally-efficient networking in IP optical networks
4. Summary

Driver for Adaptive Spectrum Allocation in 100G Era and Beyond

- For 400G/1T, rate- and distance-adaptive spectrum allocation is inevitable to achieve overall high SE
  - ✓ May not get the same mileage from the improvements in SE achieved through electrical multiplexing and grooming that we achieved before, especially for longer optical paths.



So far	Optical reach	SE im-prove-ment	400G/1T
10.7 Gb/s NRZ *50 GHz*	>>	**4 x**	448 Gb/s DP-256QAM *50 GHz*
43 Gb/s DQPSK *50 GHz*	>	**2.3 x**	448 Gb/s 2 sub-carriers DP-16QAM *87.5 GHz*
112 Gb/s DP-QPSK *50 GHz*	≈	**1.3 x**	448 Gb/s 4 sub-carriers DP-QPSK *150 GHz*
	>	**2.9 x**	1.12 Tb/s 5 sub-carriers DP-16QAM *175 GHz*

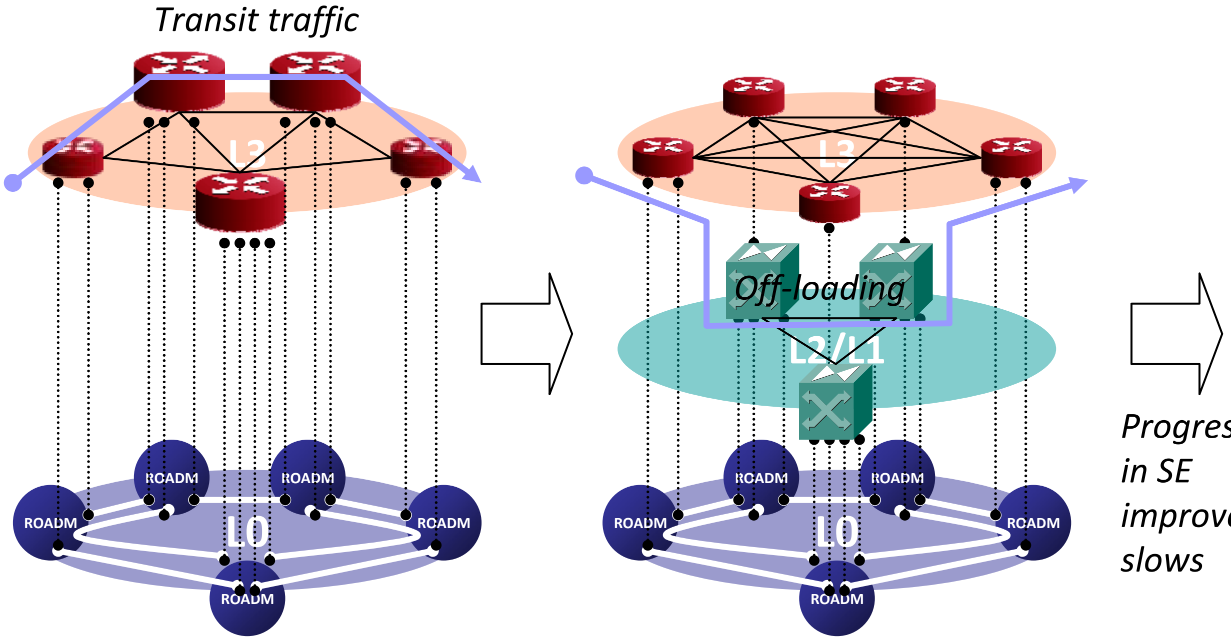
Driver for Shifting Grooming Directly to Optical Domain in 100G Era and Beyond

- Off-loading of transit traffic from core routers to energy-efficient and low-cost Layer 2 or Layer 1 switches in next generation 40G/100G networks
- Will electrical bypass still be feasible in 400G/1T era from view points of energy consumption, cost, and footprint?

Current IP NW
10G/40G

Near future IP NW (~2012)
40G/100G

Future IP NW (~2020)
100G/400G/1T

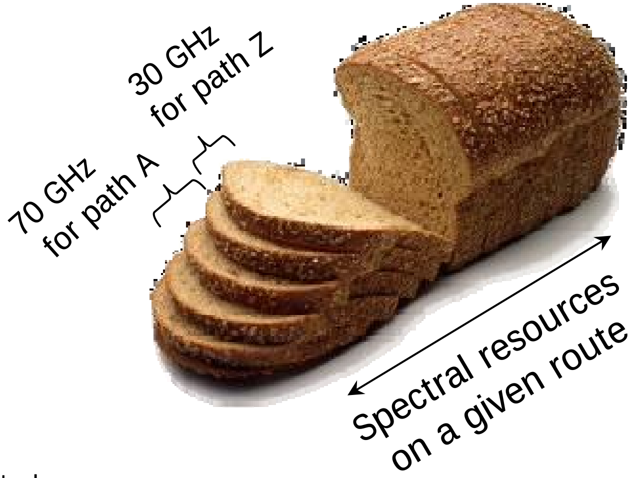


Progress in SE improvement slows

Optical bypass with spectrally-efficient transport of transit traffic

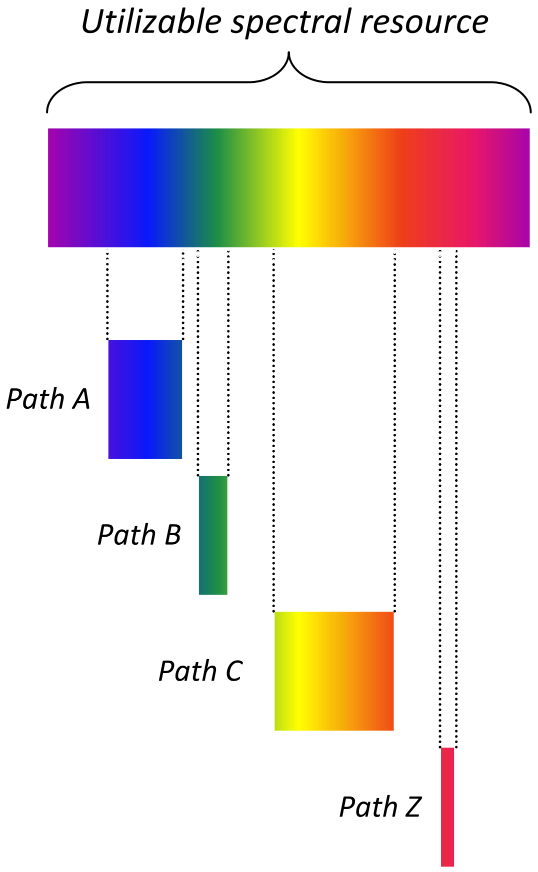
SLICE Concept

- Introducing elasticity and adaptation into optical domain
- Novel optical network architecture based on "elastic optical paths"
  - ✓ SLICE: Spectrum-sliced elastic optical path network architecture
  - ✓ Alternative to rigid bandwidth allocation
- Spectrum-efficient transport with flexible granular grooming in optical domain
- Adaptive allocation of right-sized bandwidth to an end-to-end optical path by "slicing off" the necessary spectral resources .



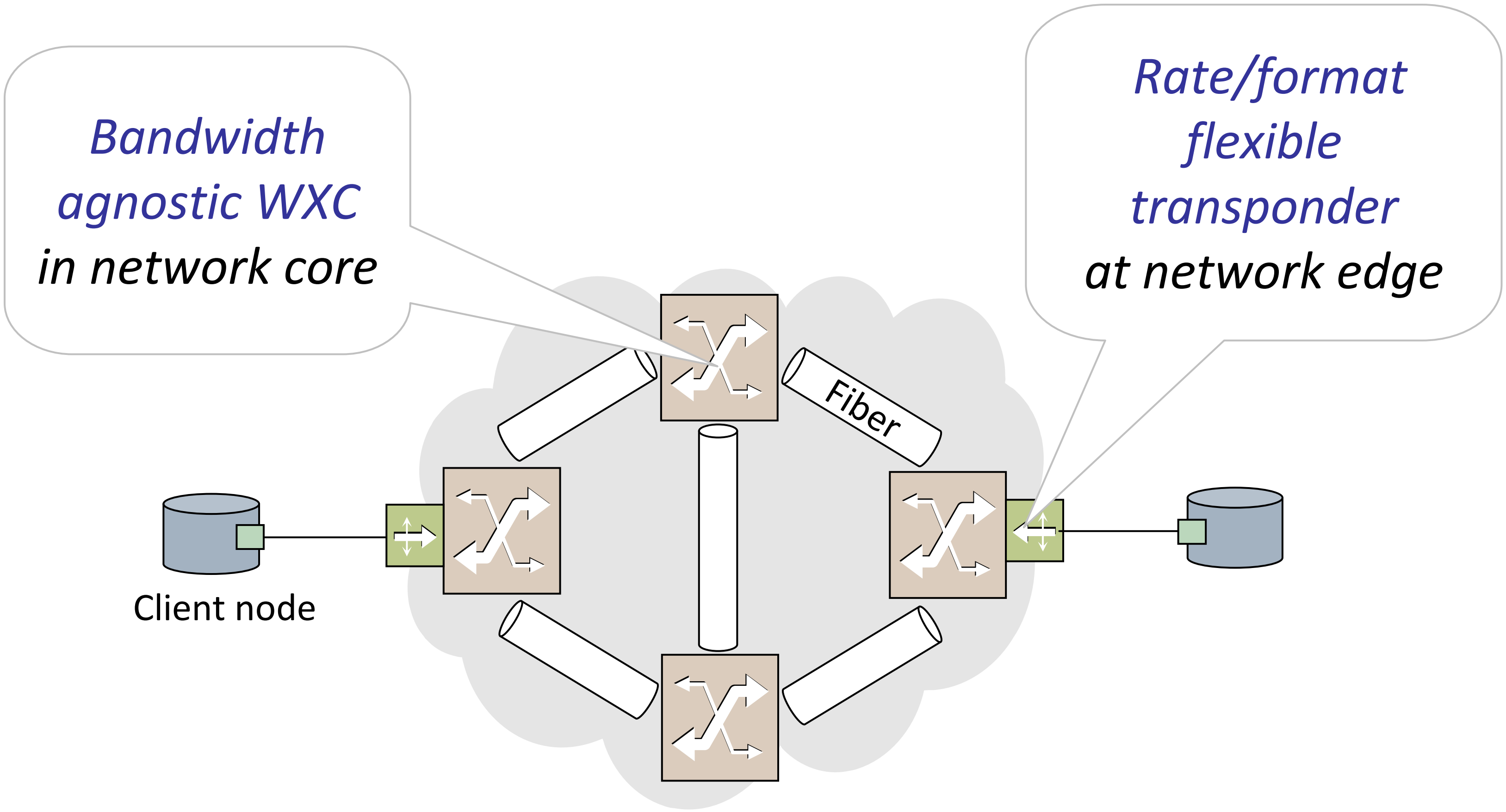
Adaptive Spectral Allocation

1. Adapt to actual user traffic volume
   - ✓ Mitigate granularity mismatch with client layer
   - ✓ Enable spectral efficient sub-wavelength, super-wavelength path provisioning in optical domain
2. Adapt to physical condition on route, *e.g.*, path length and node hops
   - ✓ Enhance network utilization efficiency by saving spectrum resources for shorter paths
3. Adapt to bandwidth available on route
   - ✓ Achieve highly survivable bandwidth squeezing restoration



Adaptive spectral resource allocation

SLICE Network Model

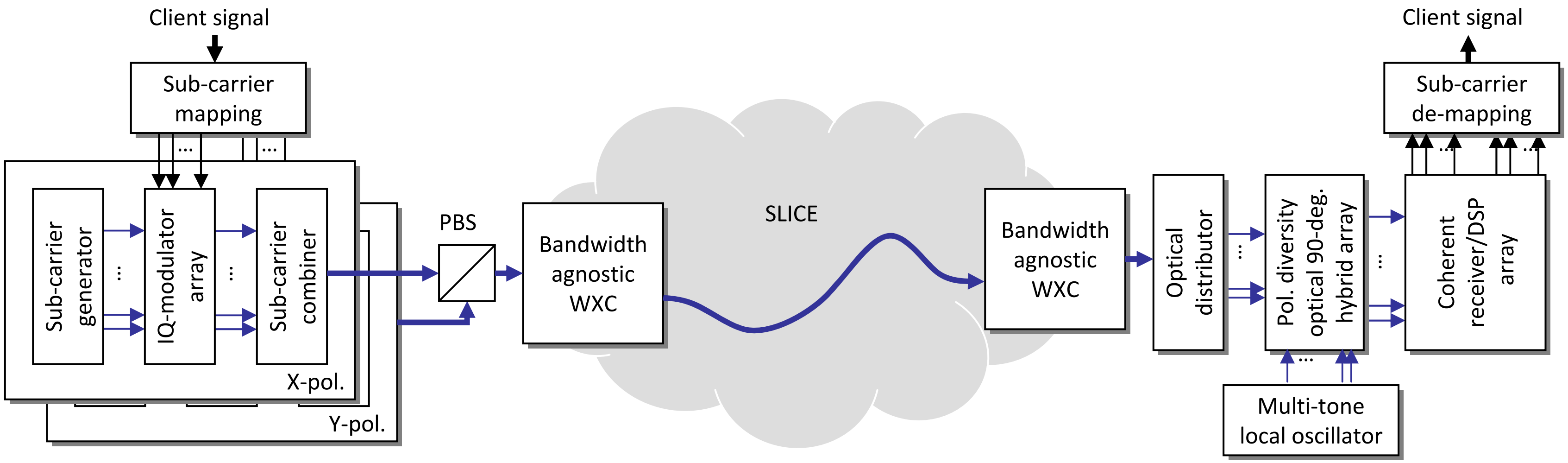


Bandwidth agnostic WXC in network core

Rate/format flexible transponder at network edge

Rate and Format Flexible Transponder

- Introduce of coherent detection followed by DSP
  - ✓ Optimizing 3 parameters provides required data rate and optical reach while minimizing spectral width
    - (Symbol rate) x (Number of modulation levels) x（Number of sub-carriers）
- Optical OFDM
  - ✓ Provides compact spectrum comprising with sub-carries that satisfy orthogonal condition
  - ✓ Optical multiplexing of orthogonal optical sub-carriers with a frequency spacing equal to the inverse of the symbol duration
- Evolution of photonic IC technology

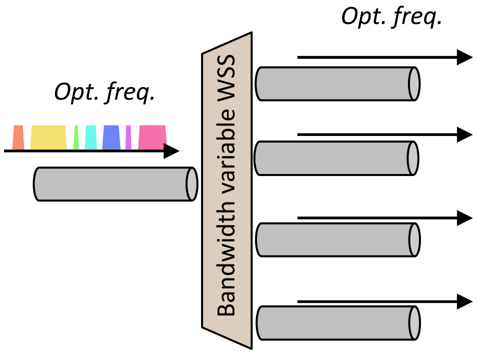


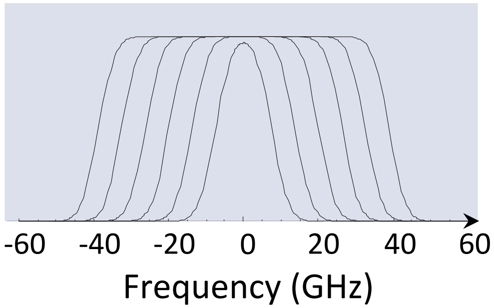
Bandwidth Agnostic WXC

- Introduce bandwidth-variable WSS based on *e.g.* LCoS
- Required minimum spectrum window (optical corridor) is open at every node along optical path

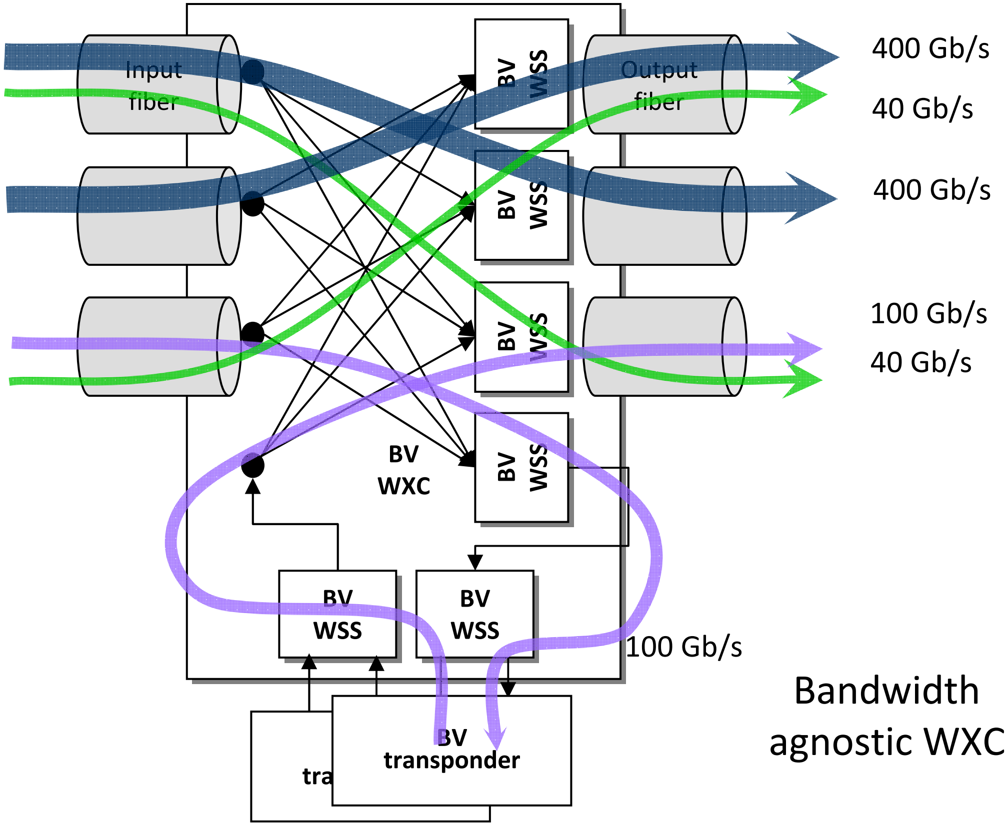
Next slide

✓ Required width of optical corridor is determined by factoring in the signal spectral width and filter clipping effect accumulated along the nodes.



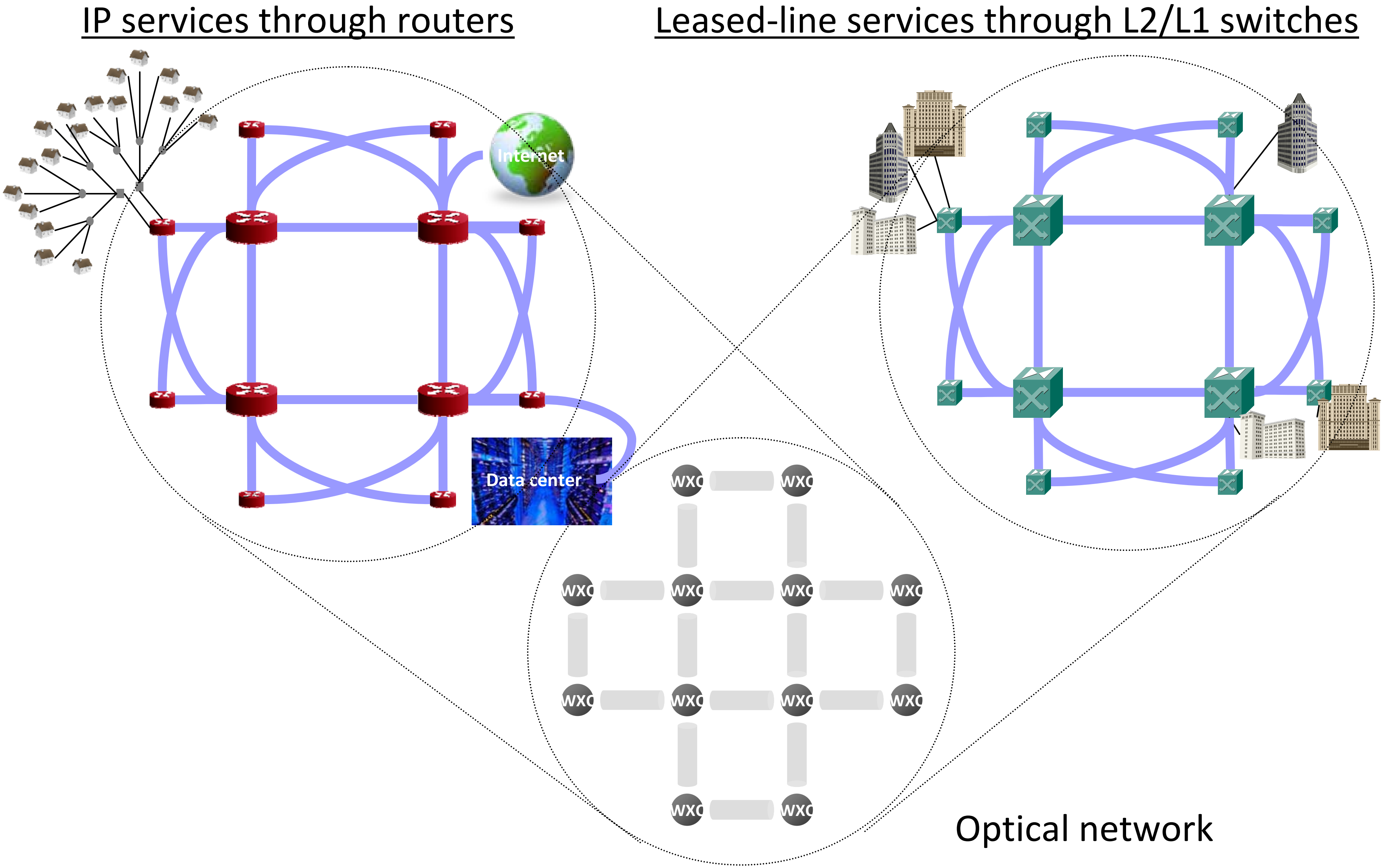


Variable bandwidth of BV-WSS



Bandwidth agnostic WXC

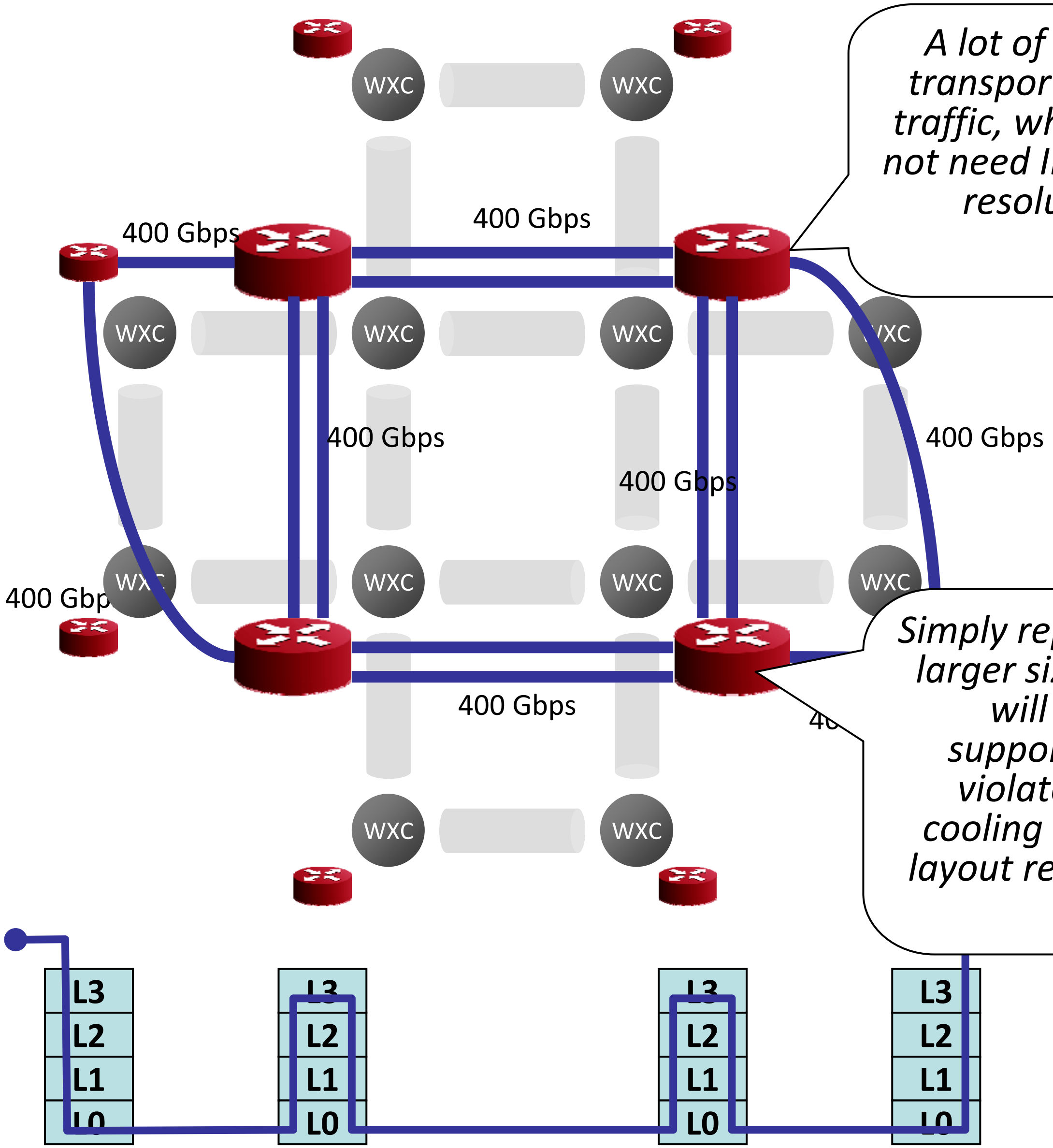
Two Major Services Over Optical Networks



IP services through routers

Leased-line services through L2/L1 switches

IP Over Optical Network

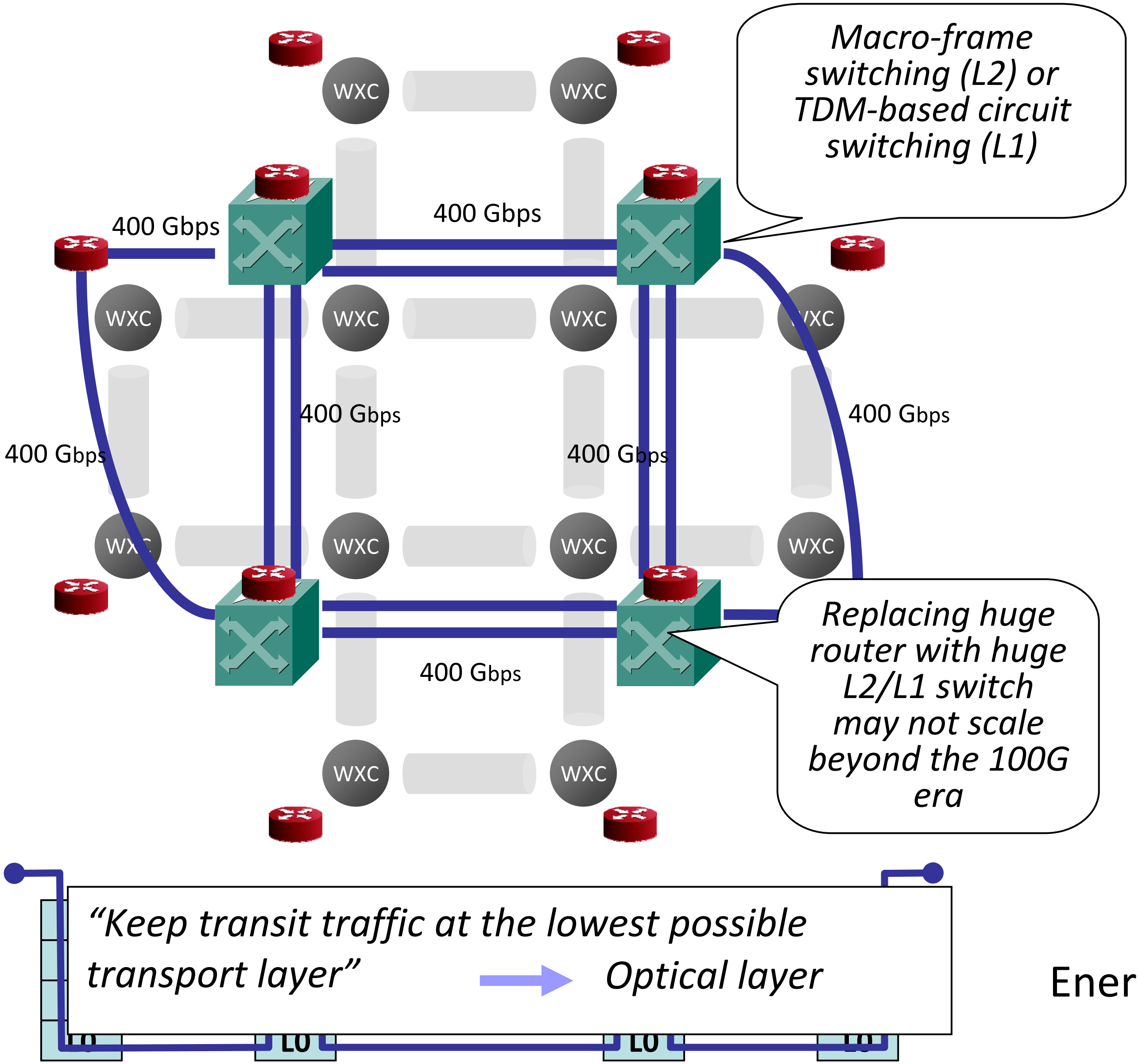


A lot of cost to transport transit traffic, which does not need IP address resolution

Simply replacing with larger sized routers will not be supportable, as violate power, cooling and office-layout requirements

Energy consumption, CAPEX

L2/L1 Bypass Over Optical Network



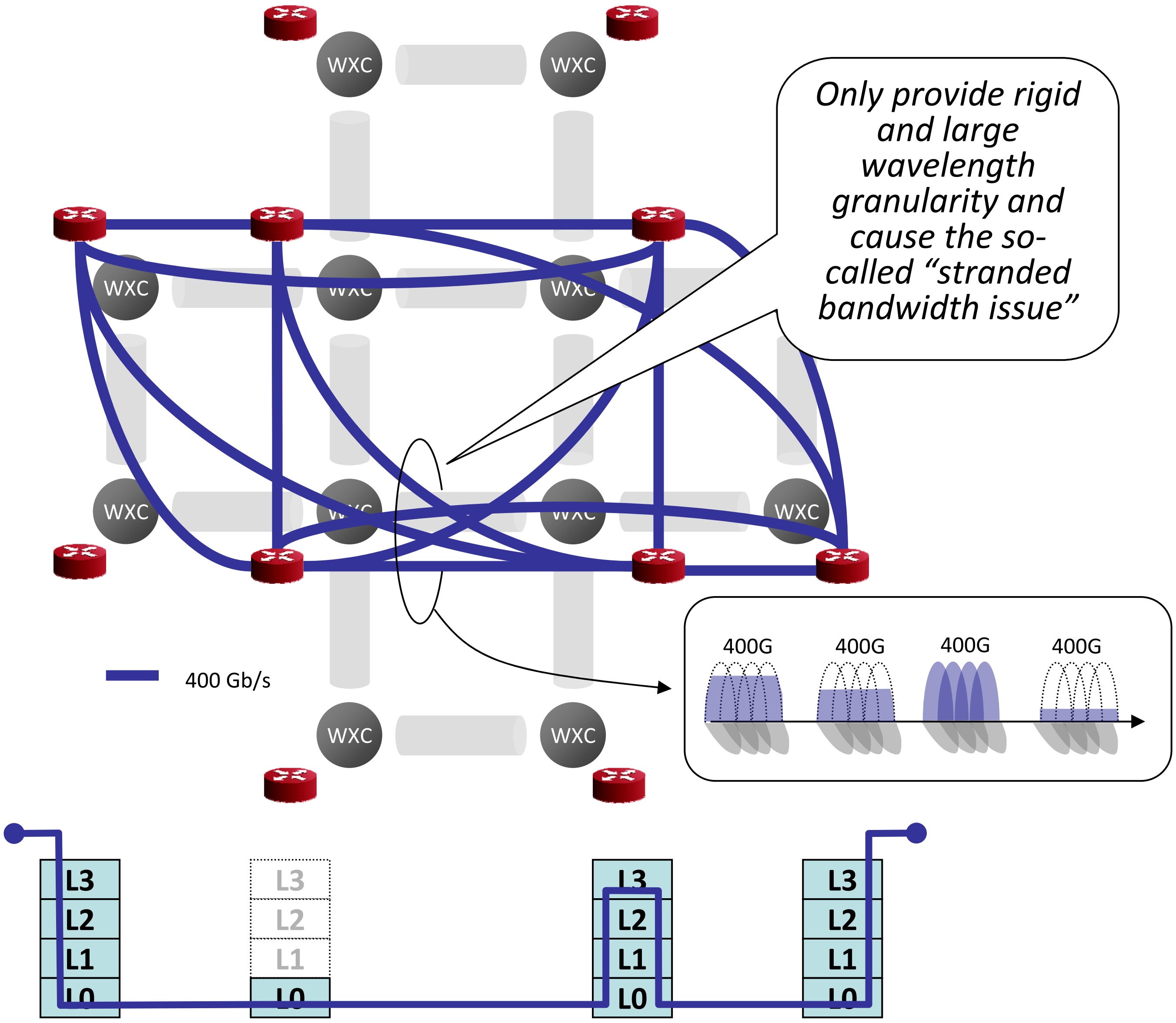
Macro-frame switching (L2) or TDM-based circuit switching (L1)

Replacing huge router with huge L2/L1 switch may not scale beyond the 100G era

“Keep transit traffic at the lowest possible transport layer” → *Optical layer*

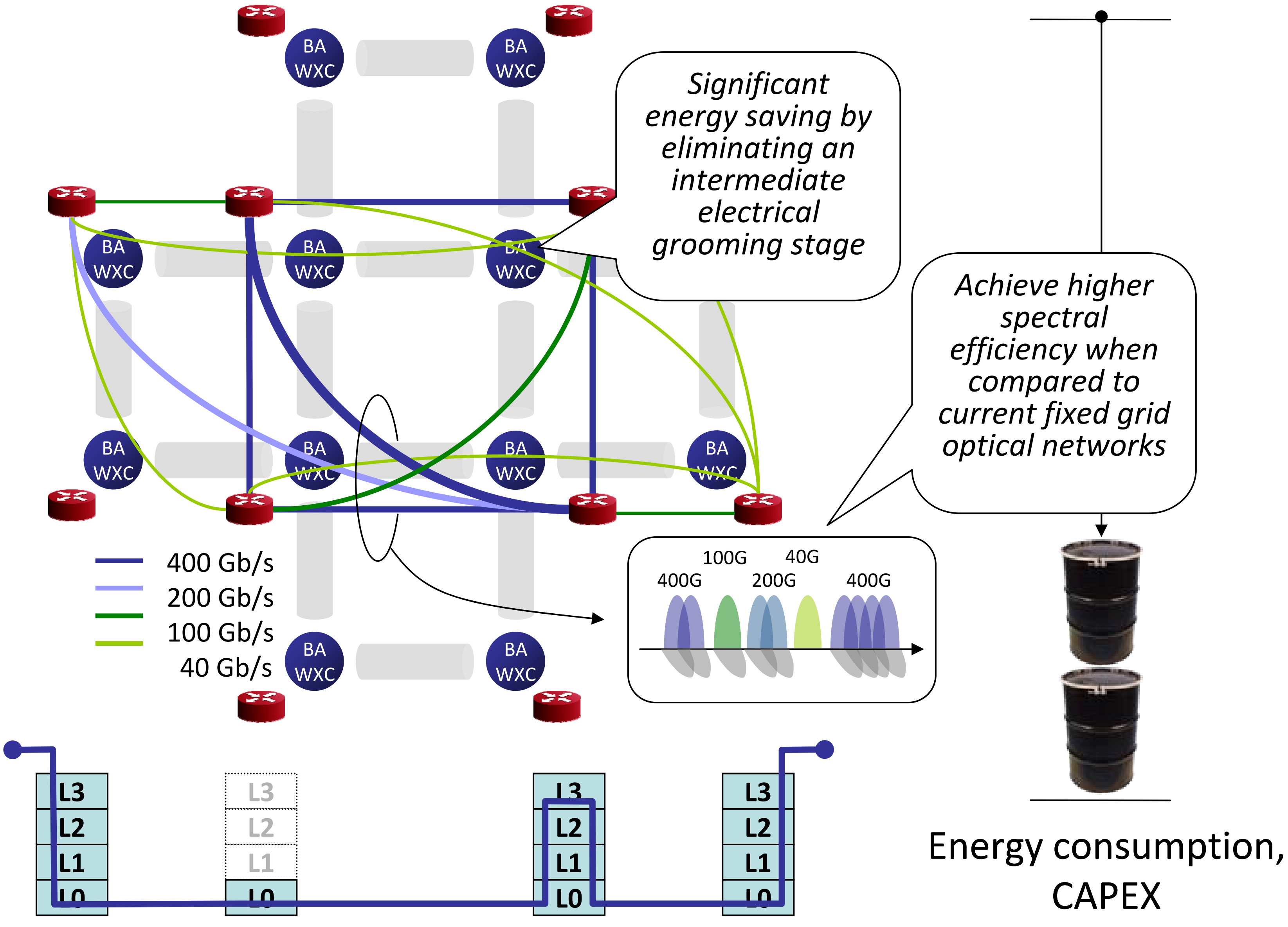
Energy consumption, CAPEX

Optical Bypass in Conventional Optical Network Based on Fixed Grid



Only provide rigid and large wavelength granularity and cause the so-called "stranded bandwidth issue"

SLICE: Optical Bypass with Rate and Distance Adaptive Spectral Allocation

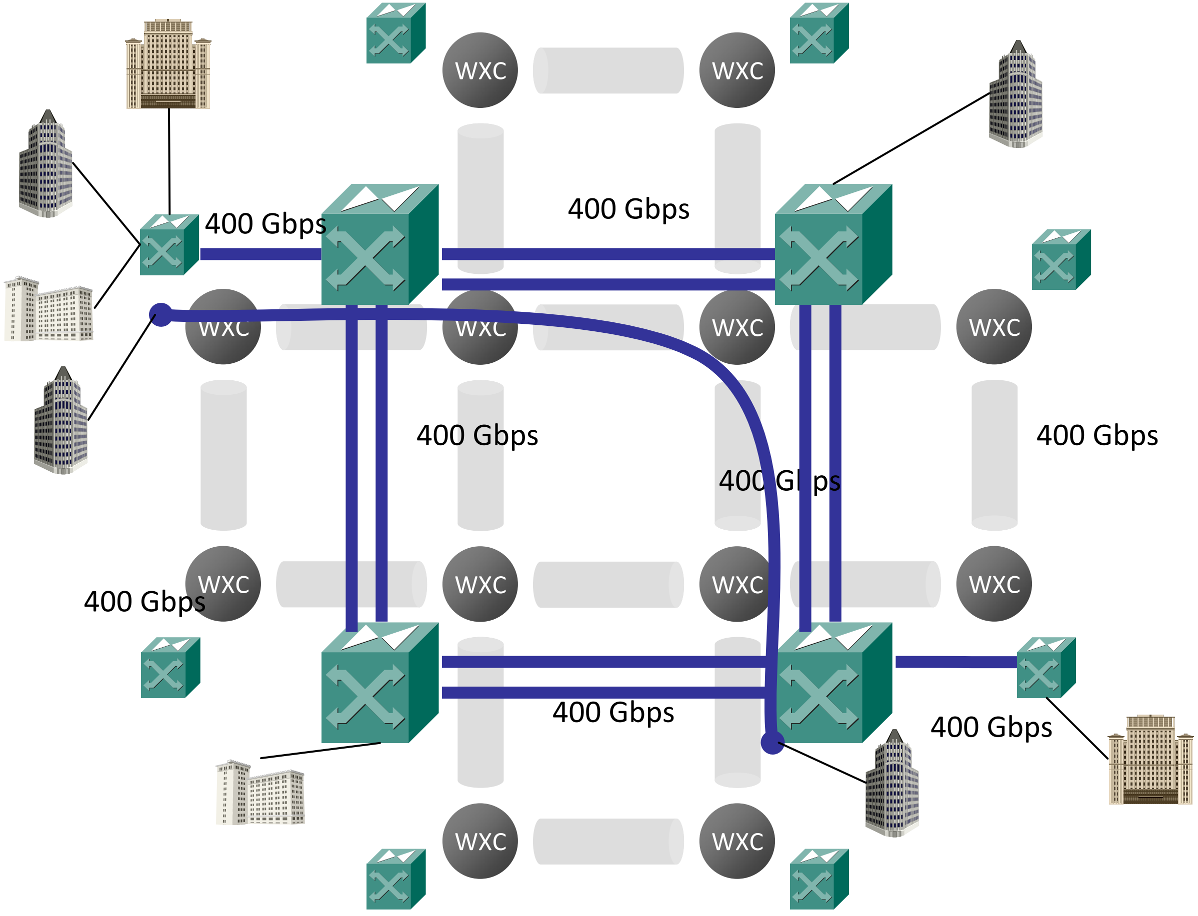


Significant energy saving by eliminating an intermediate electrical grooming stage

Achieve higher spectral efficiency when compared to current fixed grid optical networks

Energy consumption, CAPEX

Leased-Line Service Based on L2/L1 Over Optical Network

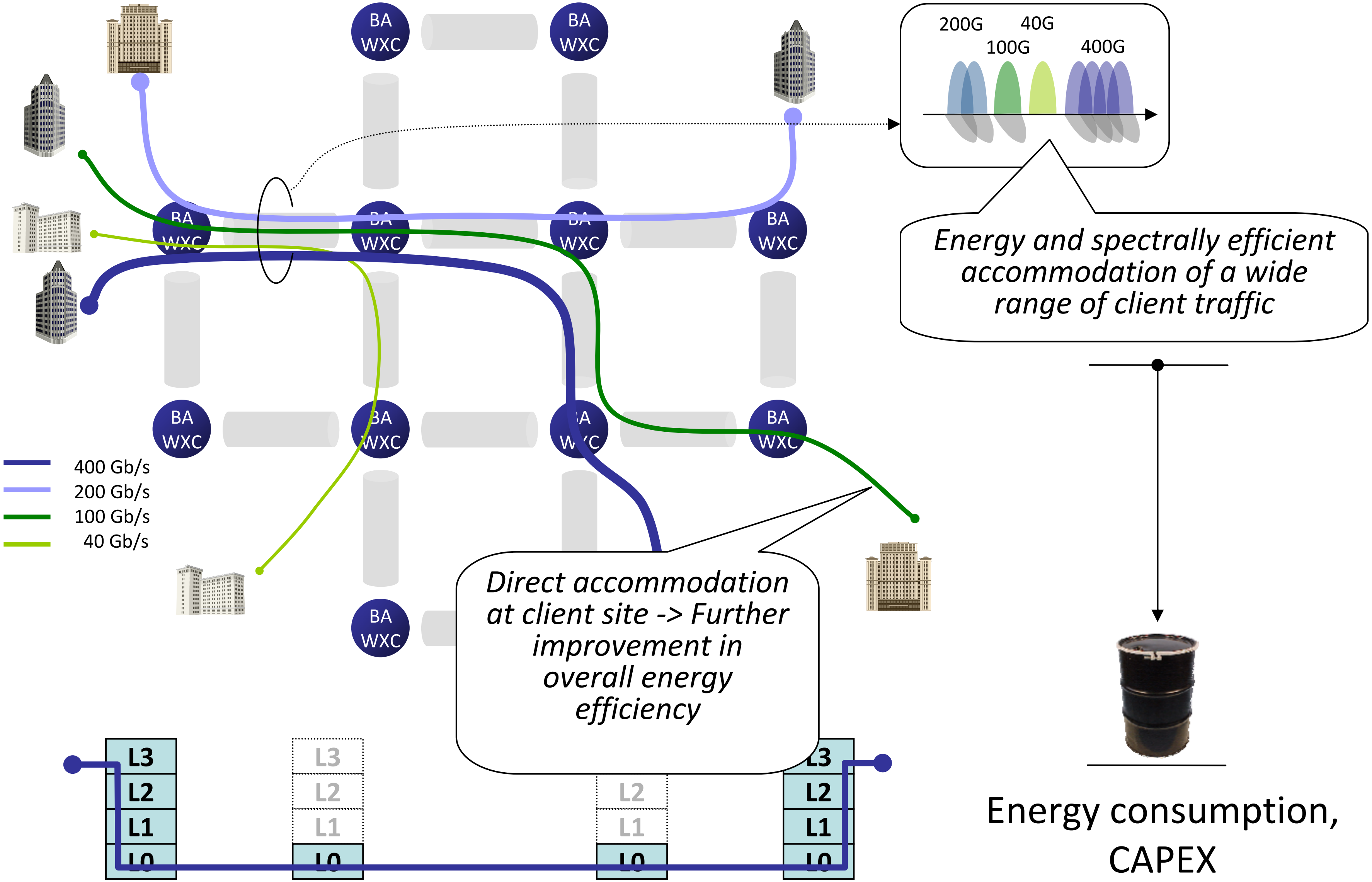


Progress in SE improvement will most likely slow

Provide wideband leased line service in fully optical domain

Energy consumption, CAPEX

Leased-Line Over SLICE w/ Direct Accommodation and Distance-Adaptive Resource Allocation



Energy and spectrally efficient accommodation of a wide range of client traffic

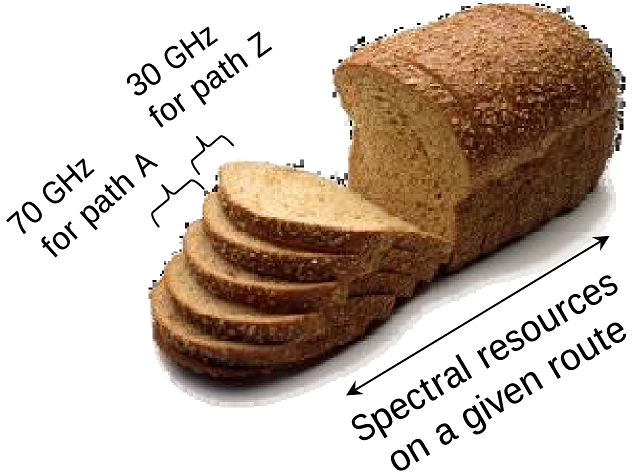
Direct accommodation at client site -> Further improvement in overall energy efficiency

Energy consumption, CAPEX

Summary

- For 400G/1T, rate- and distance-adaptive spectrum allocation is inevitable to achieve overall high SE
- Optical bypass with spectrally-efficient transport of transit traffic will become key to achieve energy-efficient IP optical networks.
- SLICE provides a platform for such energy-efficient IP networks through right-sized optical bandwidth allocation according to client data rate and required optical reach.
  - ✓ Introducing elasticity and adaptation into the optical domain.

Thank you!



Acknowledgements

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References

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Photonics in Switching 2010
Workshop on Energy-Efficient Networking and System

Energy and Spectrally Efficient Elastic Optical Path Network:

Introducing Elasticity and Adaptation into Optical Domain

2010.7.25

NTT Network Innovation Laboratories

Masahiko Jinno

Outline

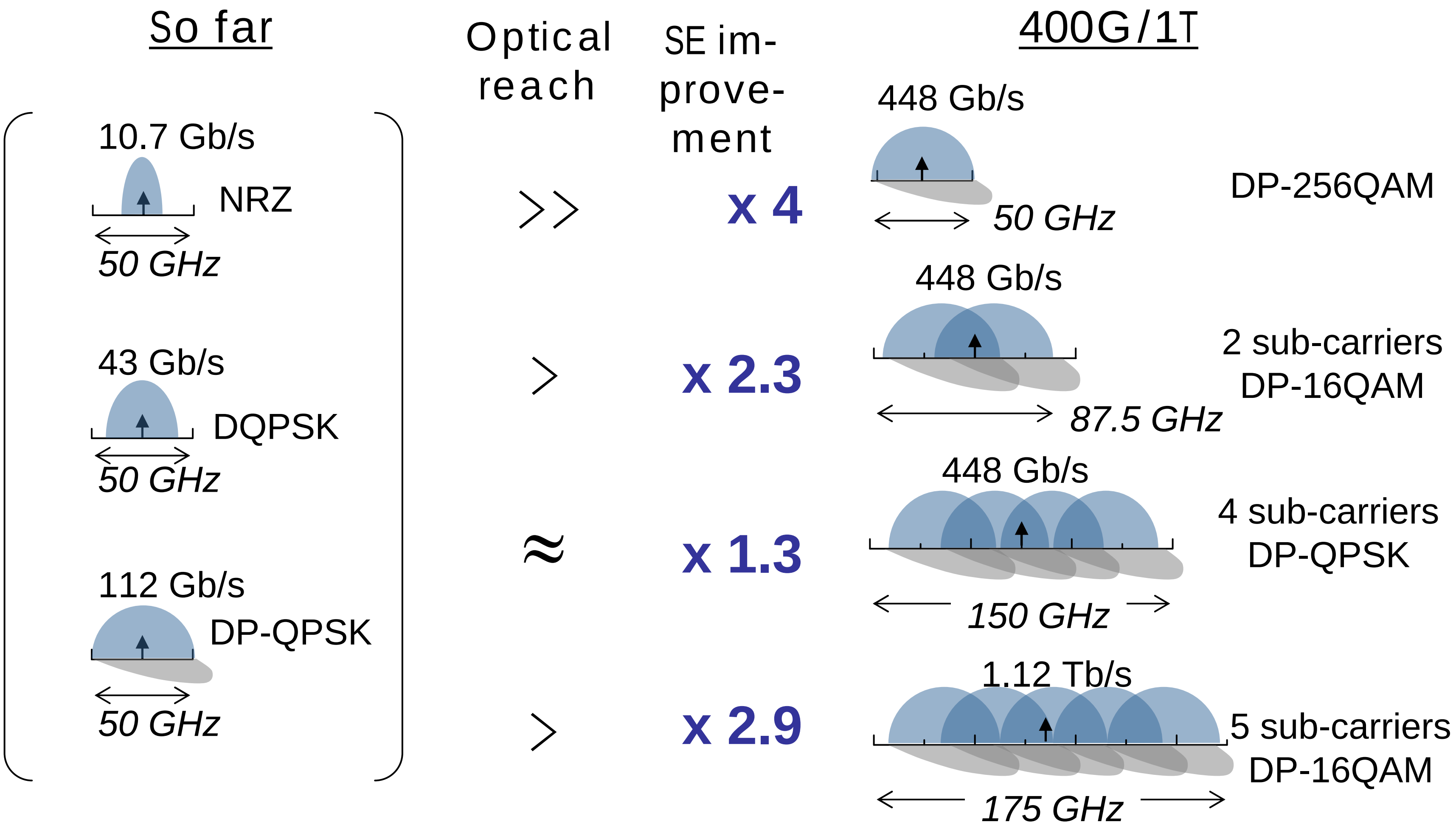
1. Drivers
   - Adaptive spectrum allocation
   - Shifting grooming and multiplexing functionalities directly to optical domain

   in 100G era and beyond
2. SLICE concept, enabling technology, and M&C framework
   - Spectrum-sliced elastic optical path network
3. Energy and spectrally-efficient networking in IP optical networks
4. Summary

1. Drivers for Adaptive Spectrum Allocation and Grooming in Optical Domain

Driver for Adaptive Spectrum Allocation in 100G Era and Beyond

- For 400G/1T, rate- and distance-adaptive spectrum allocation is inevitable to achieve overall high SE
  - ✓ May not get the same mileage from the improvements in SE achieved through electrical multiplexing and grooming that we achieved before, especially for longer optical paths.



So far	Optical reach	SE im-prove-ment	400G/1T
10.7 Gb/s NRZ *50 GHz*	>>	**x 4**	448 Gb/s DP-256QAM *50 GHz*
43 Gb/s DQPSK *50 GHz*	>	**x 2.3**	448 Gb/s 2 sub-carriers DP-16QAM *87.5 GHz*
112 Gb/s DP-QPSK *50 GHz*	≈	**x 1.3**	448 Gb/s 4 sub-carriers DP-QPSK *150 GHz*
	>	**x 2.9**	1.12 Tb/s 5 sub-carriers DP-16QAM *175 GHz*

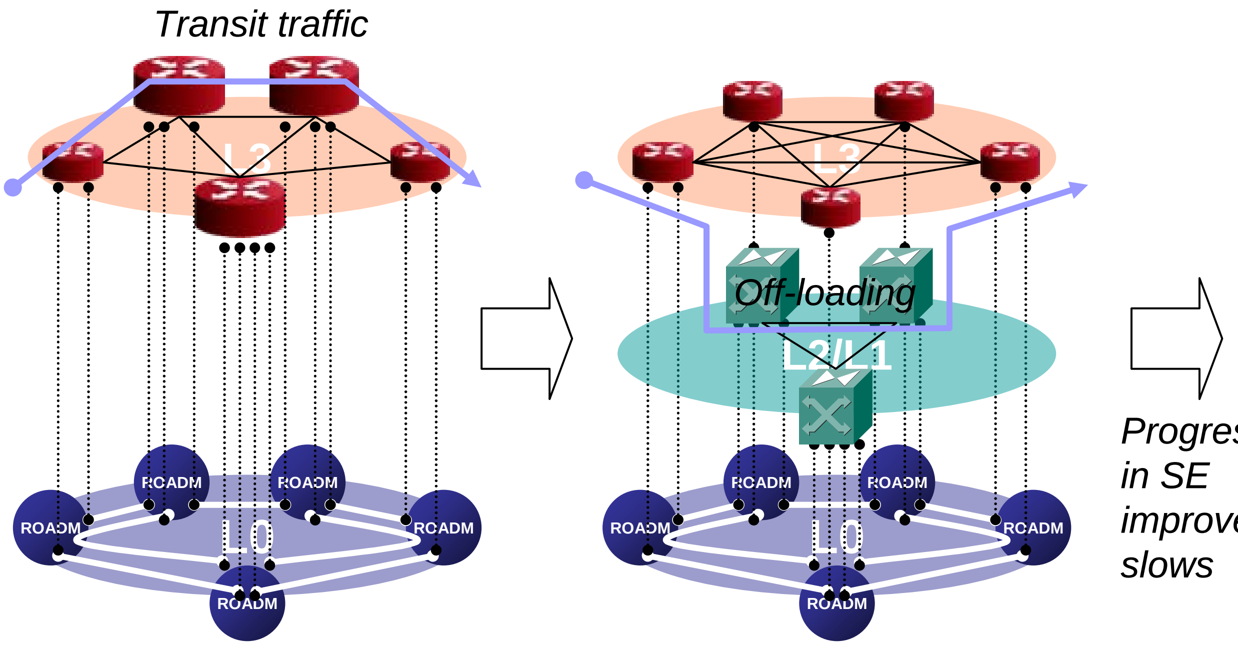
Driver for Shifting Grooming Directly to Optical Domain in 100G Era and Beyond

- Off-loading of transit traffic from core routers to energy-efficient and low-cost Layer 2 or Layer 1 switches in next generation 40G/100G networks
- Will electrical bypass still be feasible in 400G/1T era from view points of energy consumption, cost, and footprint?

Current IP NW
10G/40G

Near future IP NW (~2012)
40G/100G

Future IP NW (~2020)
100G/400G/1T



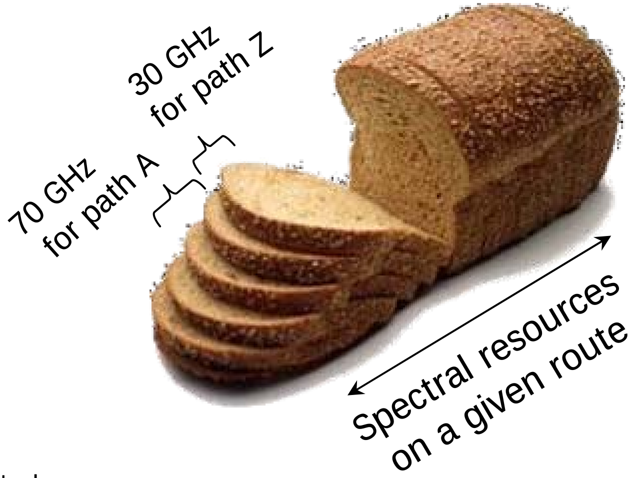
Progress in SE improvement slows

Optical bypass with spectrally-efficient transport of transit traffic

2. SLICE Concept, Enabling Technology, M&C Framework

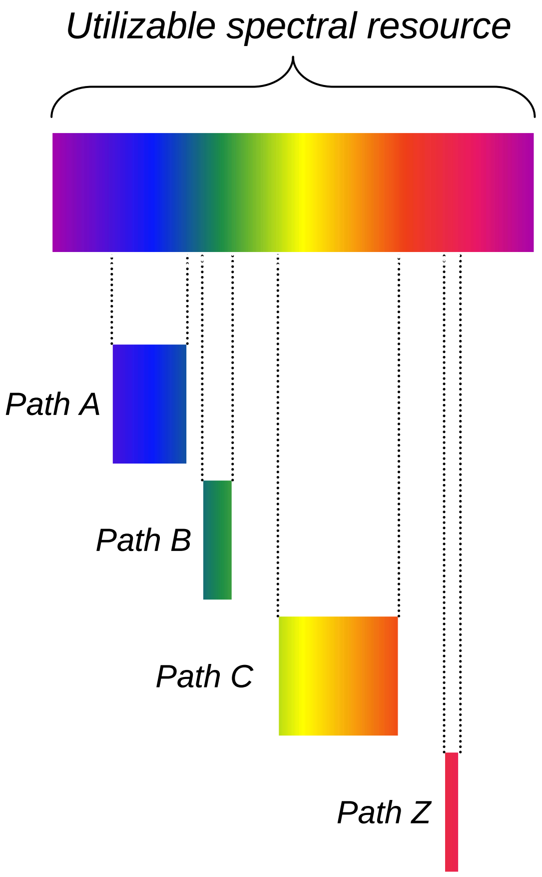
SLICE Concept

- Introducing elasticity and adaptation into optical domain
- Novel optical network architecture based on "elastic optical paths"
  - ✓ SLICE: Spectrum-sliced elastic optical path network architecture
  - ✓ Alternative to rigid bandwidth allocation
- Spectrum-efficient transport with flexible granular grooming in optical domain
- Adaptive allocation of right-sized bandwidth to an end-to-end optical path by "slicing off" the necessary spectral resources .



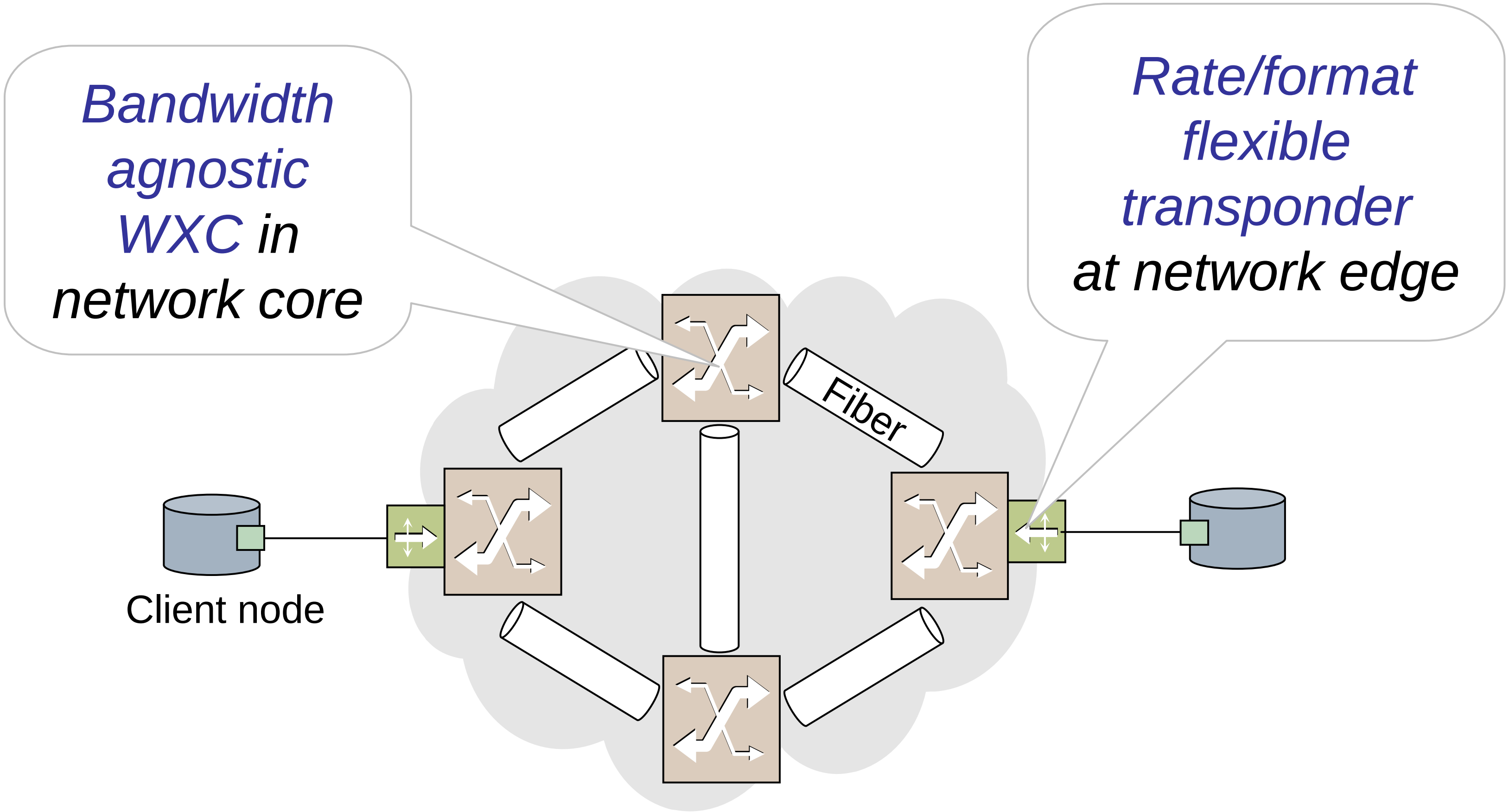
Adaptive Spectral Allocation

1. Adapt to actual user traffic volume
   - ✓ Mitigate granularity mismatch with client layer
   - ✓ Enable spectral efficient sub-wavelength, super-wavelength path provisioning in optical domain
2. Adapt to physical condition on route, *e.g.*, path length and node hops
   - ✓ Enhance network utilization efficiency by saving spectrum resources for shorter paths
3. Adapt to bandwidth available on route
   - ✓ Achieve highly survivable bandwidth squeezing restoration



Adaptive spectral resource allocation

SLICE Network Model

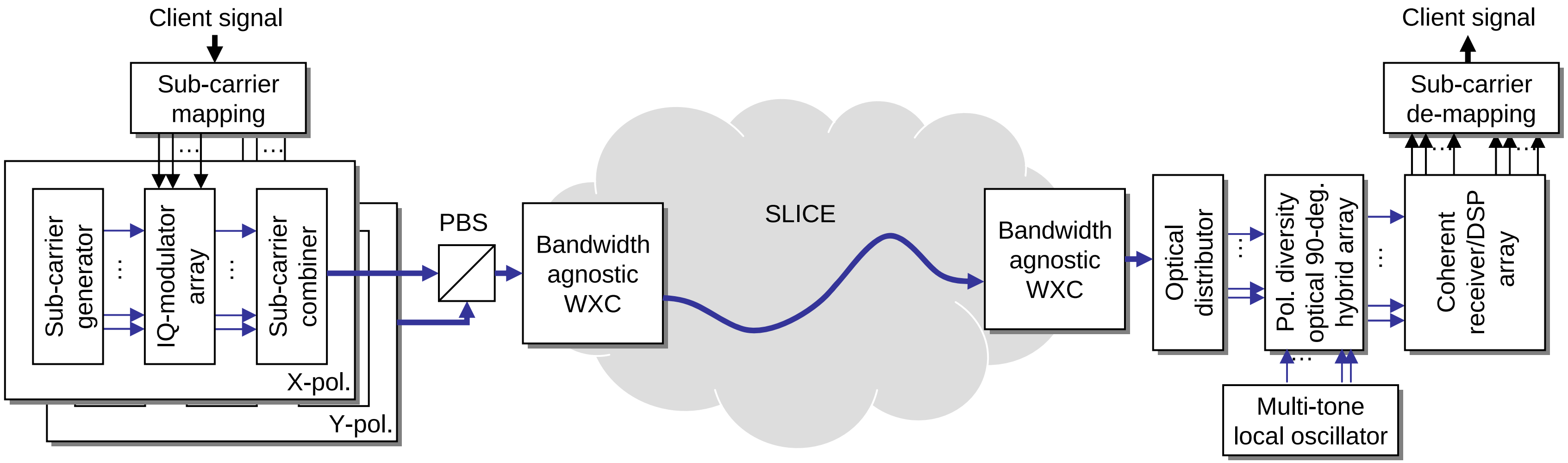


Bandwidth agnostic WXC in network core

Rate/format flexible transponder at network edge

Rate and Format Flexible Transponder

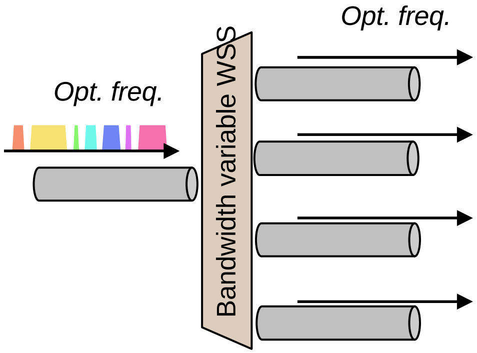
- Introduce of coherent detection followed by DSP
  - ✓ Optimizing 3 parameters provides required data rate and optical reach while minimizing spectral width
    - (Symbol rate) x (Number of modulation levels) x (Number of sub-carriers)
- Optical OFDM
  - ✓ Provides compact spectrum comprising with sub-carries that satisfy orthogonal condition
  - ✓ Optical multiplexing of orthogonal optical sub-carriers with a frequency spacing equal to the inverse of the symbol duration
- Evolution of photonic IC technology

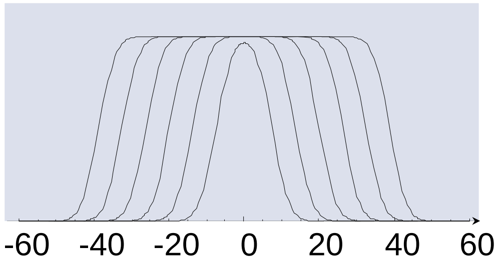


Bandwidth Agnostic WXC

- Introduce bandwidth-variable WSS based on *e.g.* LCoS
- Required minimum spectrum window (optical corridor) is open at every node along optical path
  - ✓ Required width of optical corridor is determined by factoring in the signal spectral width and filter clipping effect accumulated along the nodes.

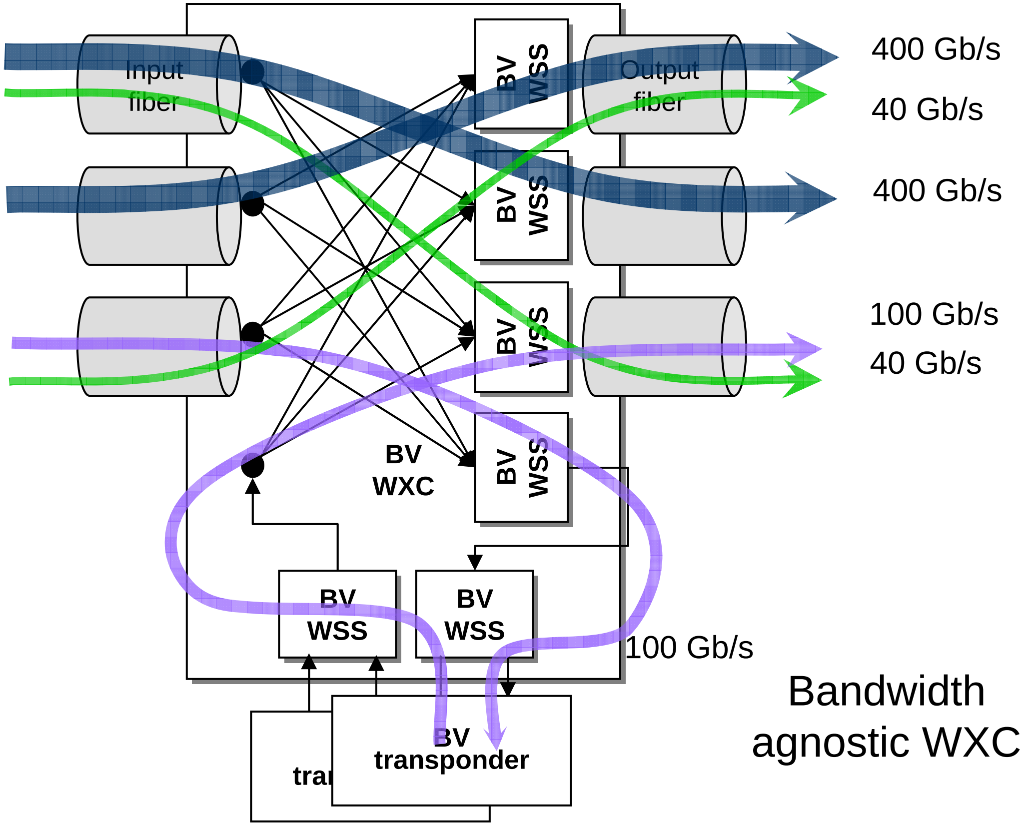
Next slide





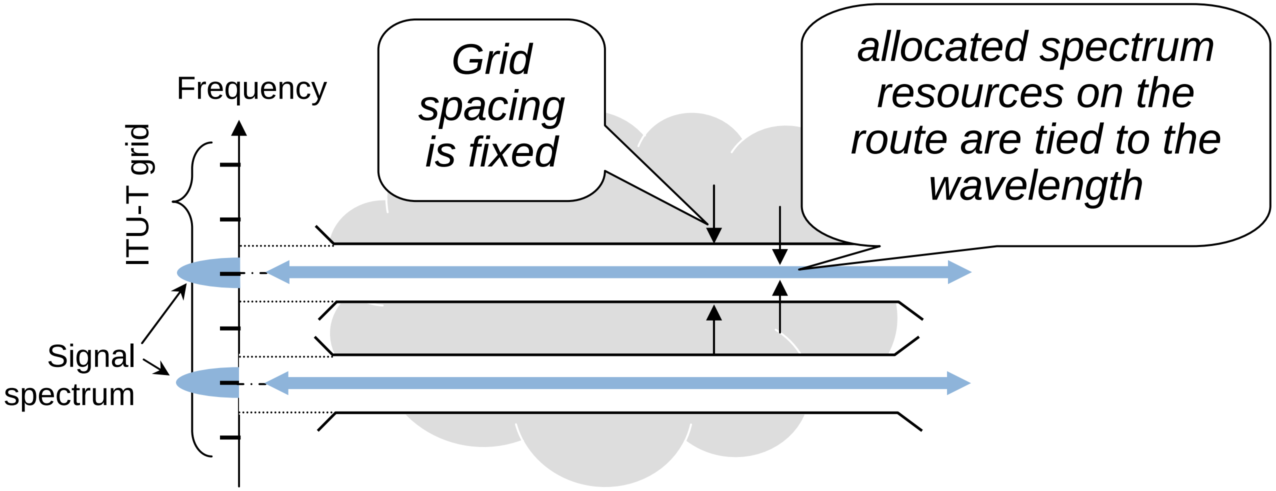
Frequency (GHz)

Variable bandwidth of BV-WSS



Bandwidth agnostic WXC

Explicit Spectral Resource Allocation: Optical Corridor

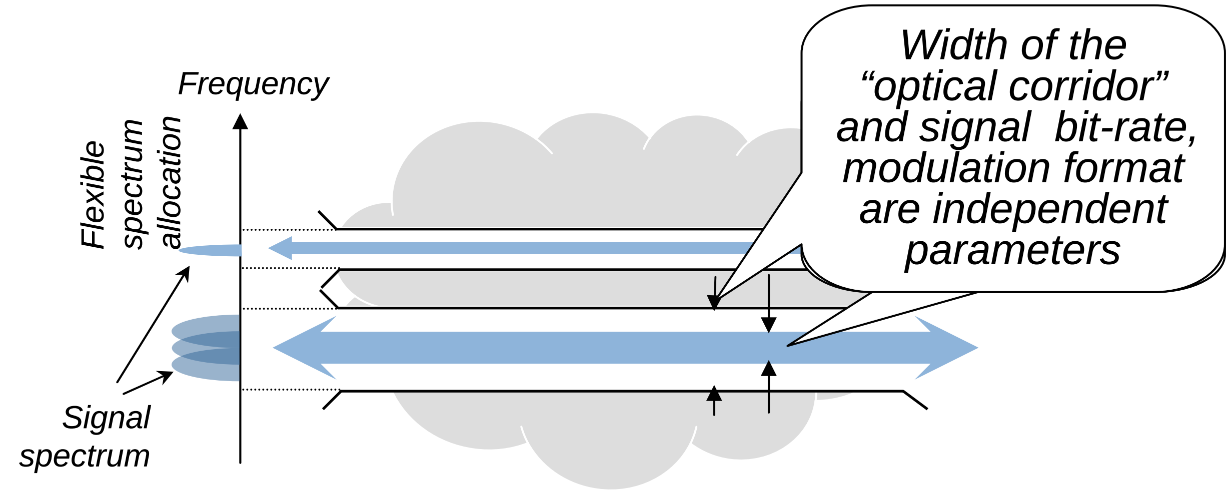


(a) Current wavelength-routed optical network

Resource identifier:

f_{center}

(Wavelength)



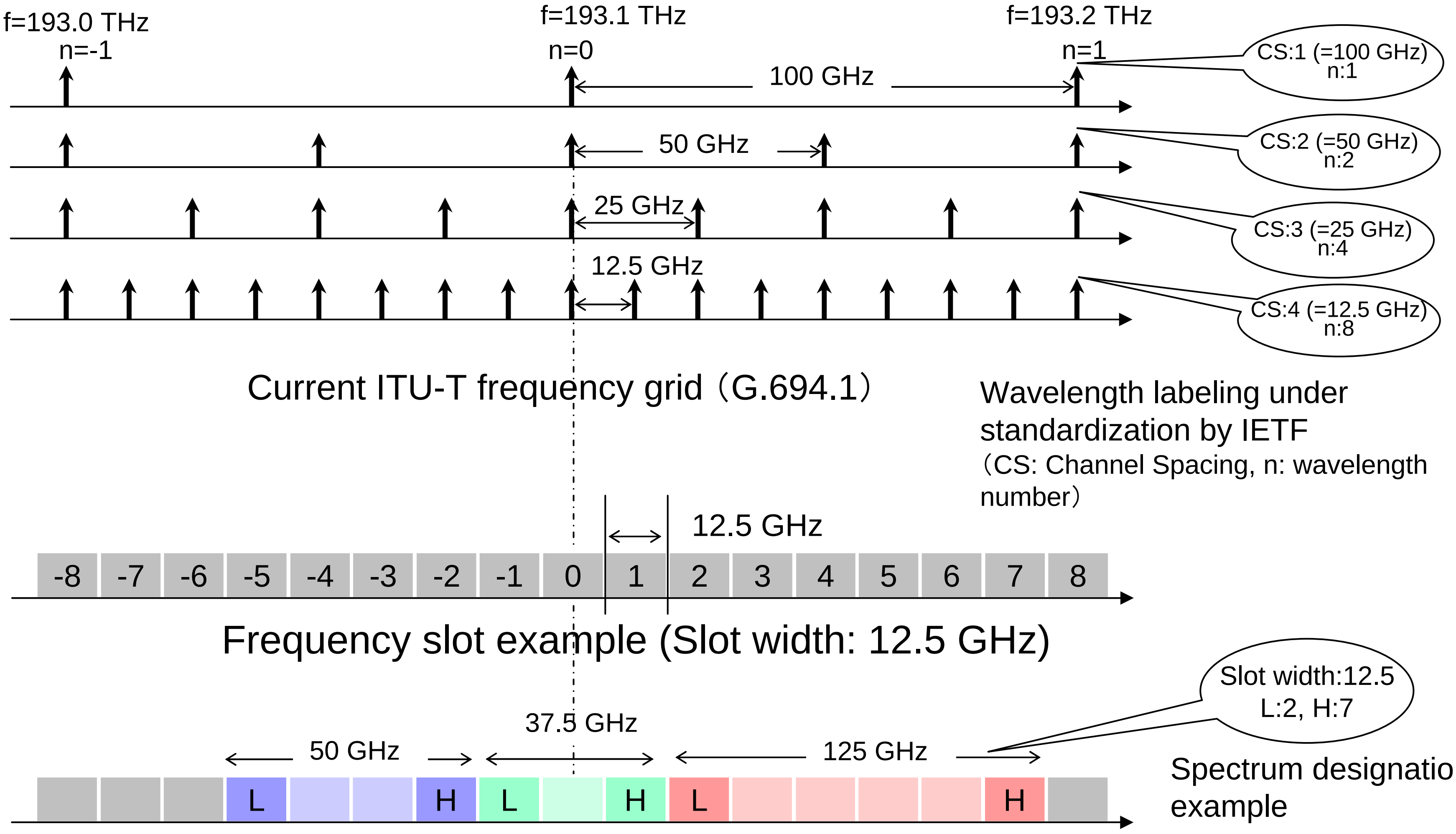
(b) Elastic optical path network

Optical corridor: Spectral window opened at every node along route

Resource identifier:

f_{low} and f_{high}

Optical Frequency Slot



f=193.0 THz
n=-1

f=193.1 THz
n=0

f=193.2 THz
n=1

100 GHz

50 GHz

25 GHz

12.5 GHz

CS:1 (=100 GHz)
n:1

CS:2 (=50 GHz)
n:2

CS:3 (=25 GHz)
n:4

CS:4 (=12.5 GHz)
n:8

Current ITU-T frequency grid（G.694.1）

Wavelength labeling under standardization by IETF
（CS: Channel Spacing, n: wavelength number）

12.5 GHz

-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8

Frequency slot example (Slot width: 12.5 GHz)

Slot width:12.5
L:2, H:7

50 GHz

37.5 GHz

125 GHz

			L			H	L		H	L					H	

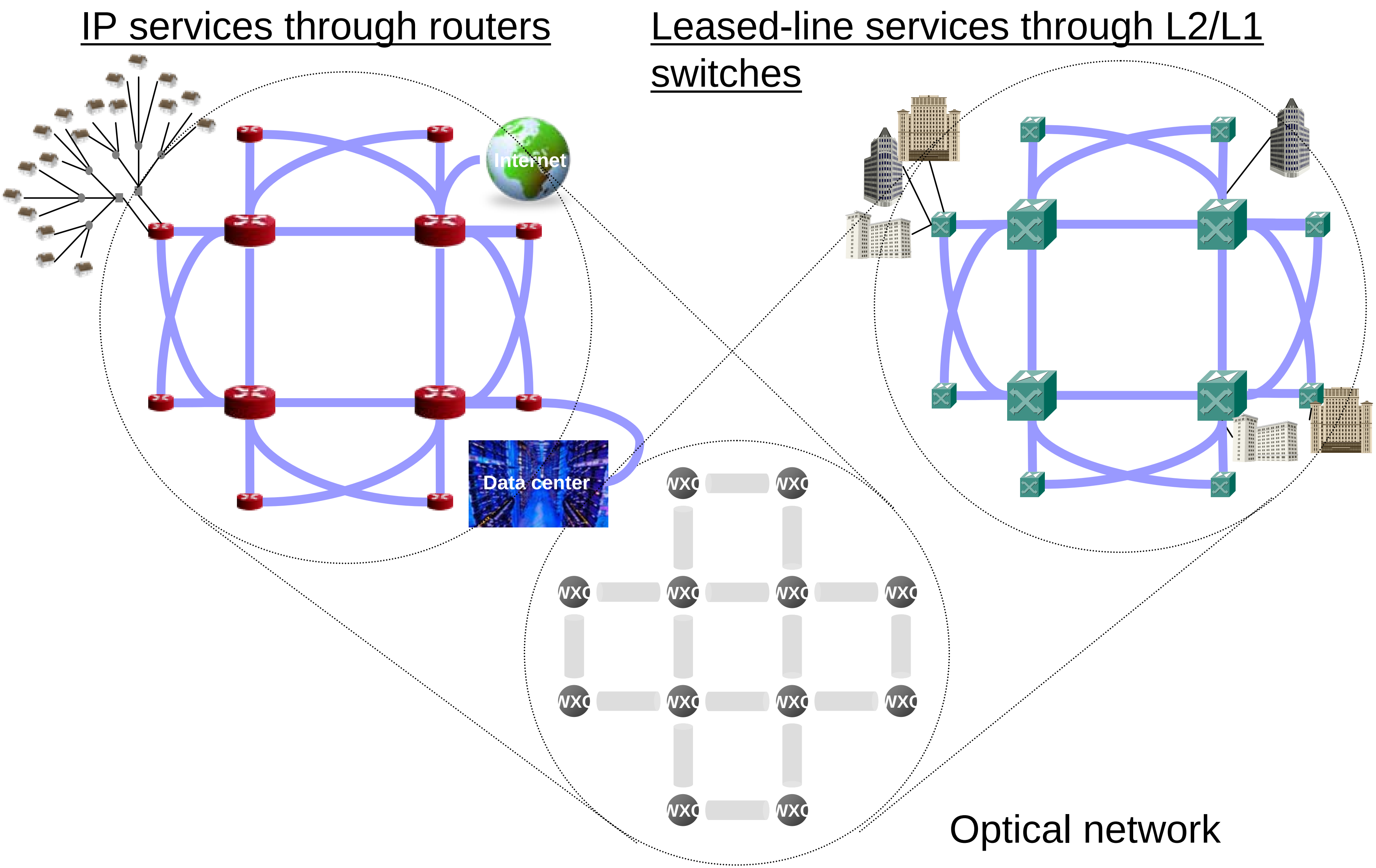
Spectrum designation example

(L/H: lowest/Highest slot number)

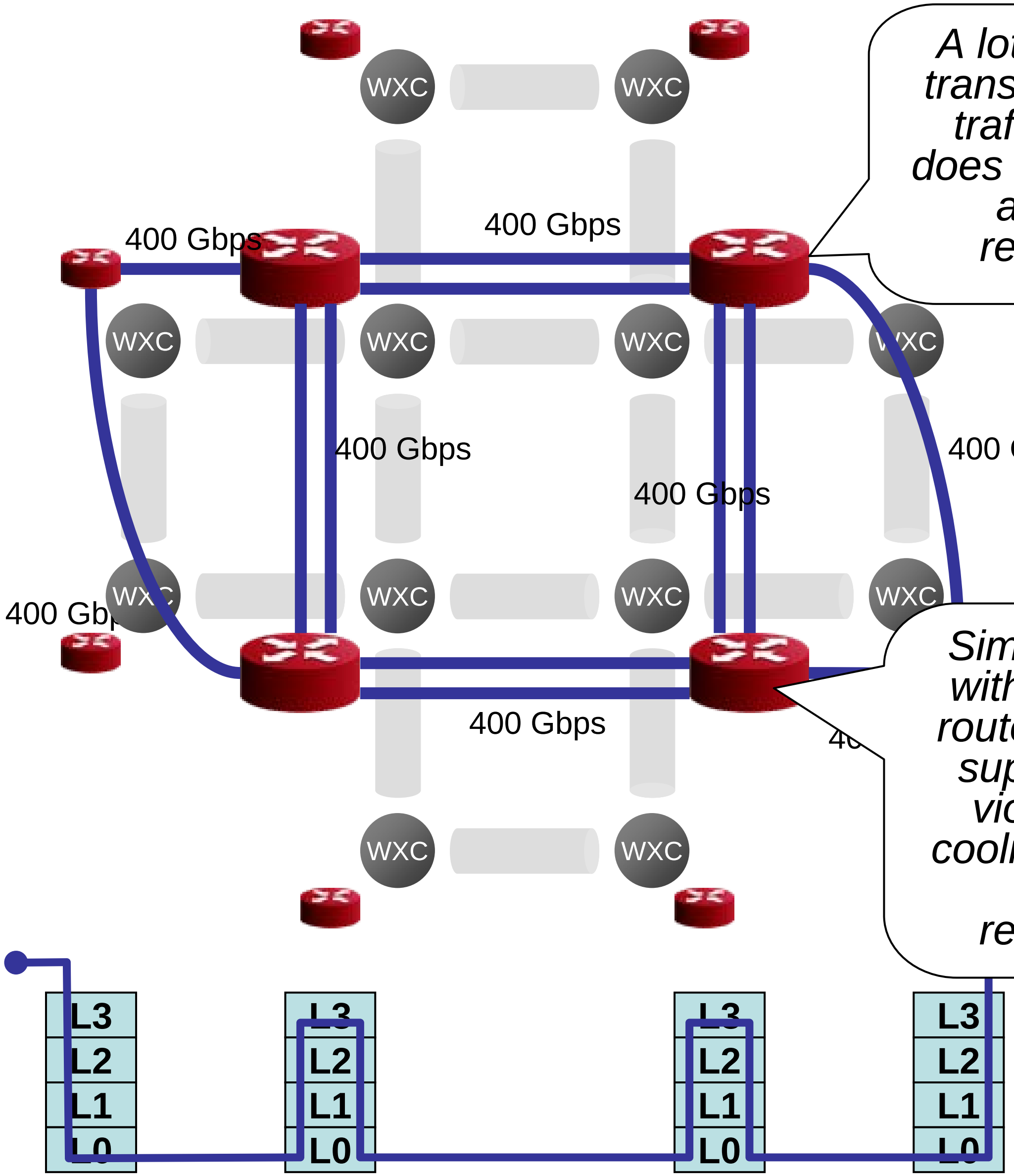
Spectrum resource allocation by assigning required number of contiguous frequency slots

3. Energy and Spectrally-Efficient Networking in SLICE

Two Major Services Over Optical Networks



IP Over Optical Network

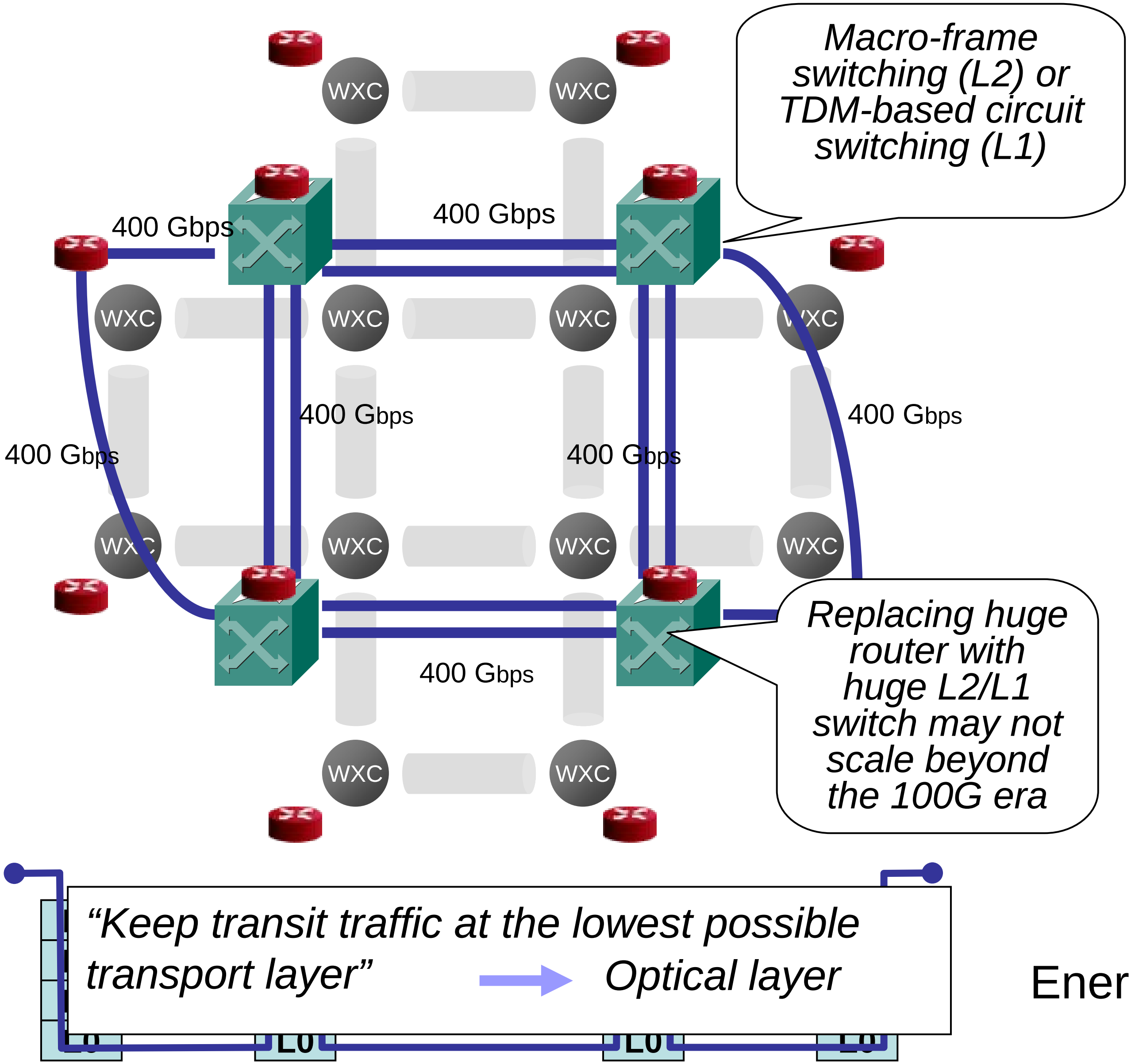


A lot of cost to transport transit traffic, which does not need IP address resolution

Simply replacing with larger sized routers will not be supportable, as violate power, cooling and office-layout requirements

Energy consumption, CAPEX

L2/L1 Bypass Over Optical Network



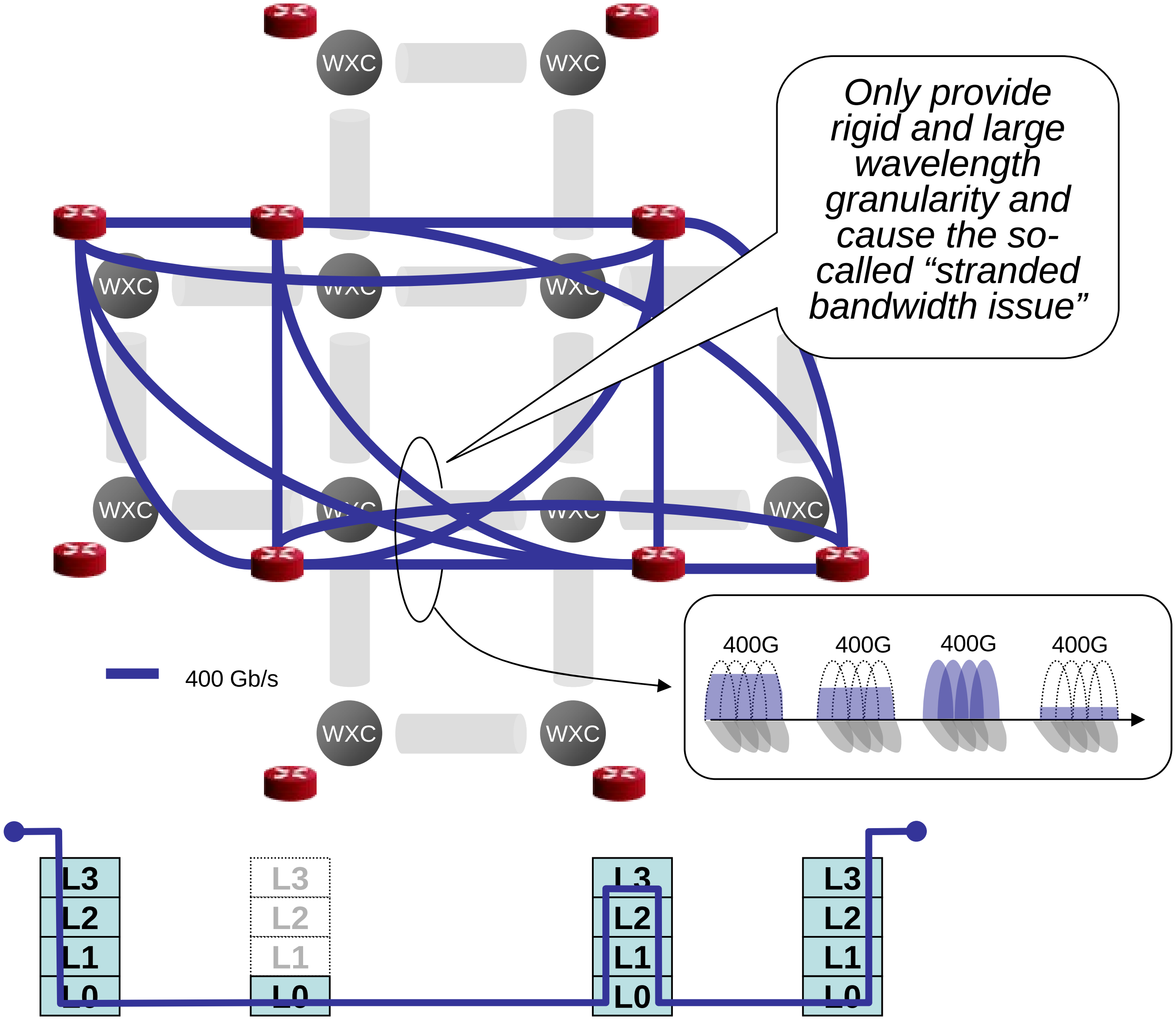
Macro-frame switching (L2) or TDM-based circuit switching (L1)

Replacing huge router with huge L2/L1 switch may not scale beyond the 100G era

“Keep transit traffic at the lowest possible transport layer” → *Optical layer*

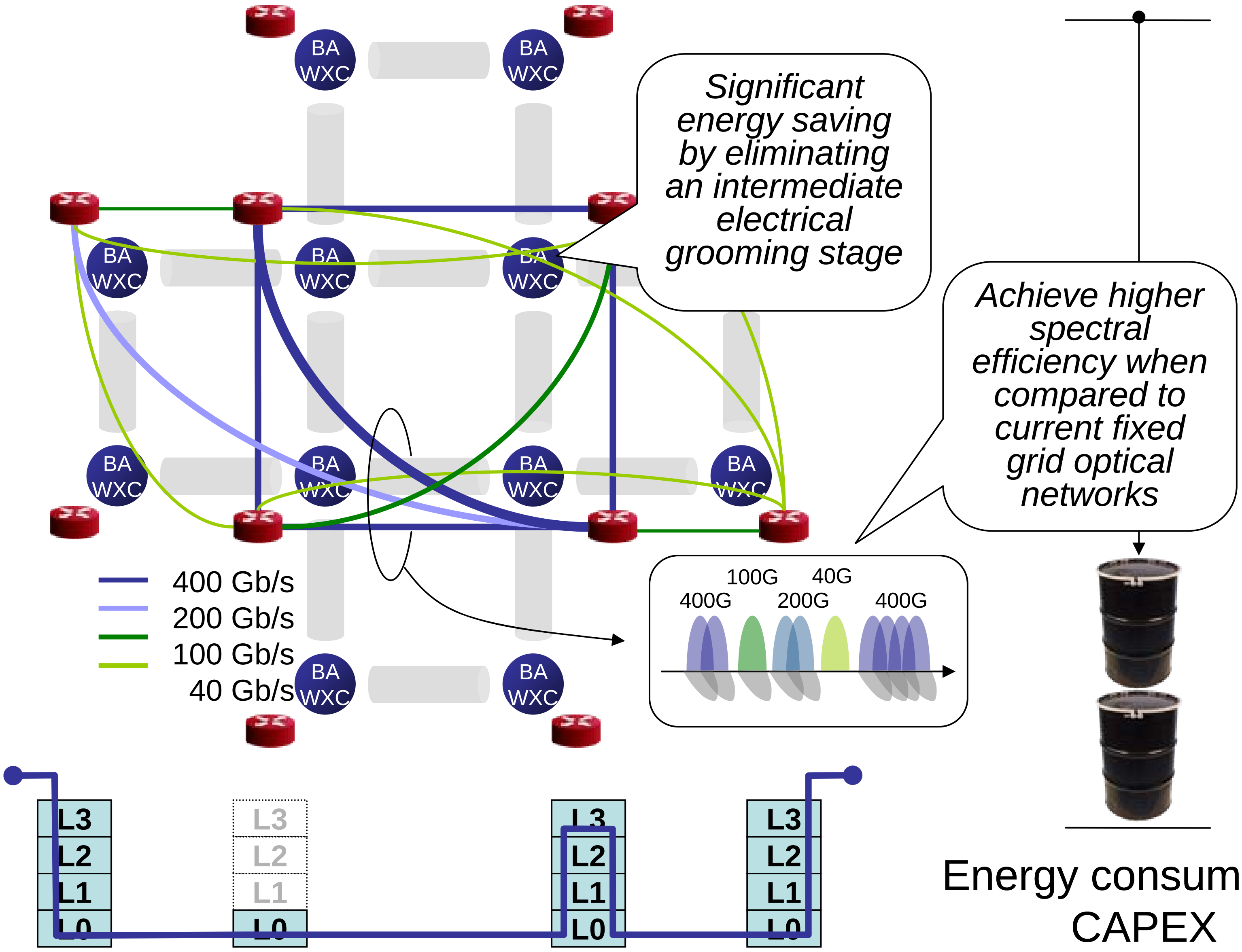
Energy consumption, CAPEX

Optical Bypass in Conventional Optical Network Based on Fixed Grid



Only provide rigid and large wavelength granularity and cause the so-called “stranded bandwidth issue”

SLICE: Optical Bypass with Rate and Distance Adaptive Spectral Allocation

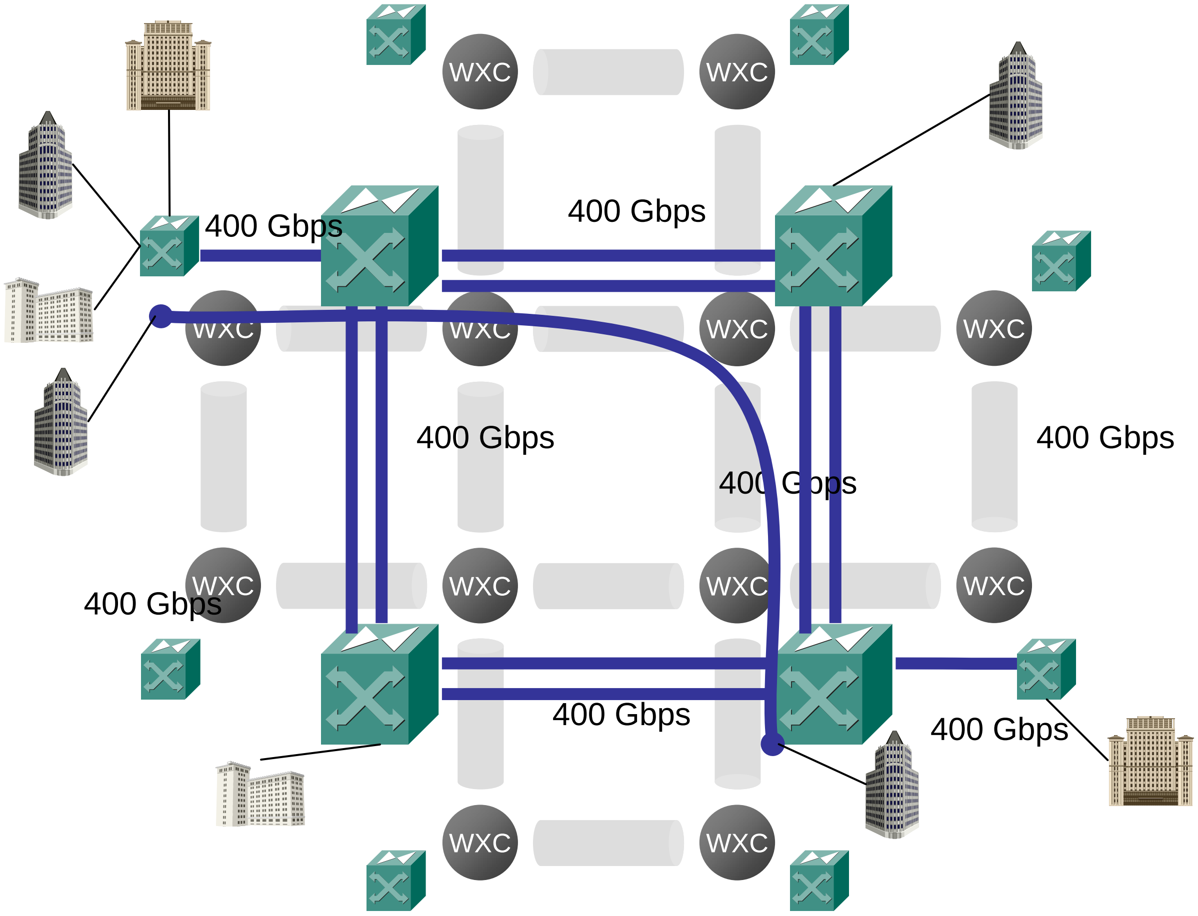


Significant energy saving by eliminating an intermediate electrical grooming stage

Achieve higher spectral efficiency when compared to current fixed grid optical networks

Energy consumption, CAPEX

Leased-Line Service Based on L2/L1 Over Optical Network

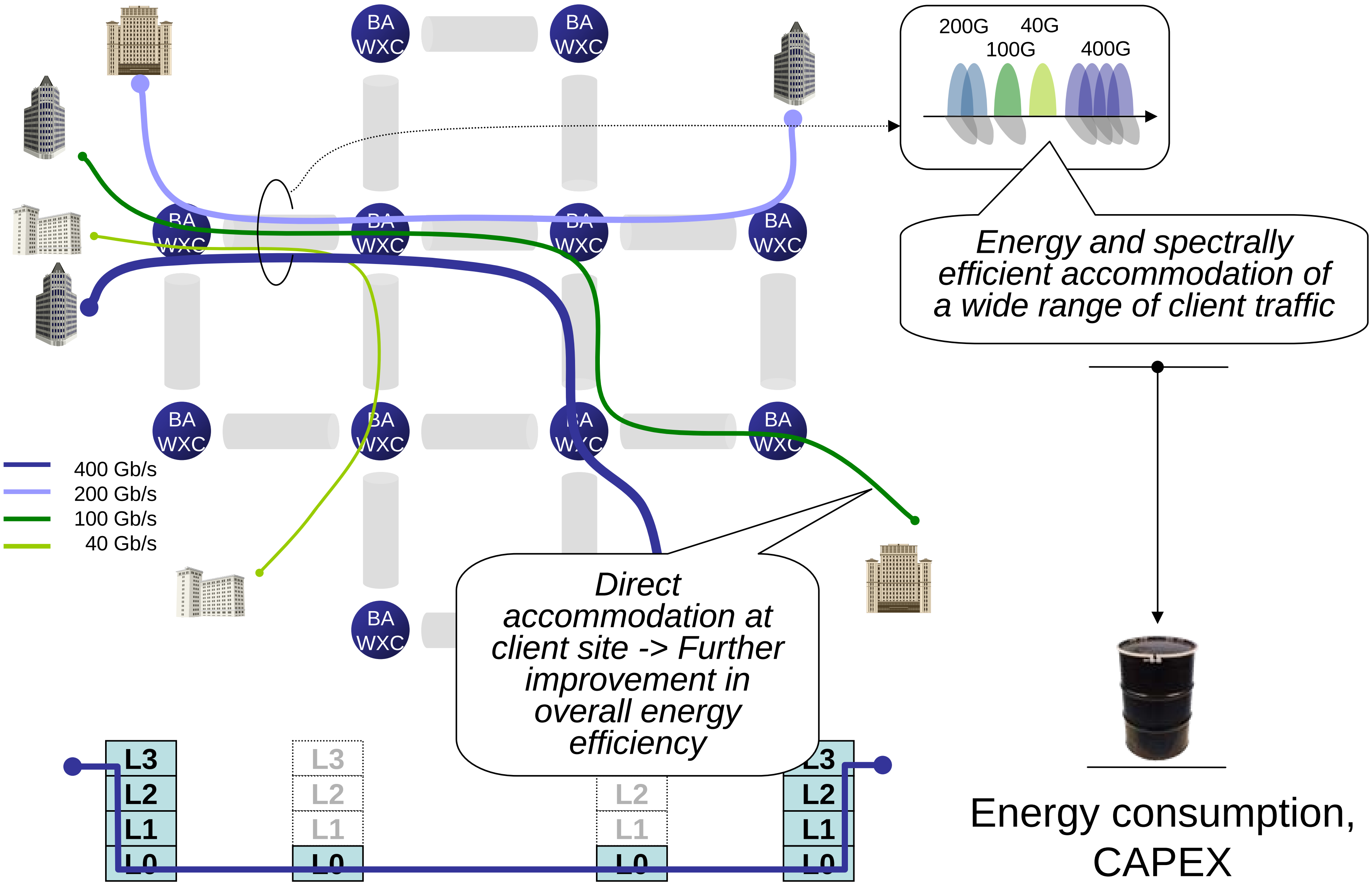


Progress in SE improvement will most likely slow

Provide wideband leased line service in fully optical domain

Energy consumption, CAPEX

Leased-Line Over SLICE w/ Direct Accommodation and Distance-Adaptive Resource Allocation



Energy and spectrally efficient accommodation of a wide range of client traffic

Direct accommodation at client site -> Further improvement in overall energy efficiency

Energy consumption, CAPEX

Summary

- For 400G/1T, rate- and distance-adaptive spectrum allocation is inevitable to achieve overall high SE
- Optical bypass with spectrally-efficient transport of transit traffic will become key to achieve energy-efficient IP optical networks.
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  - ✓ Introducing elasticity and adaptation into the optical domain.

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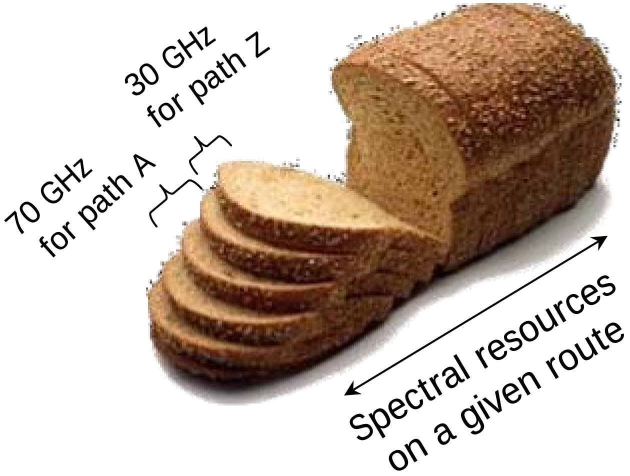

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Workshop on Energy Efficient Networking and Systems
in Photonics in Switching 2010

Optical Packet and Circuit Integrated Network for New Generation Energy Efficient ICT

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Web: http://nag.nict.go.jp

National Institute of Information and
Communications Technology (NICT), Japan

25 July 2010

Outline

1. Introduction
   - AKARI project
   - Issues for new generation optical networks
   - Motivation of the R&D

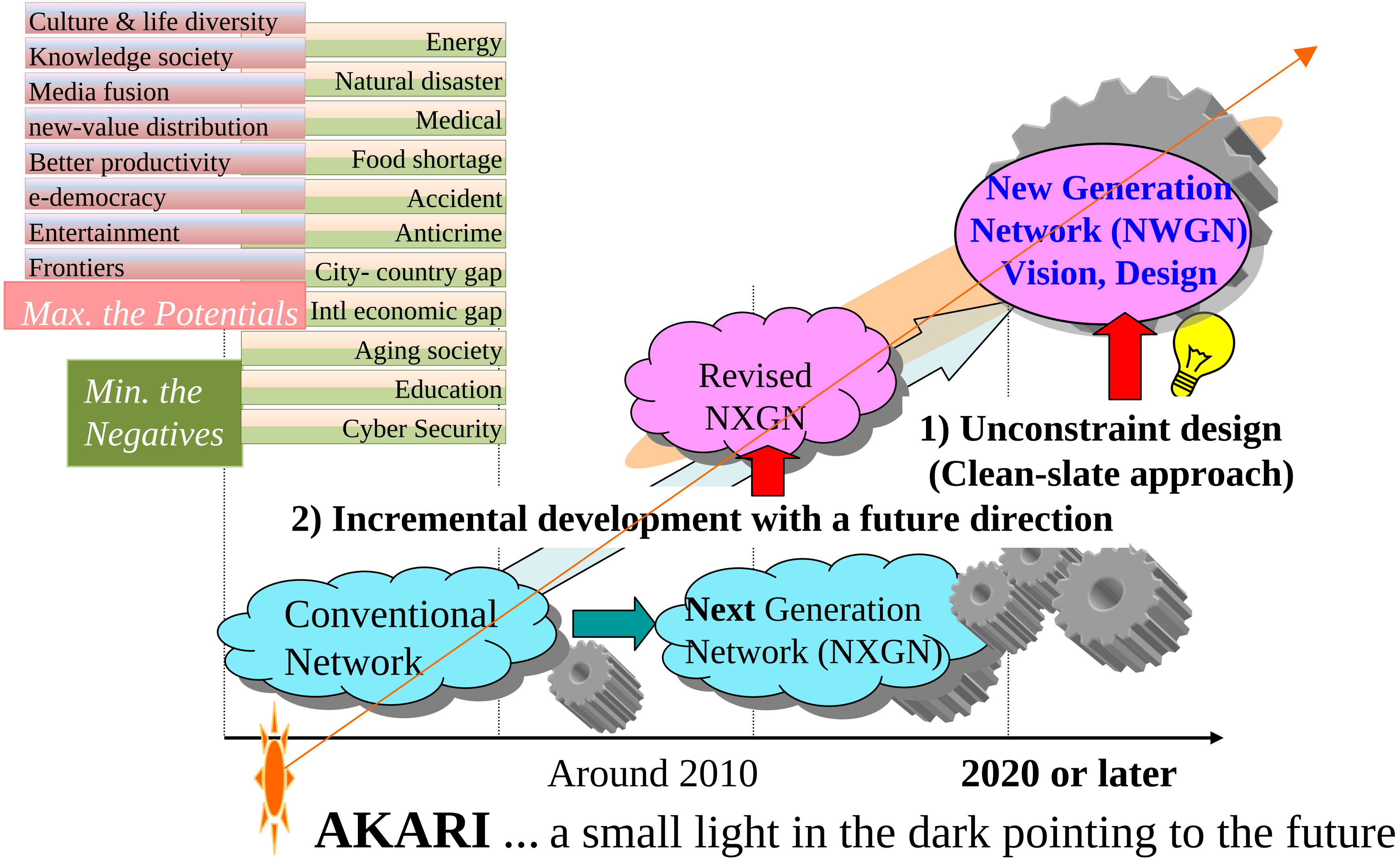
2. Optical Packet & Circuit Integrated Networks
   - Concept
   - Characteristics
   - Node architecture which we have been developing
   - Our current experimental network

3. Potential for reduction of power consumption

4. Remarks

Co-Researchers:
Hideaki Furukawa,
Kenji Fujikawa,
Naoya Wada,
Hiroaki Harai

1.1 *AKARI architecture design project* for NeW-Generation Network (NWGN)



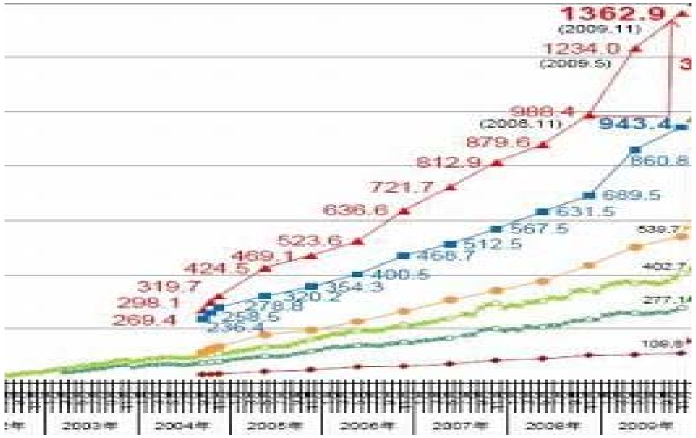
AKARI … a small light in the dark pointing to the future

*Web Page → http://akari-project.nict.go.jp/eng/index2.htm

1. Introduction - Issues for new generation opt. networks -

Increase of amount of network traffic and power consumption

1.36Tbps in download traffic and 943Gbps in upload traffic (Japan, Nov. 2009)



- 1.4 time/year →Download: 40Tbps in 2020
→ 1Pbps in 2030

- Drastic Increase of Power consumption.

→ Necessity for Optical switching

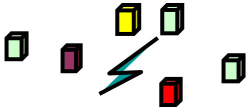
* Surveys by MIC, Japan
http://www.soumu.go.jp/

Diversification of Applications / End-Users' demands

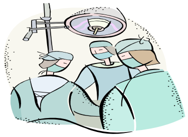
Web access,
File transfer

Mobile

Sensors, tags



High-quality
Video transfer



Remote
surgery

Online game

E-science

…

etc

Complexity in network control & management

e.g. Internet, NGN, VPN, (G)MPLS, …

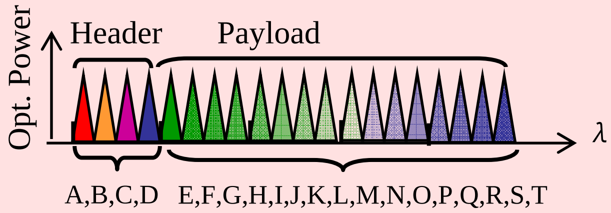
Necessity for efficient network management and simplification of equipments

1. Introduction - Motivation of the R&D -

Objective: Satisfy diversified users' needs with large capacity, low power consumption and simple control mechanism.

Opt. Packet Networks

Packet-by-packet(PBP) processing, Bandwidth-shared
→ *Efficient bandwidth utilization*



- Multi-wavelength optical packet switch with optical buffer (1.28Tbps/port)
S. Shinada et al., ECOC2009.

Control plane
for opt. path network

Opt. Circuit(=Path) Networks

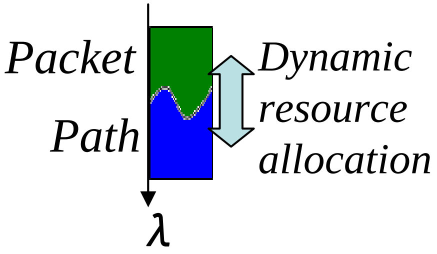
End-to-end occupied bandwidth, transparent data transfer w/o PBP processing → *Guaranteeing high QoS*

- Host-to-Host or Application-to-Application lightpaths
- Reliable global path networking with distributed controls

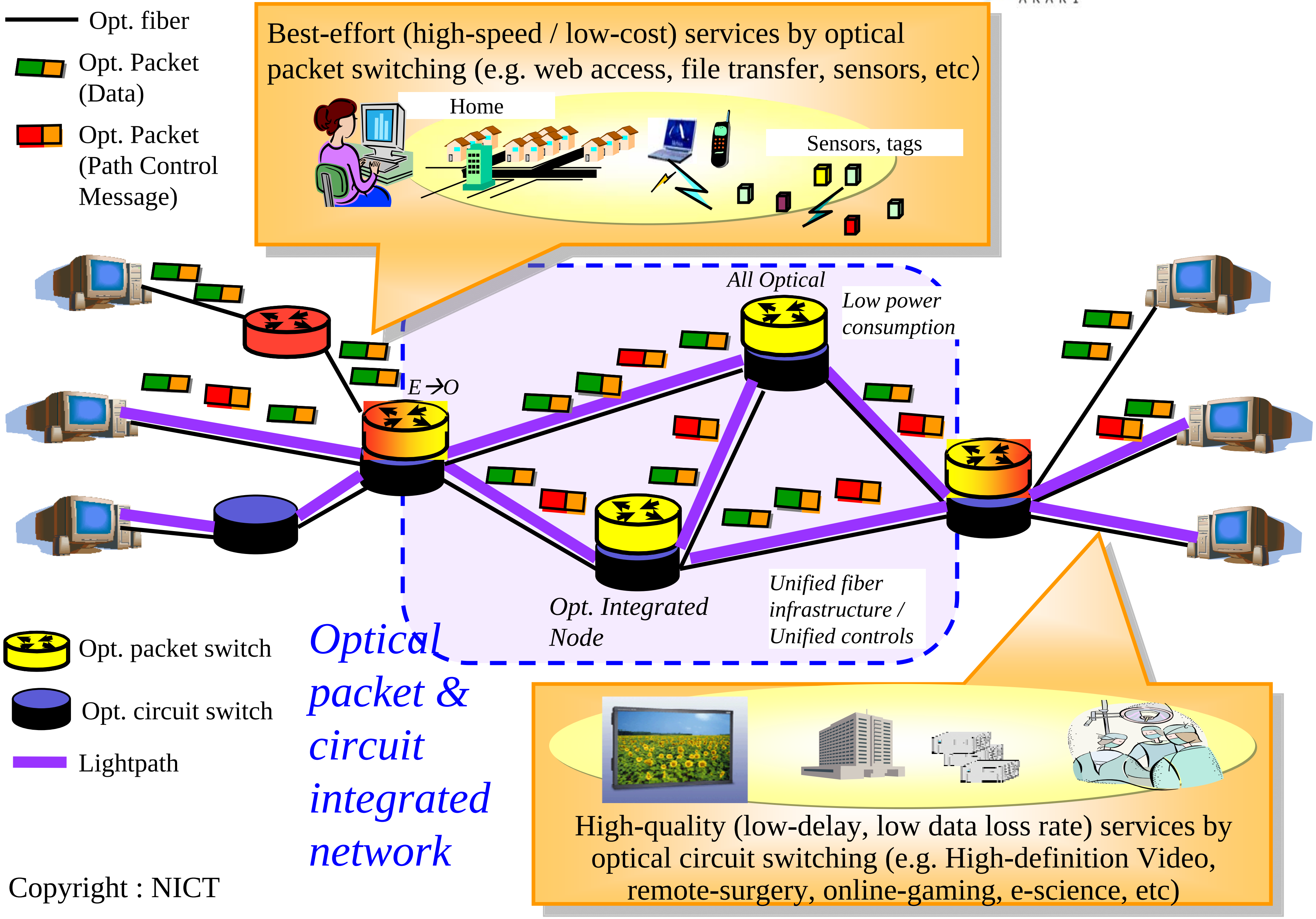
Common fiber infrastructure (WDM-based)

Unified control

Optical Packet and Circuit Integrated Network



2. Optical Integrated Networks - Concept -



— Opt. fiber

🟩🟧 Opt. Packet (Data)

🟥🟧 Opt. Packet (Path Control Message)

Best-effort (high-speed / low-cost) services by optical packet switching (e.g. web access, file transfer, sensors, etc)

Opt. packet switch

Opt. circuit switch

Lightpath

Optical packet & circuit integrated network

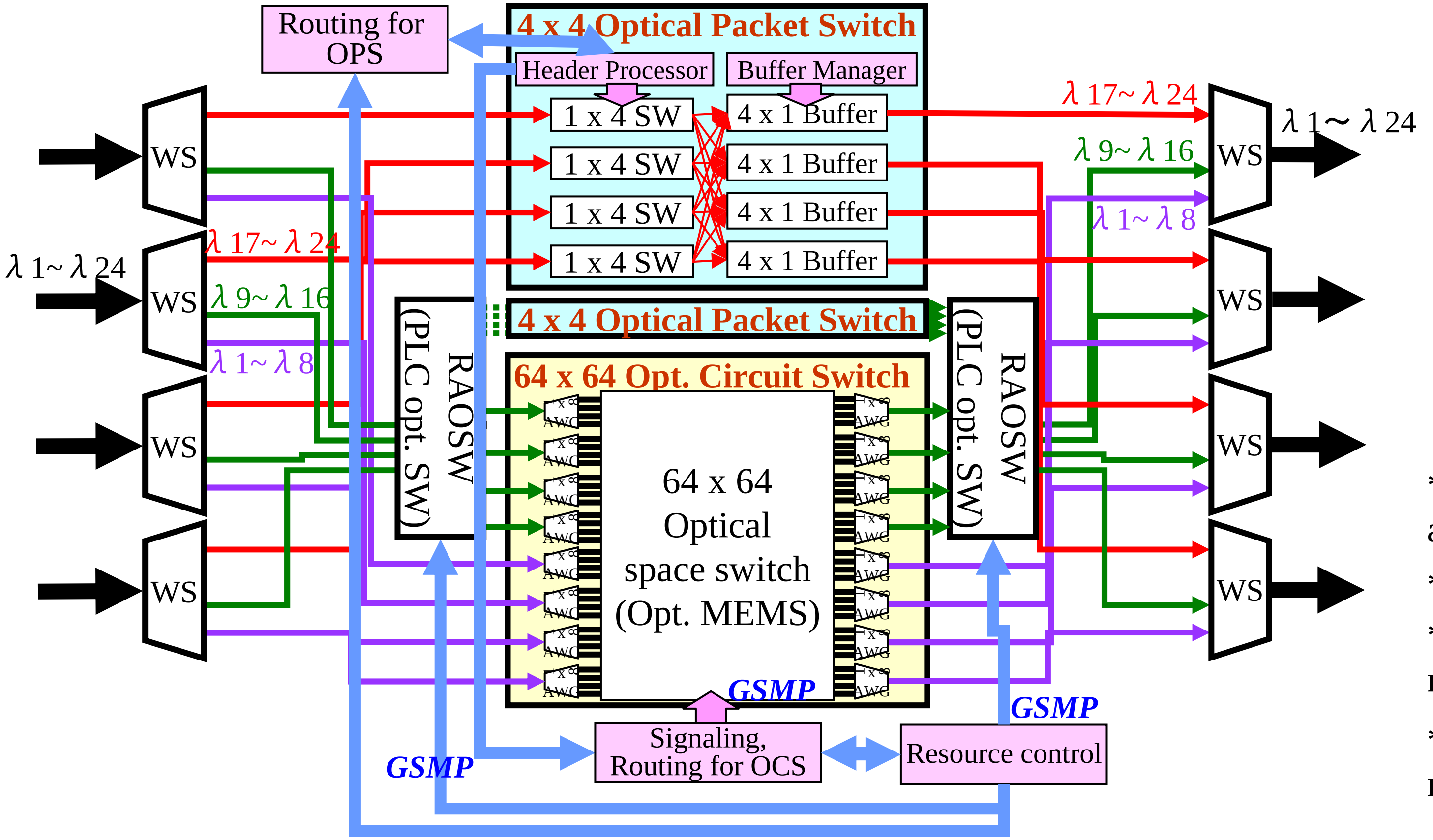
High-quality (low-delay, low data loss rate) services by optical circuit switching (e.g. High-definition Video, remote-surgery, online-gaming, e-science, etc)

2. Optical Integrated Networks - Characteristics -

- *Providing diverse services*
  - best-effort services or QoS guaranteed services by end-to-end lightpath
- *Unified control interface for both packet & path*
  - path control messages are transferred on optical packet switched network
    → Simplification of control/management equipments & Energy efficient
- *Dynamic resources adjustment between packet & path*
  - Flexibly Changing the max. number of lightpaths according to users' demands
- *Potential for supporting new/unpredictable services*
  - Flexible use of both switching schemes by shared fiber infrastructure and dynamic resources allocation → New applications/businesses
- *Potential for Lower power consumption*
  - Optical packet switching reduces O/E/O processing AMAP at each node
  - Optical circuit switching reduces packet-by-packet processing at each node
  - Unified control IF & dynamic resources allocation between packet/path

2. Optical Integrated Networks - Node architecture -

E.g. 80~100Gbps Opt. packet switch , 1~10Gbps/wavelength optical path(=circuit switching)



— Fixed opt. packet waveband

— Shared waveband

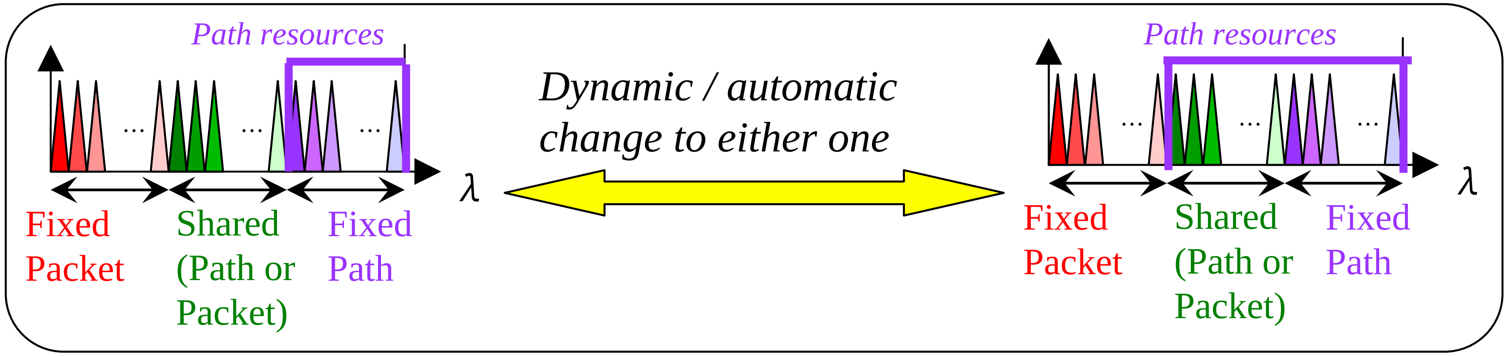
— Fixed opt. path waveband

*RAOSW…Resource adjusting optical switch

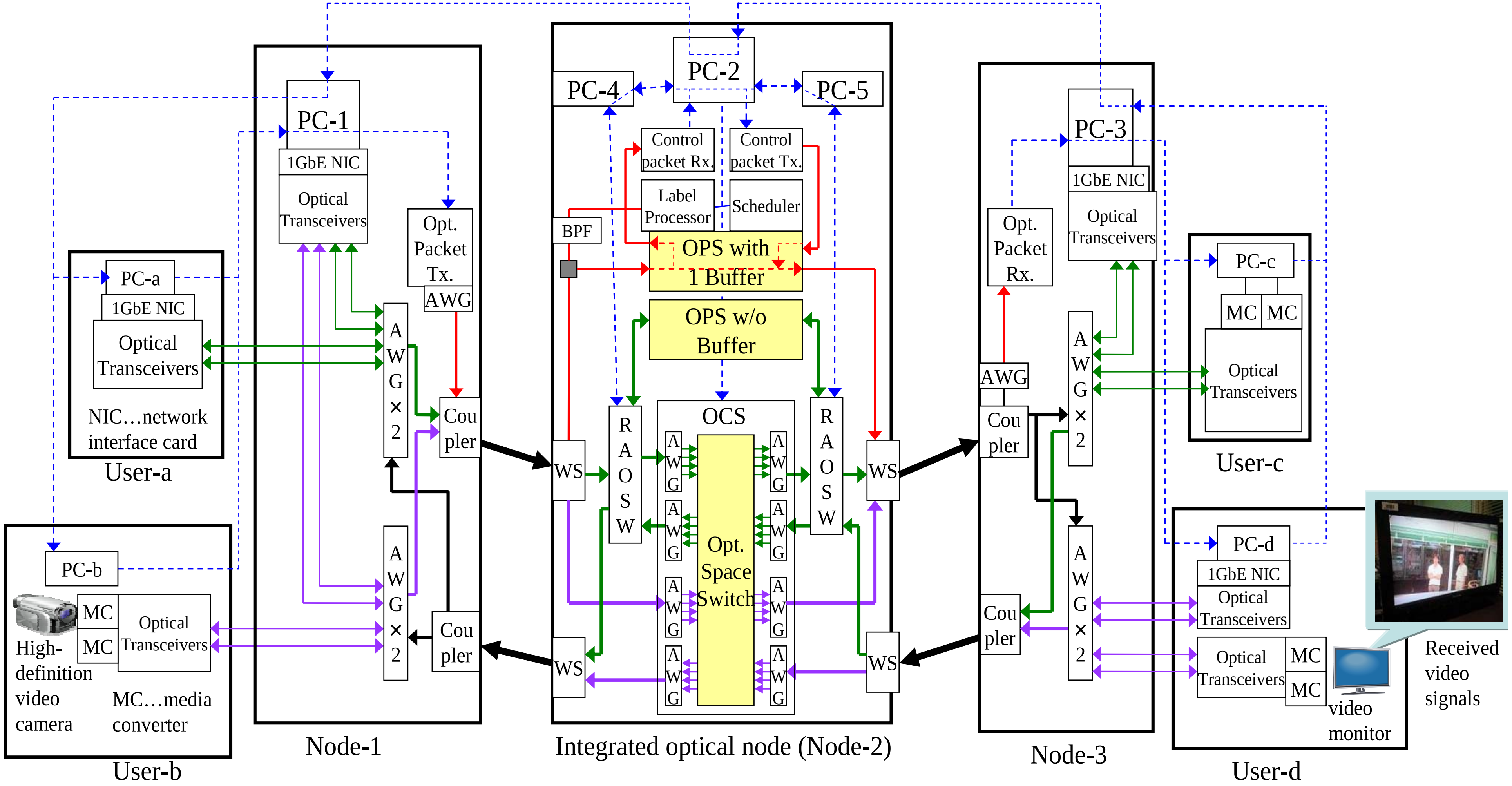
*WS…Waveband selector

*MEMS…Micro electro mechanical systems

*GSMP…General switch management protocol



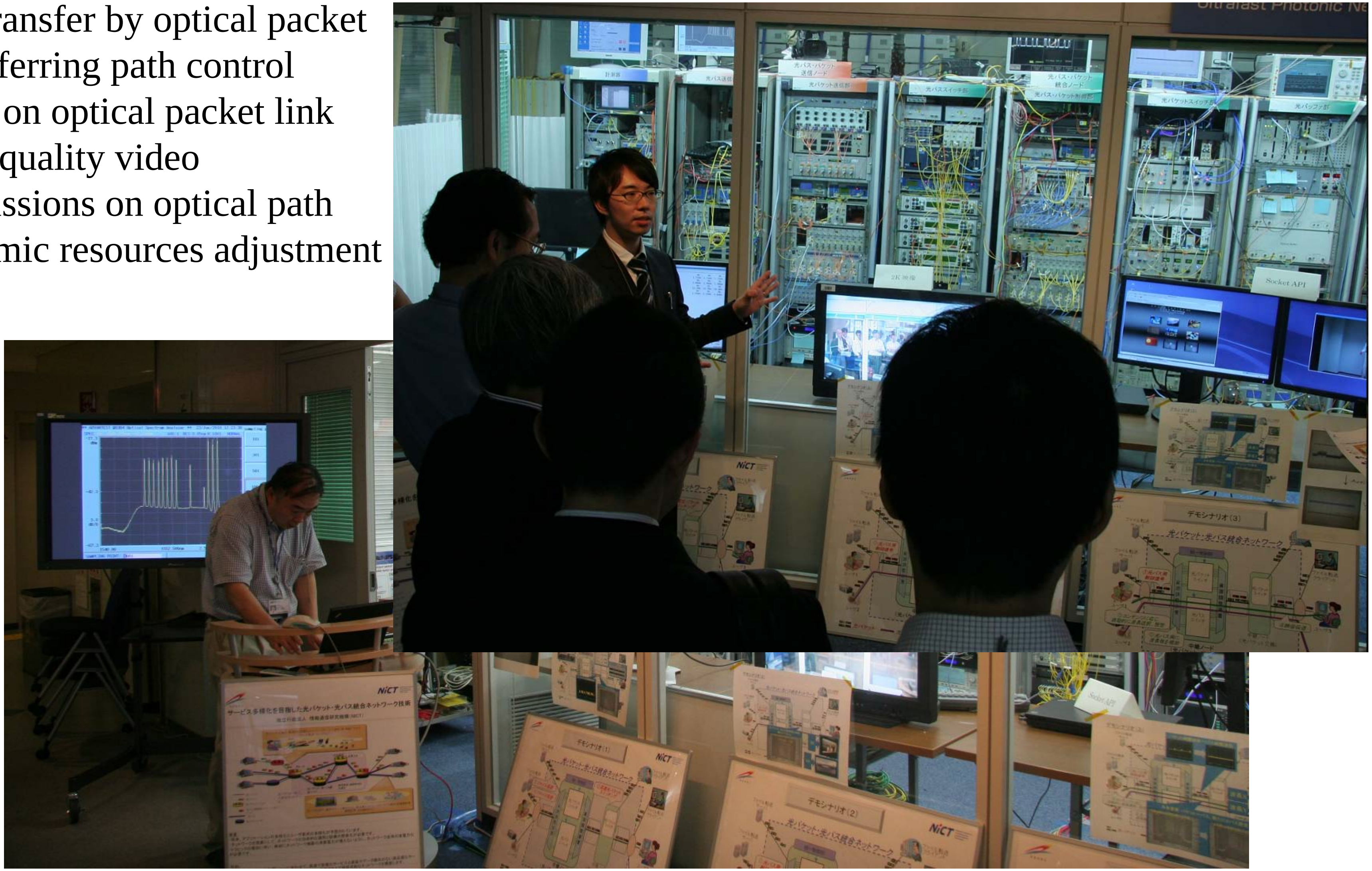
2. Optical Integrated Networks
- Our current experimental network -



Live Demonstration at NICT (June 23, 2010)

4th NWGN Workshop hosted by NICT (http://akari-project.nict.go.jp/ws4/)

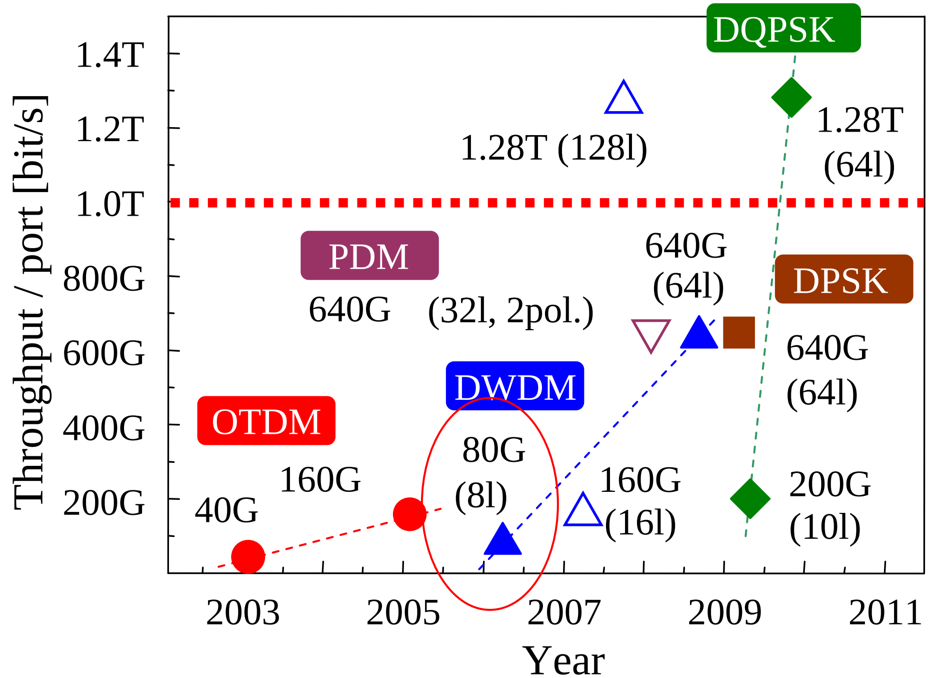
- File transfer by optical packet
- Transferring path control signals on optical packet link
- High-quality video transmissions on optical path
- Dynamic resources adjustment



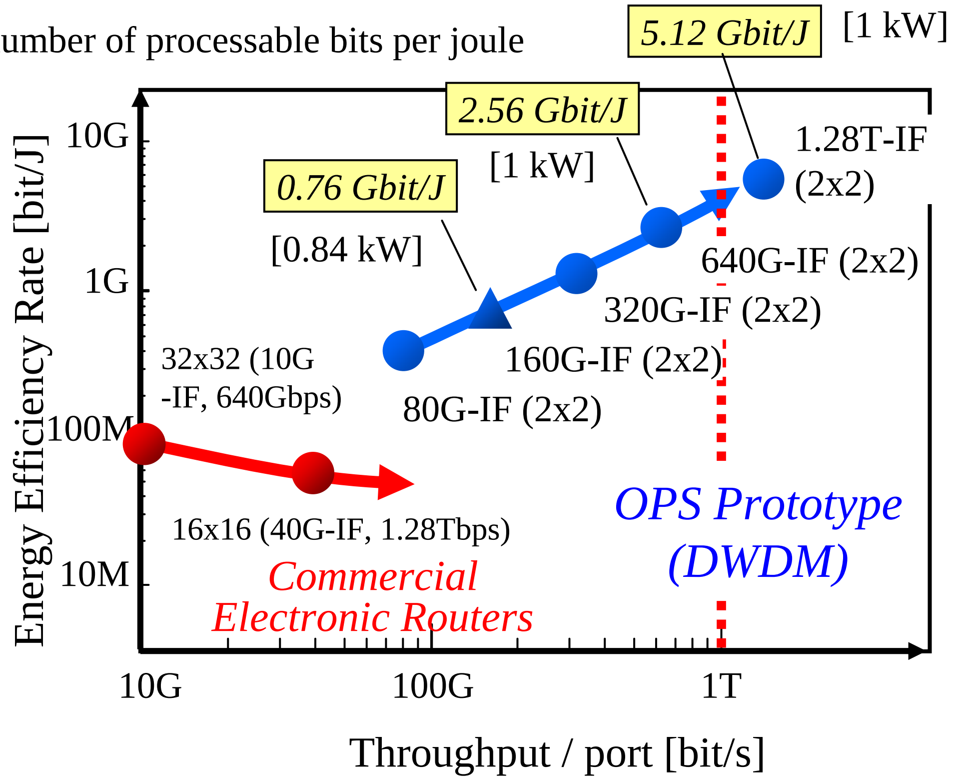
3. Potential for power saving

- Throughput and energy-efficiency in our optical packet switching -

*Energy-Efficiency-Rate (EER) = Total number of processable bits per joule



△ ▽ = only switching (w/o buffering)



cf) H. Furukawa et al., IEEE JOCN, Aug 2009.

- Our optical packet switch: Energy-Efficiency-Rate was improved (x2) without increase in power consumption (kept <1 kW)

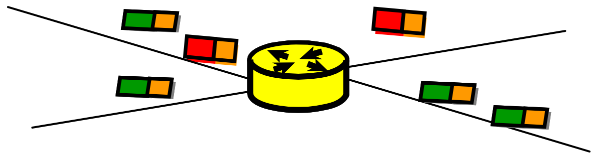
Original source: N. Wada

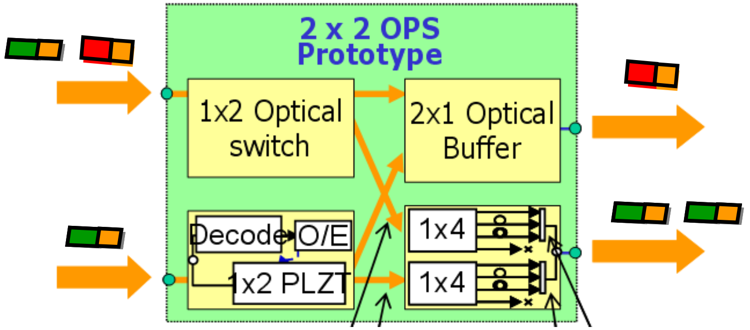
*640Gbps commercial electronic core router: approx. 4.5kW

→ 46Tbps : >300kW (estimate) → 1Pbps: >7000kW (estimate)

3. Potential for power saving - Optical circuit switching -

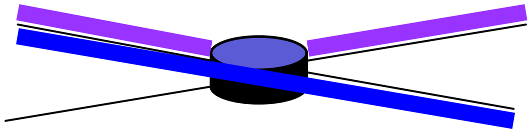
Optical packet switching

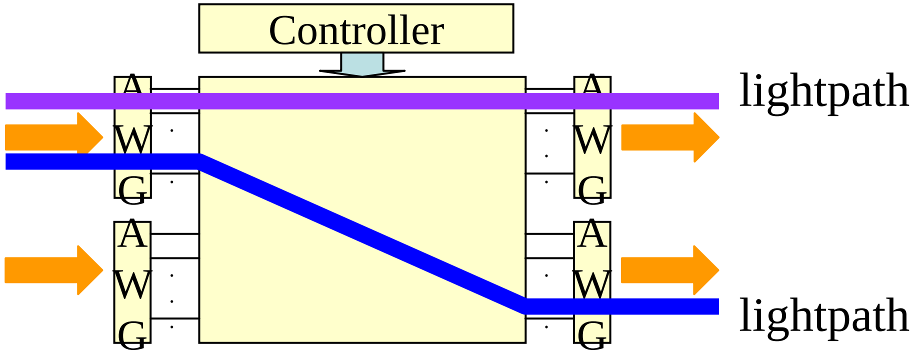




→ *Packet-by-packet processing*

Optical circuit switching





Optical circuit switch (e.g. Opt. MEMS)

→ *Transparent data transmission w/o packet-by-packet processing*

→ Potential for further higher energy efficiency at each node by partly installing optical circuit switching into the network

Optical packet & circuit integrated network is effective at both energy efficiency and bandwidth utilization efficiency

4. Remarks

Towards New-Generation Networks (around 2020~)

- *Optical Packet & Circuit Integrated Networks*
  - High switching capacity (optics in switching)
  - Potential for energy savings
    (reduce O/E/O, partly install optical path, unified control IF, DBA)
  - Using common WDM infrastructure (moving boundary)
  - Simple/Unified control plane (in-band control message transfer)
- Experiment, Demonstration and Field Trial Success
- Next Steps
  - Experimental evaluation of power consumption
    (→ Total power consumption of whole integrated networks)
  - More energy-efficient networking protocols & applications including cross-layer optimization approach
  - More stability in Optics (Gain, Power, Polarization Controls)
  - Developing a common hardware providing both optical packet switching and optical path switching functions

Appendix: Recent Main Related Achievements

T. Miyazawa, H. Furukawa, K. Fujikawa, N. Wada and H. Harai, “Partial Implementation and Experimental Demonstration of an Integrated Optical Path and Packet Node for New-Generation Networks ,” The OFC/NFOEC2010, OThP4, San Diego, CA, USA, March 2010.

K. Fujikawa, H. Ohtsuki, “Design and Implementation of Socket API Assigning Optical Paths to L4 Connections ,” The iPOP2010, Tokyo, Japan, June 2010.

H. Harai, “Optical Network Technologies Beyond the Next,” Workshop1 in OECC2010, Sapporo, Japan, July 5th 2010.

T. Miyazawa, H. Furukawa and H. Harai, **“**Implementation of Automatic Resources Adjustment for Optical Integrated Path and Packet Networks**,”** The Photonics in Switching (PS) 2010, PTuD1, Monterey, CA, USA, July 2010.

H. Furukawa, T. Miyazawa, K. Fujikawa, N. Wada and H. Harai, “Control-message exchange of lightpath setup over colored optical packet switching in an optical packet and circuit integrated network,” IEICE Electronics Express (ELEX), vol.7, no.14, pp.1079-1085, July 25th, 2010.

etc

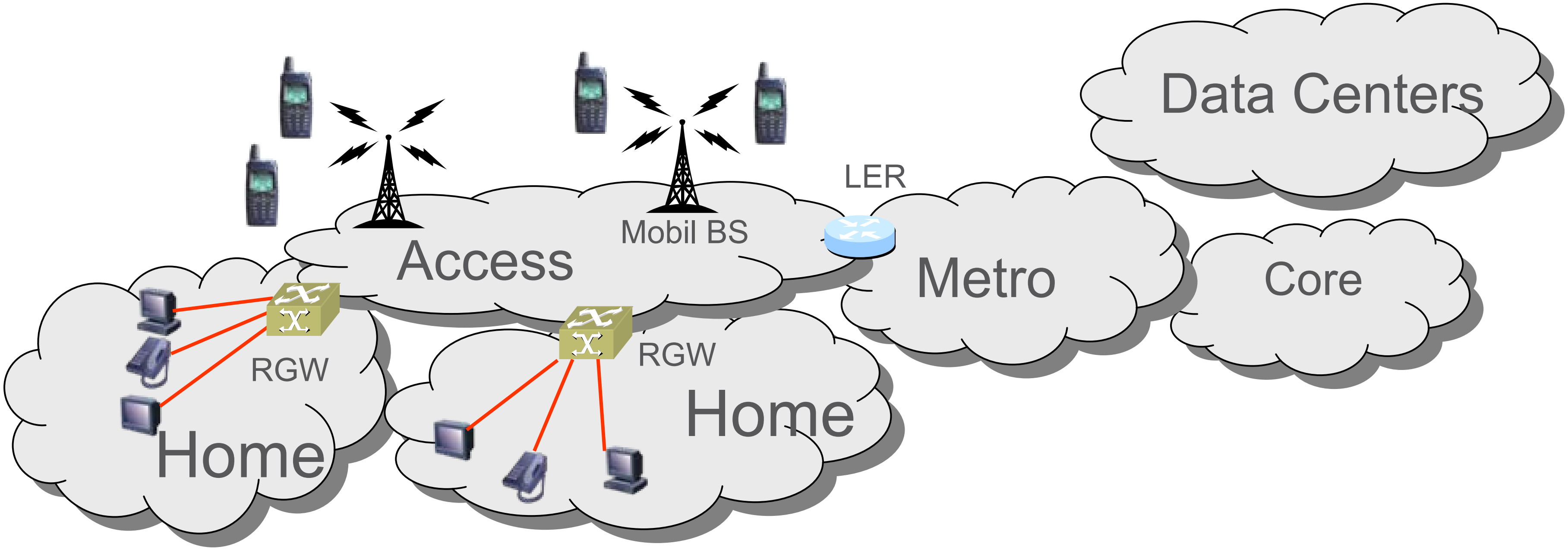
ENERGY EFFICIENCY OF ACCESS NETWORKS IN A LIFE CYCLE PERSPECTIVE

PS, MONTEREY, JULY 25TH

STEFAN DAHLFORT, PHD
BROADBAND TECHNOLOGIES
ERICSSON RESEARCH USA

OUTLINE

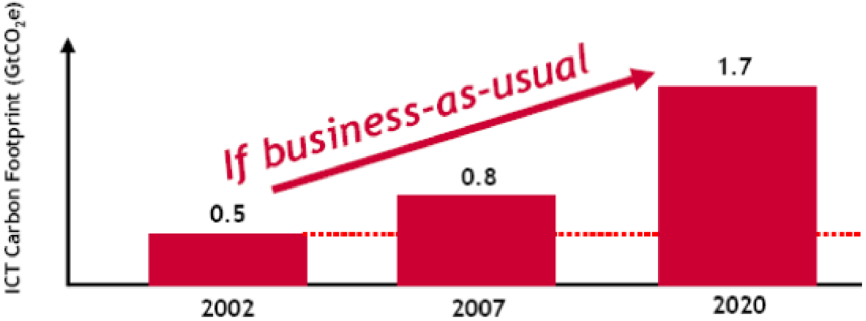
- Information and communication technologies (ICT) and energy efficiency (EE)
- Life cycle assessment of Mobile and Fixed broadband
- Model and analysis of EE of Fixed broadband access
- Access network evolution and impact on EE



GROWING ENERGY CONSUMPTION

- More connections - “50 Billion Devices by 2020” *
- Increased video-rich applications
- Increased storage
- More frequent and longer periods of connectivity

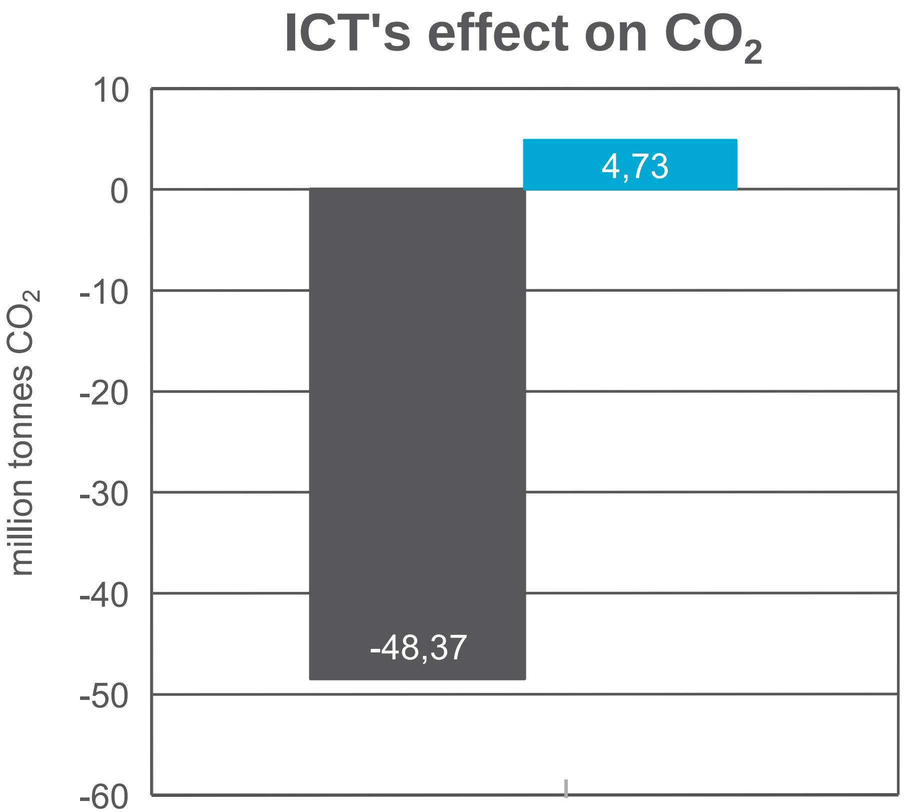
Growing energy consumption



Source: McKinsey analysis 2008

* “Ericsson predicts 50B connected devices by 2020”
Press release MWC, Barcelona Jan 15, 2010

TELECOM’S SUSTAINABILITY LEVERAGE



ICT services and applications:

- Teleworking or Flexi-working
- Virtual presence or Telepresence
- m/e-commerce or ”Internet shopping”
- From products to services dematerialization
- Forerunners: ”Internet”-banking, booking m/e-health, -governance, -learning etc.
- Smart manufacturing and transport systems
- Smart buildings – Connected home
- The future smart electric grid - Metering
- ”Information, monitoring and control”

■ Indirect impact
■ Direct impact

10 times leverage on Telecom CO_2

Source: World Wide Fund for Nature and European Telecommunications Network Operators' Association

LIFE CYCLE ASSESSMENT (LCA)

Complete environmental impact

- Direct power consumption
- Manufacturing
- Deployment
- Operation
- (End-of-life)

} Life-cycle assessment (LCA)

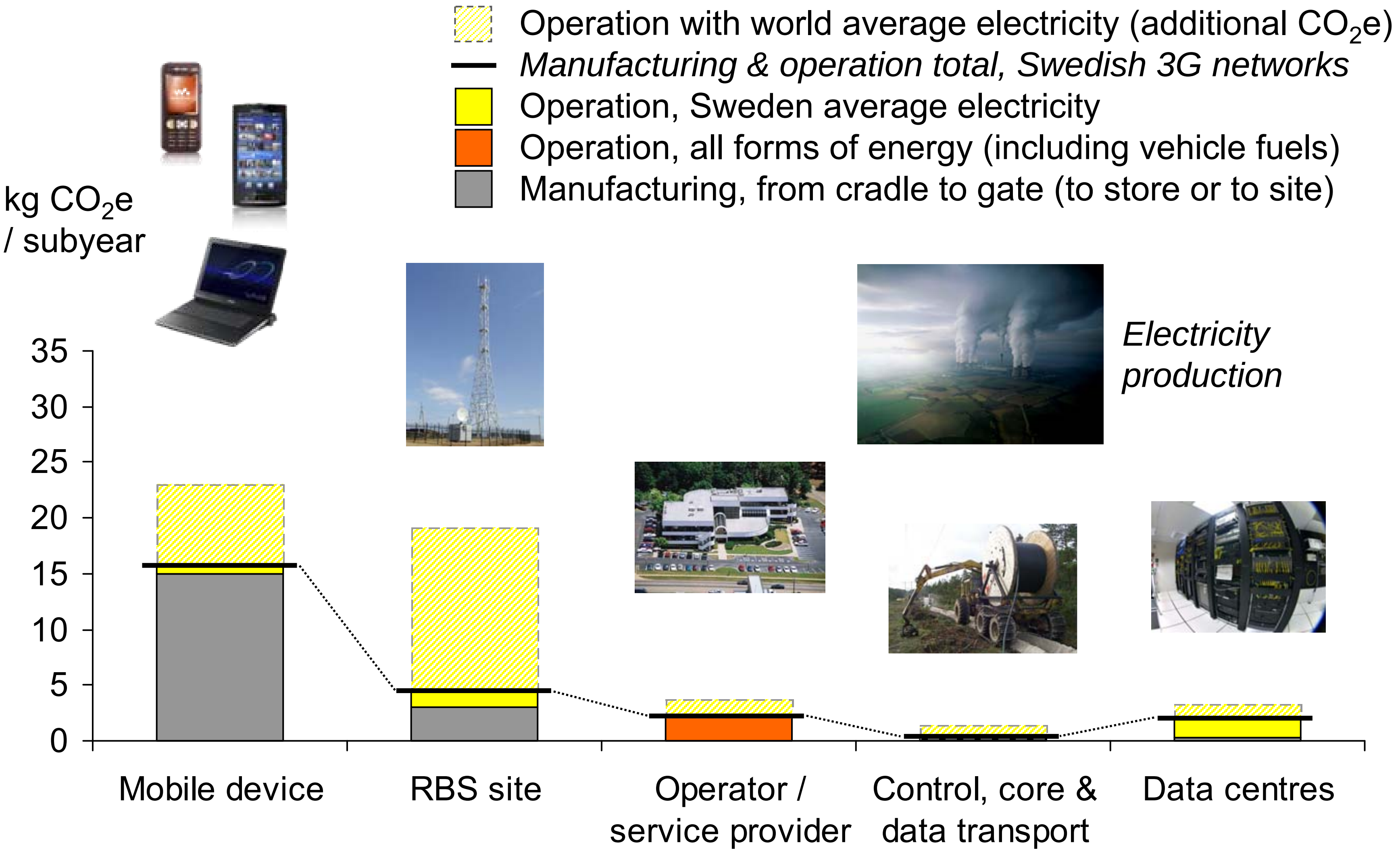
Scope: our products/services life cycle

Supply chain
Manufacturing & office sites
Transports
Raw materials & chemicals

Ericsson
Transports
Office & manufacturing sites
Business travel

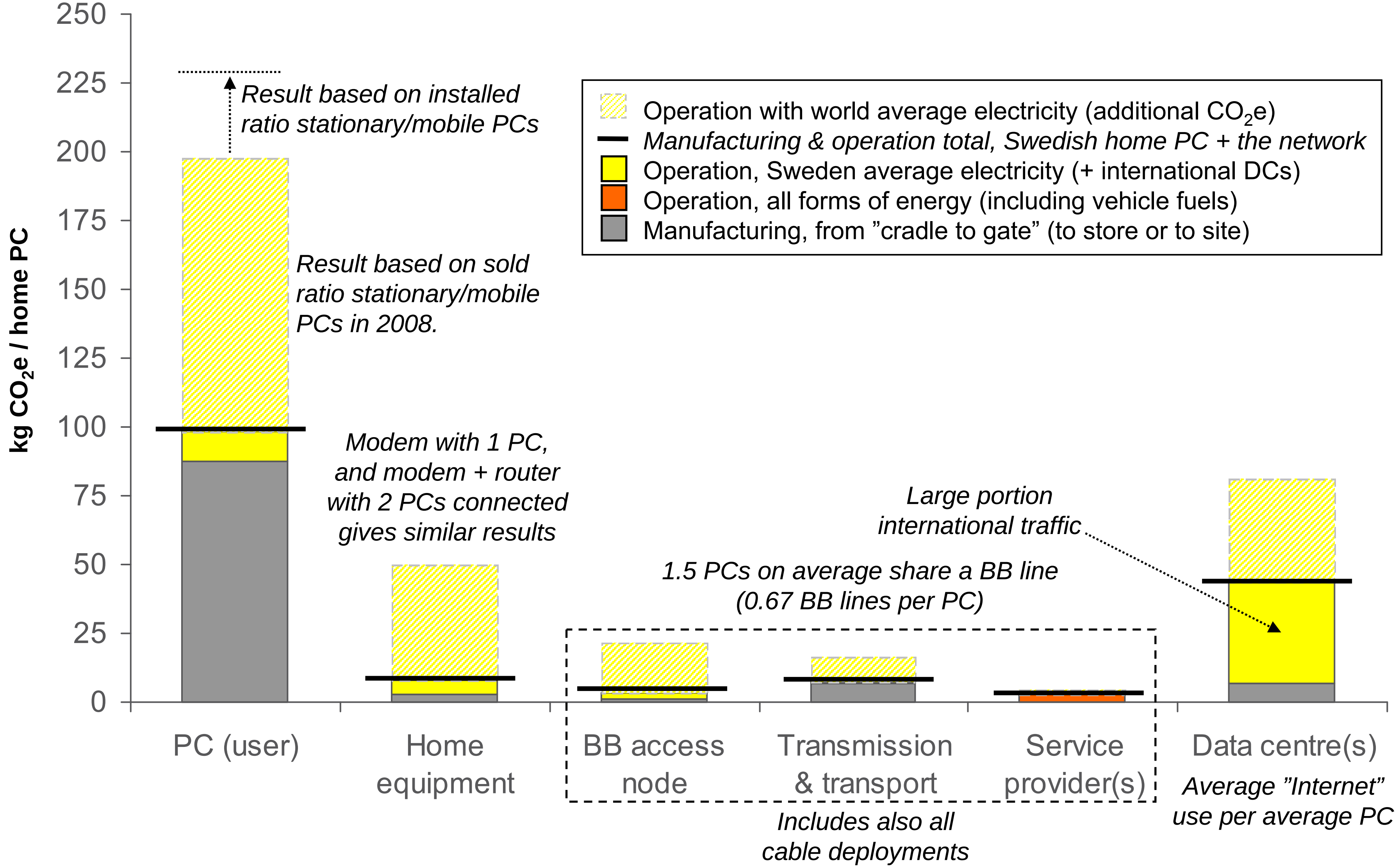
End of life
Collection/treatment
Recycling of metals
Landfill
Resource depletion

MOBILE BROADBAND



(Source: J. Malmodin, D. Lundén, ISSST 2010 Washington)

FIXED BROADBAND



Result based on installed ratio stationary/mobile PCs

Result based on sold ratio stationary/mobile PCs in 2008.

Modem with 1 PC, and modem + router with 2 PCs connected gives similar results

1.5 PCs on average share a BB line (0.67 BB lines per PC)

Large portion international traffic

Includes also all cable deployments

Average ”Internet” use per average PC

(Source: J. Malmodin, D. Lundén, ISSST 2010 Washington)

LCA CONCLUSIONS

- Large contribution from home equipment, access nodes and data centers
  - This has been concluded in many reports, see eg below

* Printers were 11% of the total ICT footprint in 2002, 8% in 2007 and will be 12% in 2020.

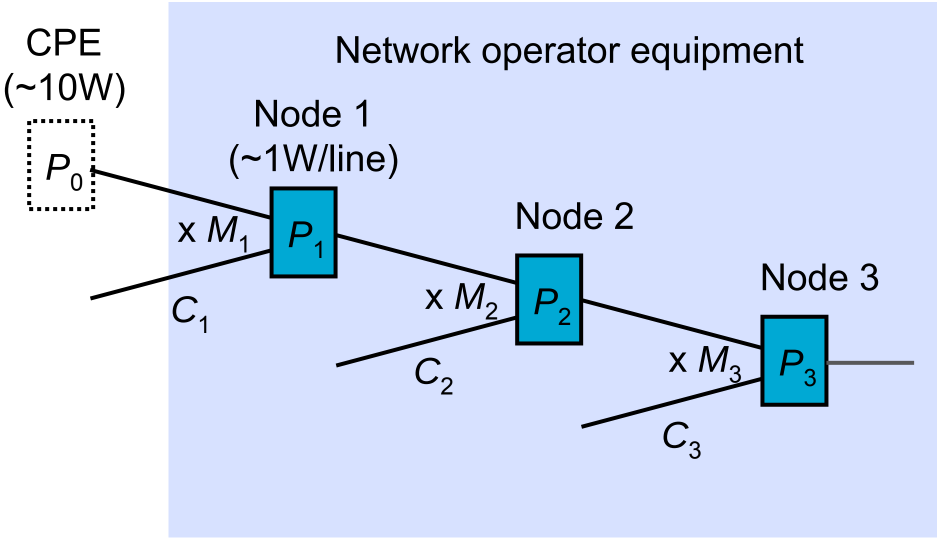
The Climate Group, SMART 2020 report 2008 (www.smart2020.org)

The number of PCs (Desktops and Laptops) globally is expected to increase from 592 Million in 2002 to more than four Billion in 2020

- For access nodes, large contribution from direct power consumption -> Motivation for EE work on equipment

FIXED ACCESS NETWORKS

- Access network tree structure *



P_n – power consumption

M_n - split

C_n – capacity

- Major part of power consumption due to network elements closest to the end-user
  - Node 1 > Node 2 etc
  - Home devices > CPE > Node 1

(* Source: B Skubic, A Lindstrom, S Dahlfort OFC’2010)

NETWORK OPERATOR EQUIPMENT

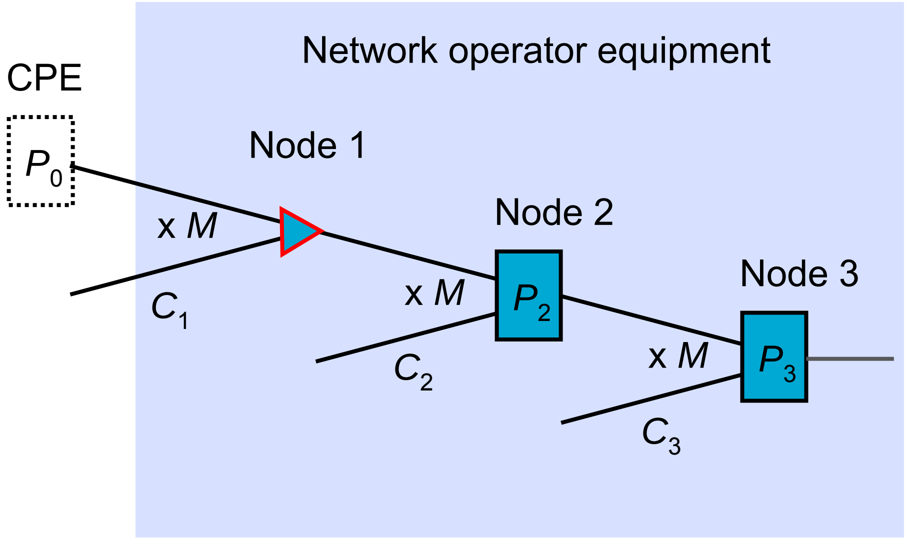
- Power consumption per line for different technologies

EC Code of Conduct *		
Year	2010 Full power state	2011 Full power state
ADSL2+	1.3 W/line	1.2 W/line
VDSL2 (profile 30a)	2.5 W/line	2.0 W/line
PtP fiber (≤1 Gbps)	5.0 W/line	5.0 W/line
GPON fiber (2.5 Gbps shared)	0.47 W/line (32 split) (15 W/port)	0.34 W/line (32 split) (11 W/port)

* http://ec.europa.eu/information_society/activities/sustainable_growth/docs/broadband_eq_code-conduct.pdf

OPTICAL ACCESS NETWORKS

- Gigabit-capable passive optical networks (GPON)



P_n – power consumption

M_n - split

C_n – capacity

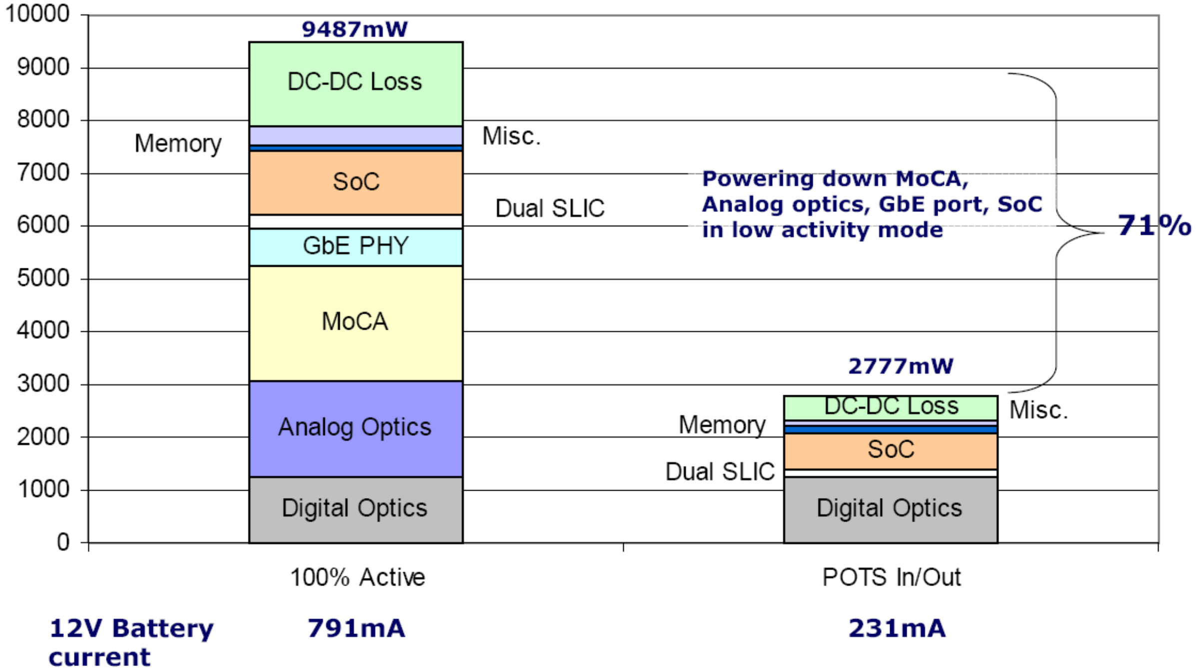
- GPON replaces Node 1 with a passive splitter allowing for reduced power consumption

CUSTOMER PREMISES EQUIPMENT

- Access networks designed for peak rate
  - Low utilization closer to the end-user
  - Larger contribution to power consumption closer to the end-user

Large potential for dynamical power saving schemes

Example: GPON ONT (CPE)

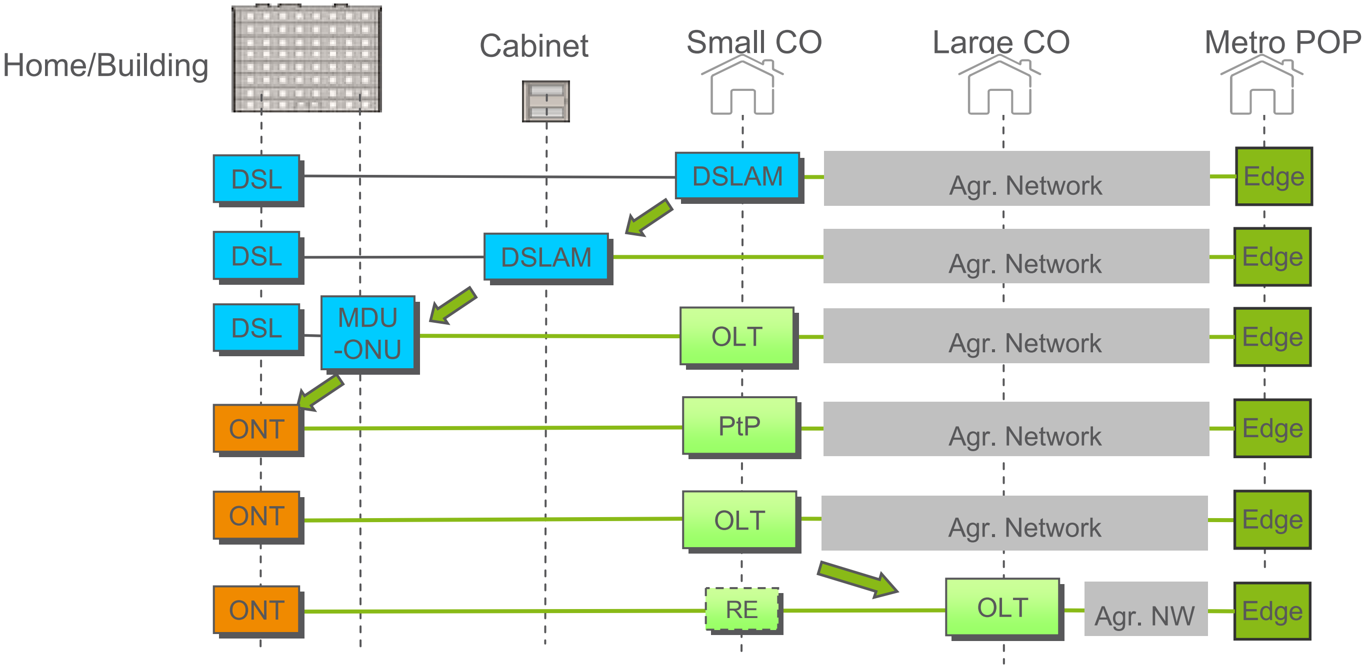


(Source: ”ONT Power Saving Proposal”, D. Hood, et. al. ITU Q2/SG15, June 2008. Also G suppl. 45)

SUMMARY

FIXED ACCESS EVOLUTION

- Deep fiber penetration
- Central office (CO) consolidation
- Dynamical power savings



Multi dimensional analysis required to understand the Energy Efficiency effect of this evolution

ERICSSON

Hybrid Optoelectronic Router for Optical Packet Switching

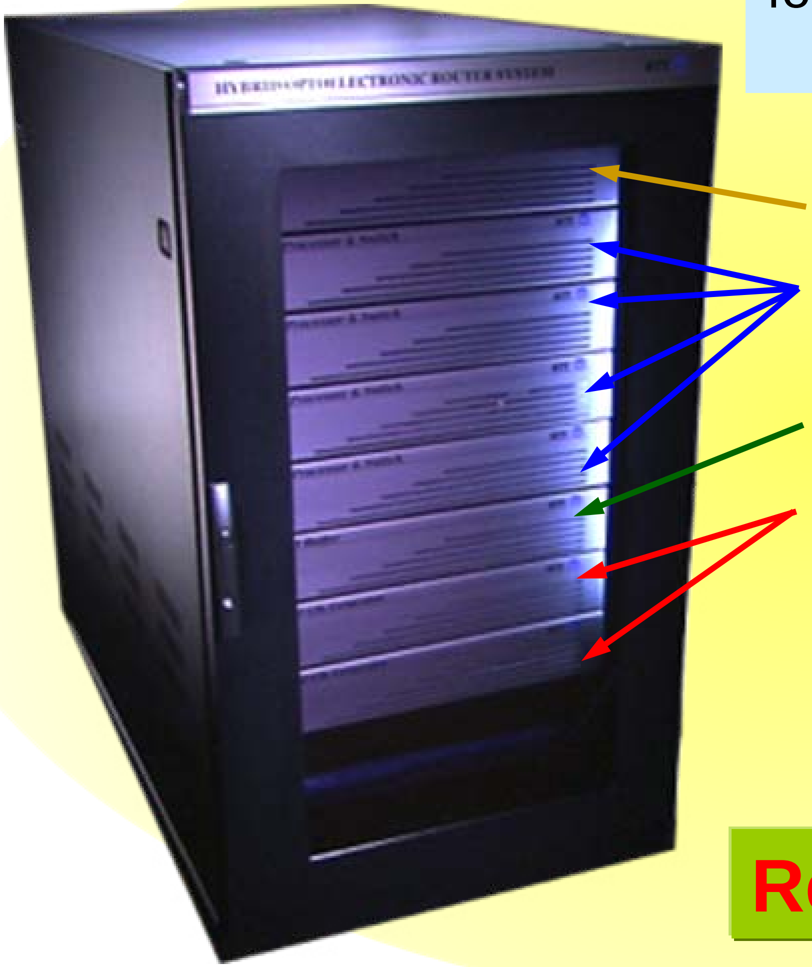
T. Nakahara, R. Urata, T. Segawa, Y. Suzaki,
H. Takenouchi, and R. Takahashi

NTT Photonics Laboratories, NTT Corporation

This work is partially supported by
the National Institute of Information and Communications Technology (NICT).

Hybrid Optoelectronic Router

8x8 (4x4, 2λs) packet switching capability for 10-Gbps asynchronous optical packets (scalable to 16x16 (4λs))



Optical Input/Output

Label Processor & Switch

Shared Buffer

Optical Clock Generator

Reduces power and latency

Background

Explosive growth of Internet and related services

Capacity

Increased node throughput is critical

Services

Flexible, traffic engineering capability is essential for high level services

NW Architecture

Optimize NW for IP Data traffic

Power Consumption

Reducing power consumption of IP-router/system is critical

Promising solutions

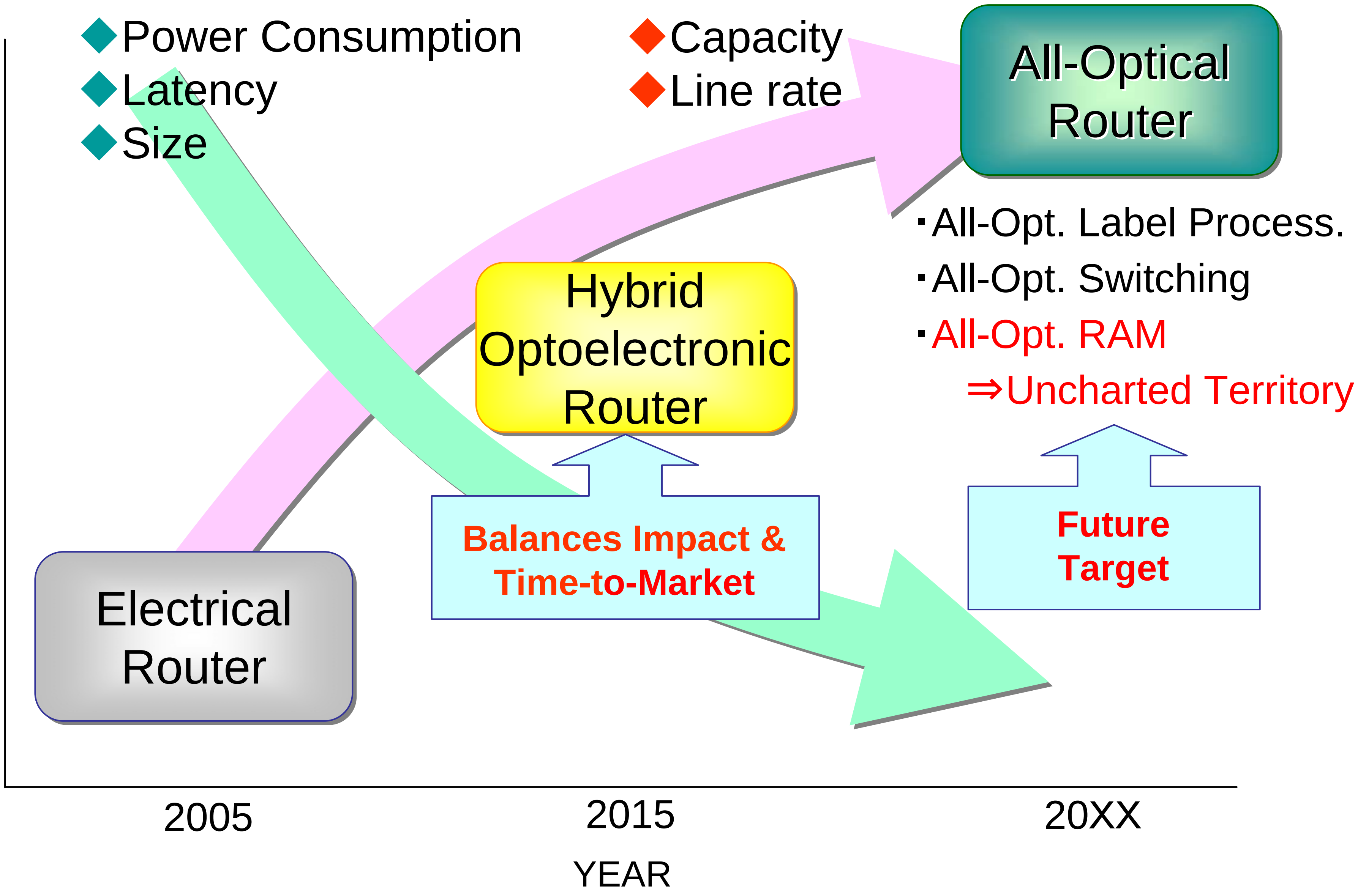
Photonic MPLS

- ✓ Optical Circuit Switching (OCS)
- ✓ Optical Burst Switching (OBS)
- ✓ Optical Packet Switching (OPS)

OPS Network

- maximizes BW utilization in the fiber
- is ideal in terms of flexibility of traffic engineering
- is ideal in terms of scalability of NW

Roadmap



◆Power Consumption
◆Latency
◆Size

◆Capacity
◆Line rate

All-Optical Router

- All-Opt. Label Process.
- All-Opt. Switching
- All-Opt. RAM

⇒Uncharted Territory

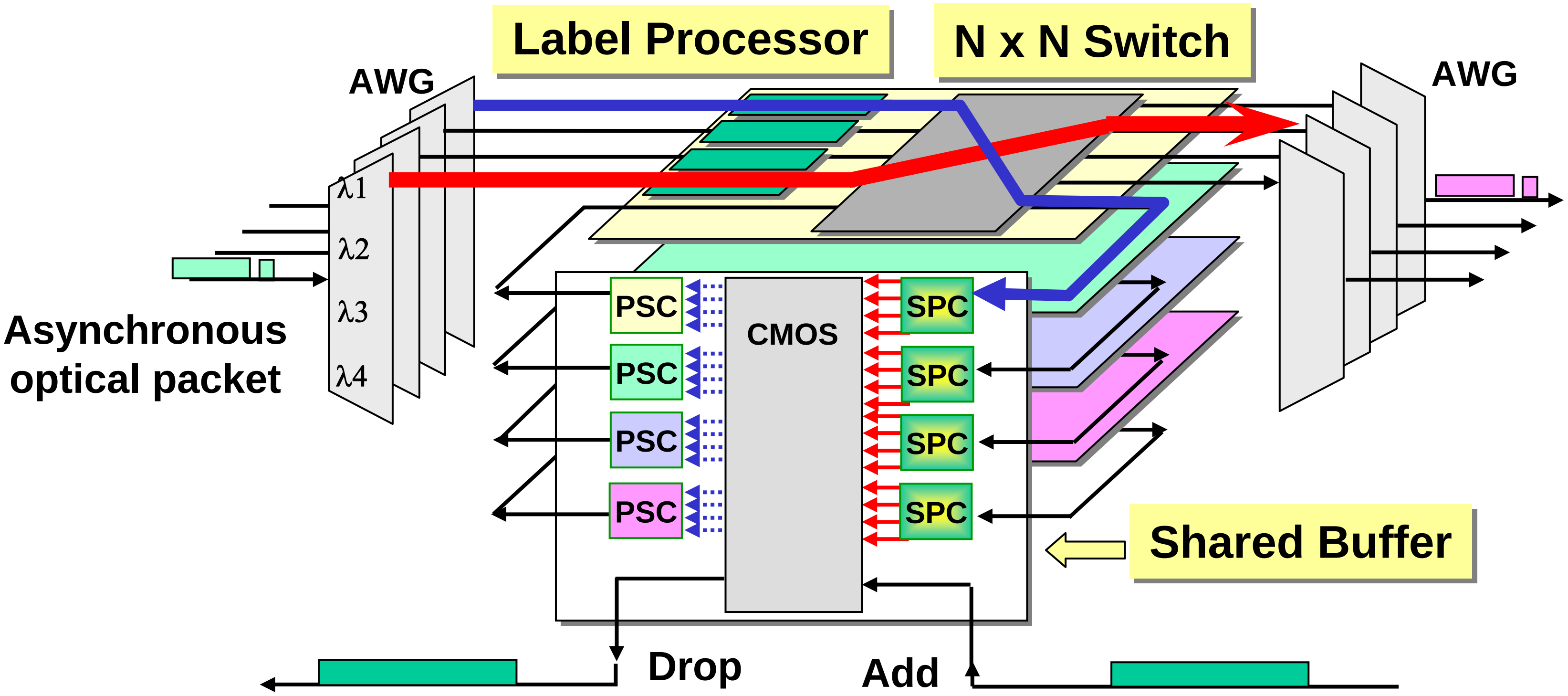
Hybrid Optoelectronic Router

Balances Impact & Time-to-Market

Future Target

Electrical Router

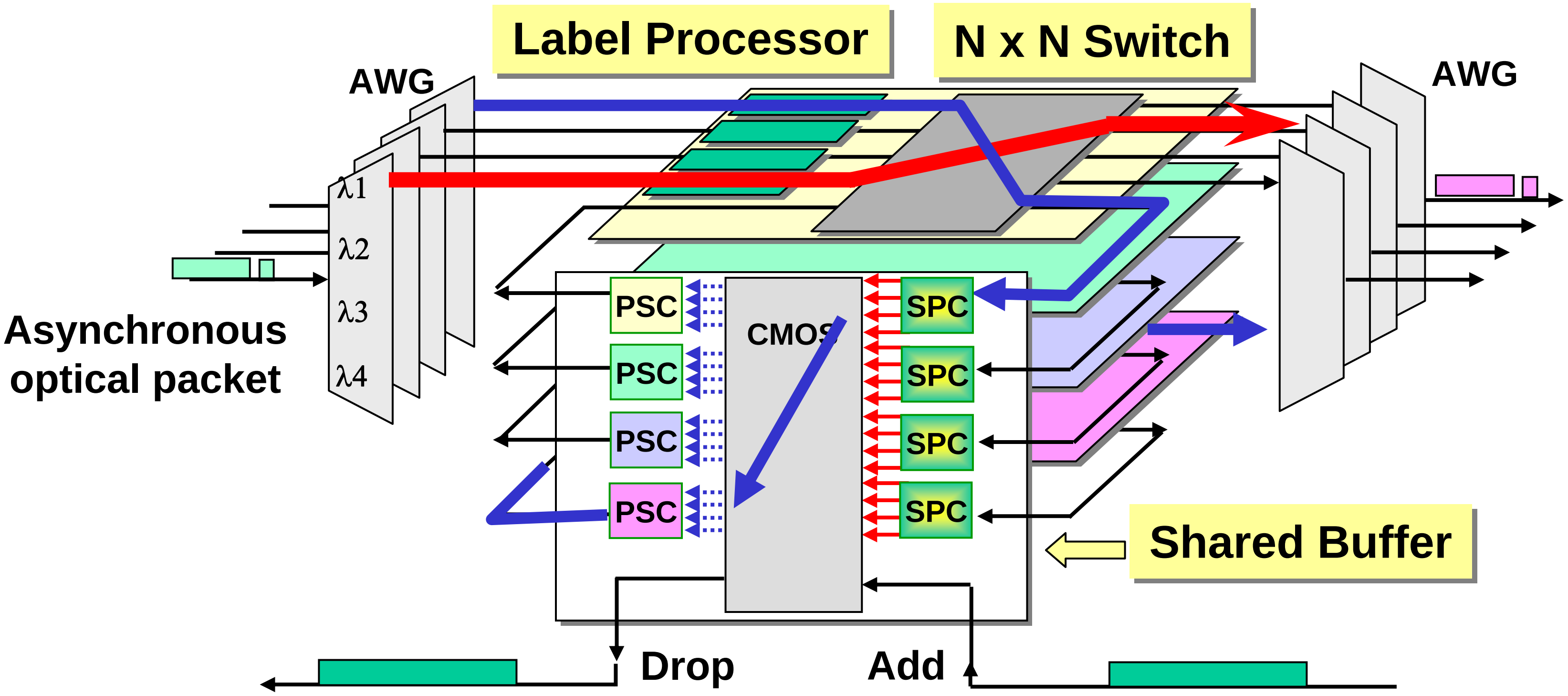
Router Architecture



No Contention → **Passes through w/o buffering**

Contention → **Forwarded to shared buffer**

Router Architecture

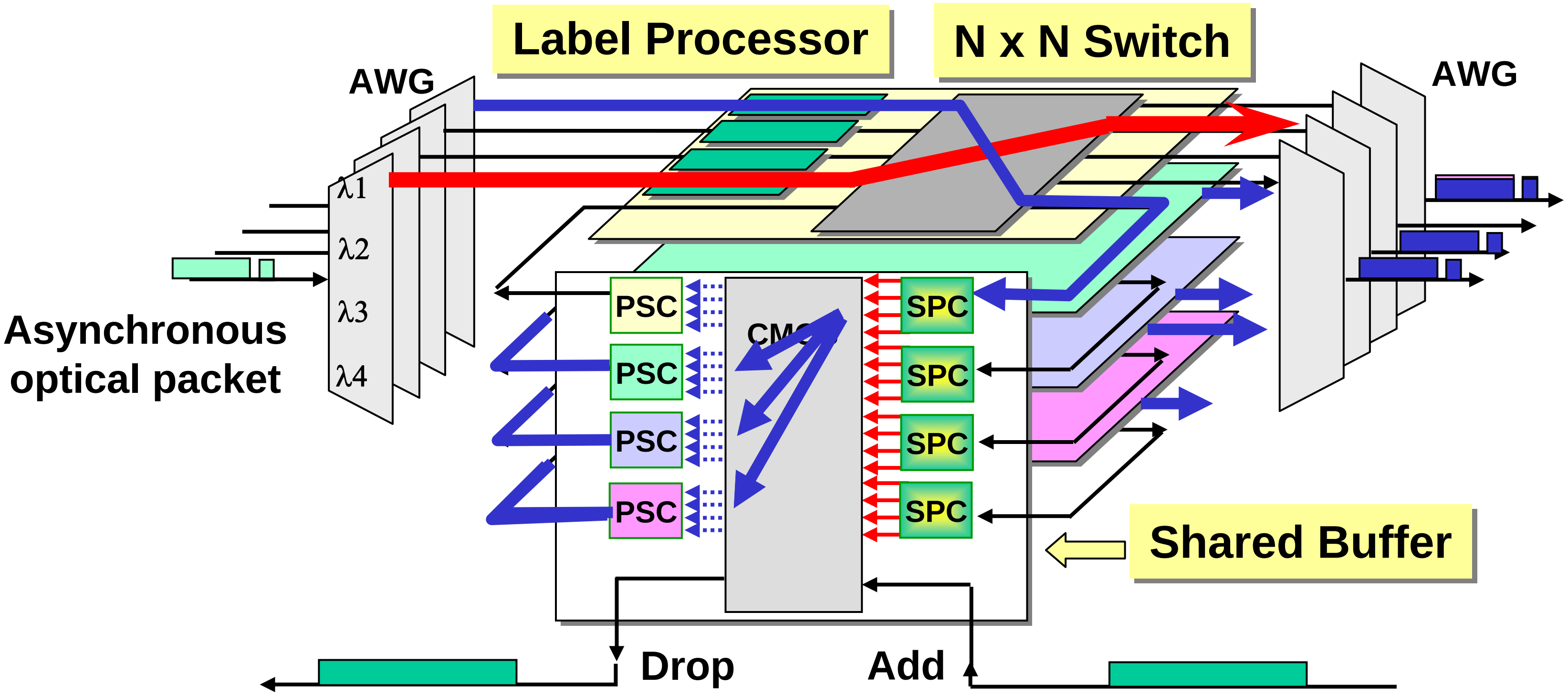


Buffering in CMOS RAM

Traffic engineering between wavelength layers

3R regeneration and FEC based on TTL in label

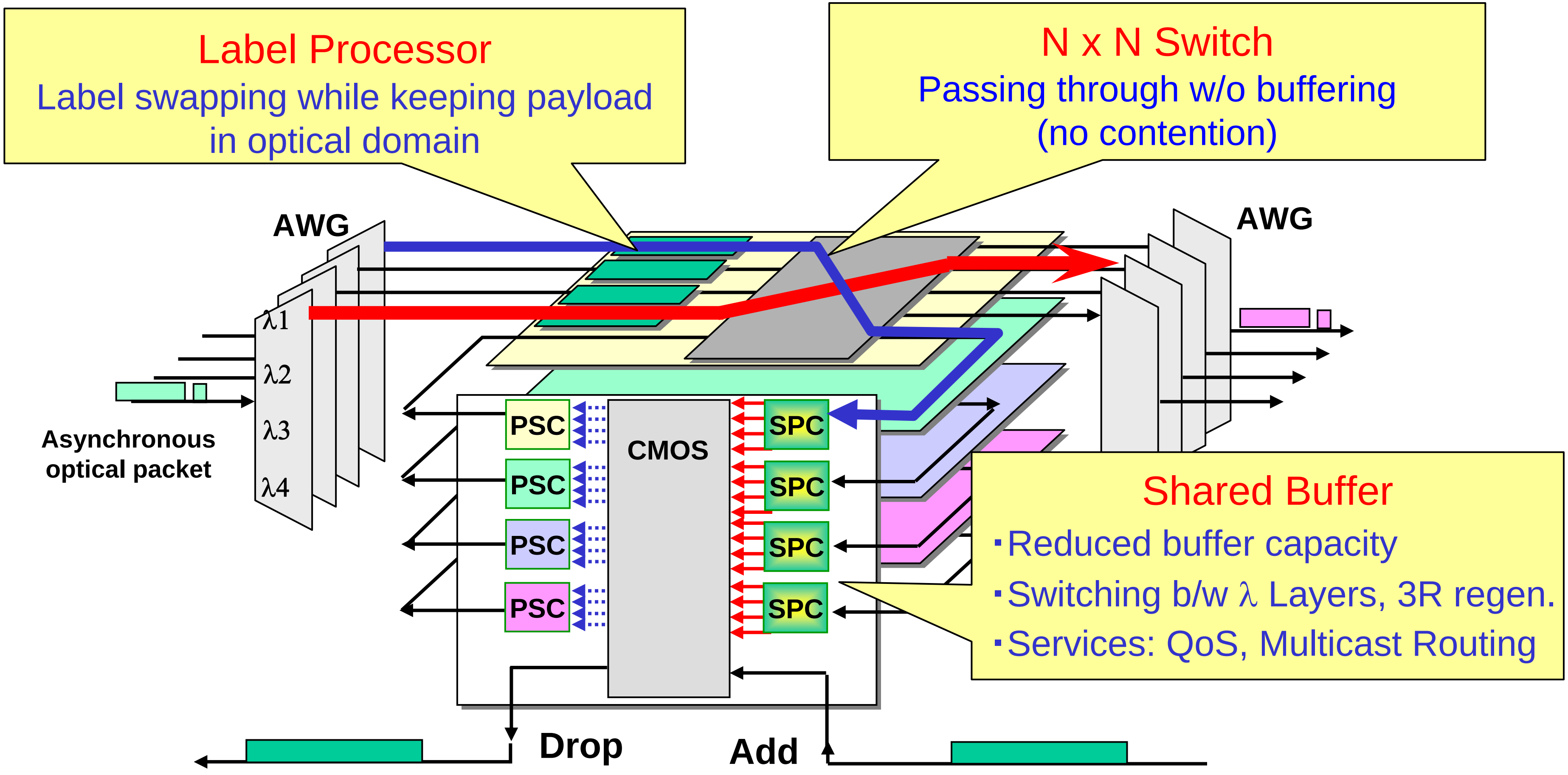
Router Architecture



Shared Buffer supports various services

such as QoS, Multicast routing ...

Advantages of Proposed Router



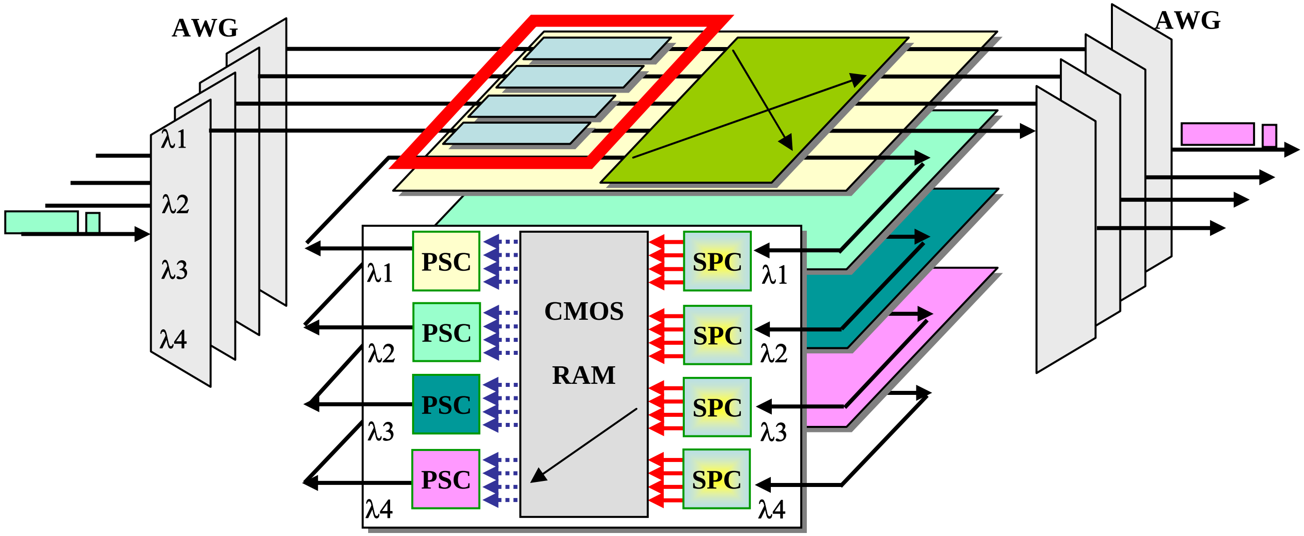
Label Processor
Label swapping while keeping payload in optical domain

N x N Switch
Passing through w/o buffering (no contention)

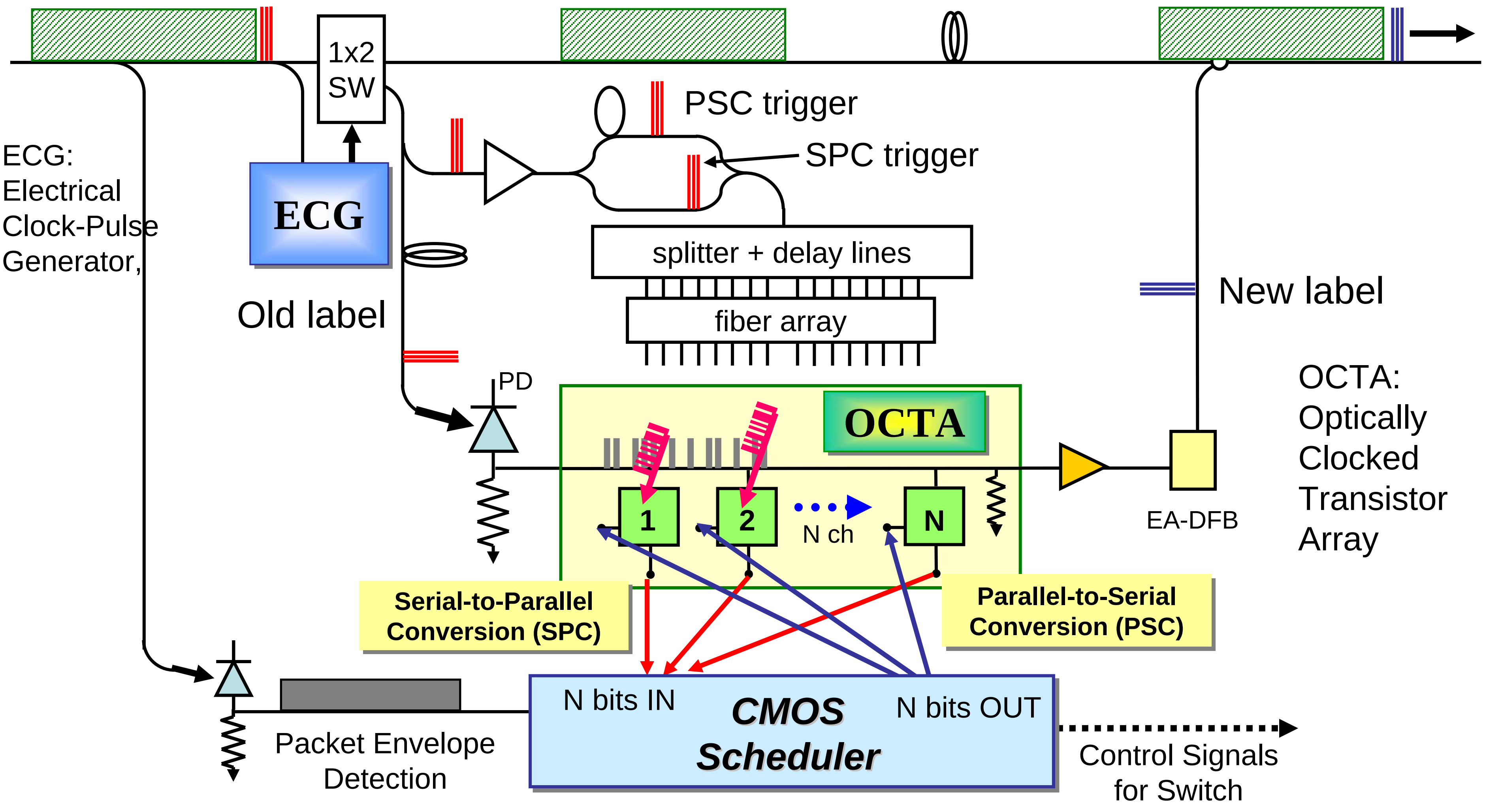
Shared Buffer
- Reduced buffer capacity
- Switching b/w λ Layers, 3R regen.
- Services: QoS, Multicast Routing

Reduces power, latency, and size while maintaining functionality to implement various services

Label Processor



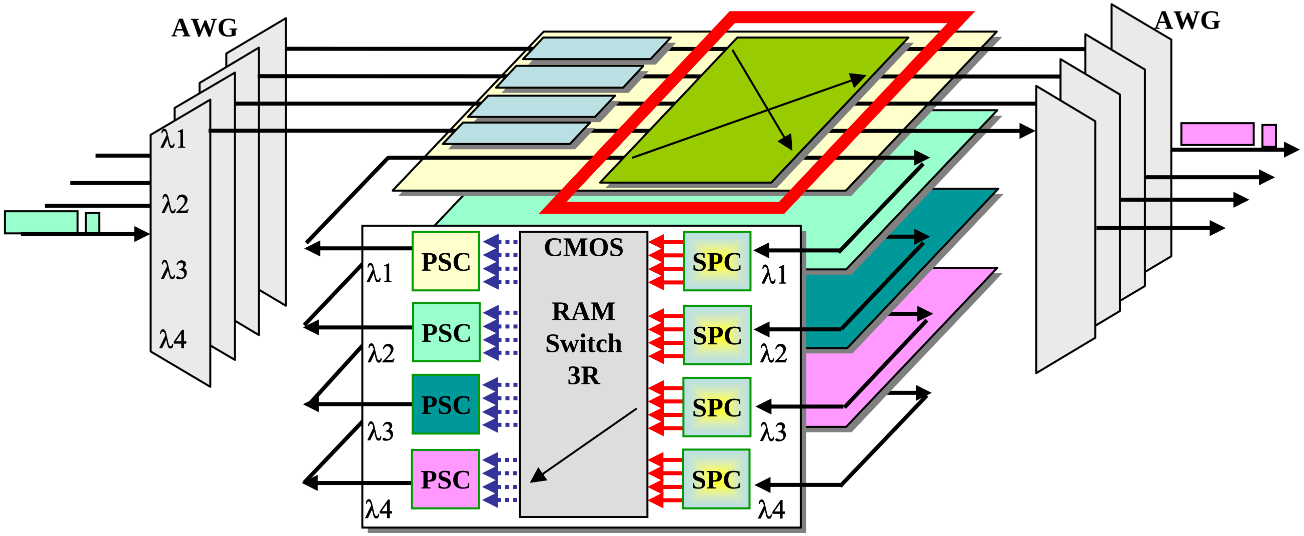
Label Processor Subsystem



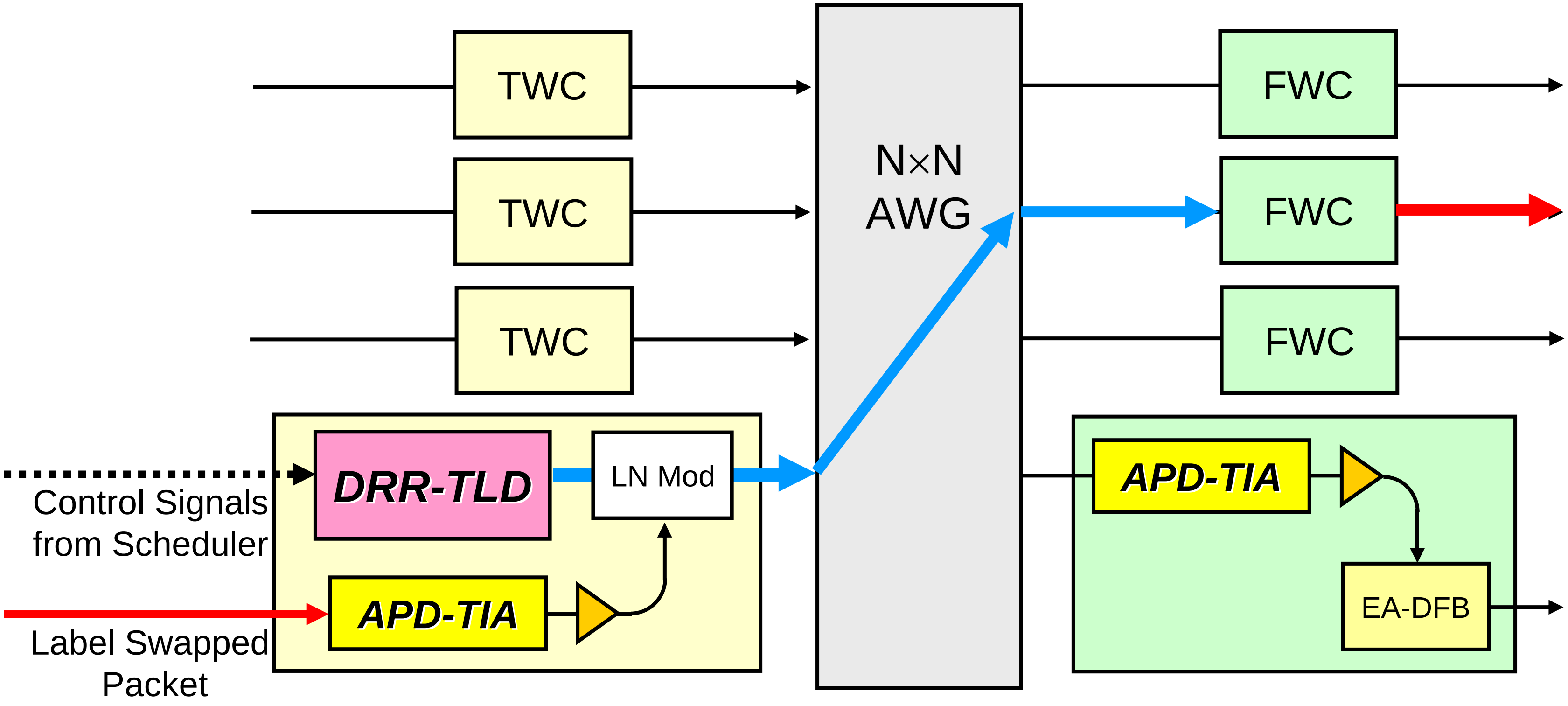
Merge SPC, PSC, Clock generation in Low-power Single OEIC Chip

Eliminates payload buffering to reduce latency and power

N x N Switch


AWG
λ1
λ2
λ3
λ4
AWG
CMOS
RAM
Switch
3R
PSC
PSC
PSC
PSC
SPC
SPC
SPC
SPC
λ1
λ2
λ3
λ4
λ1
λ2
λ3
λ4

N x N Switch Subsystem

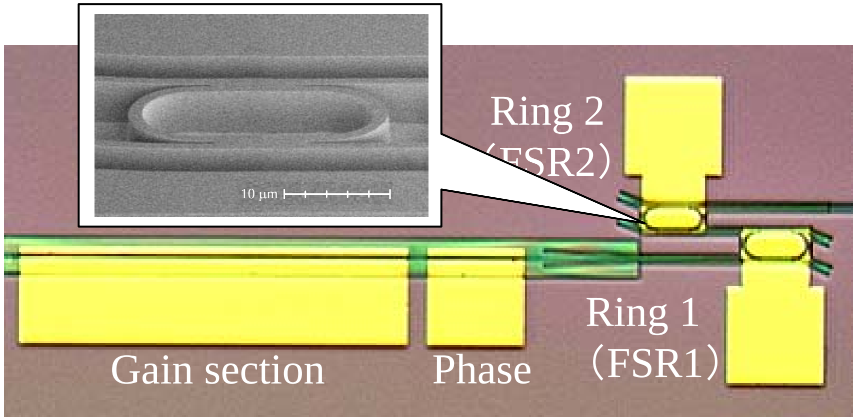


TWC, FWC: Tunable, Fixed Wavelength Converter
DRR-TLD: Double-Ring-Resonator-Coupled Tunable Laser Diode

N×N non-blocking switch for packet-level switching

Low power, compact, fast switching, scalable

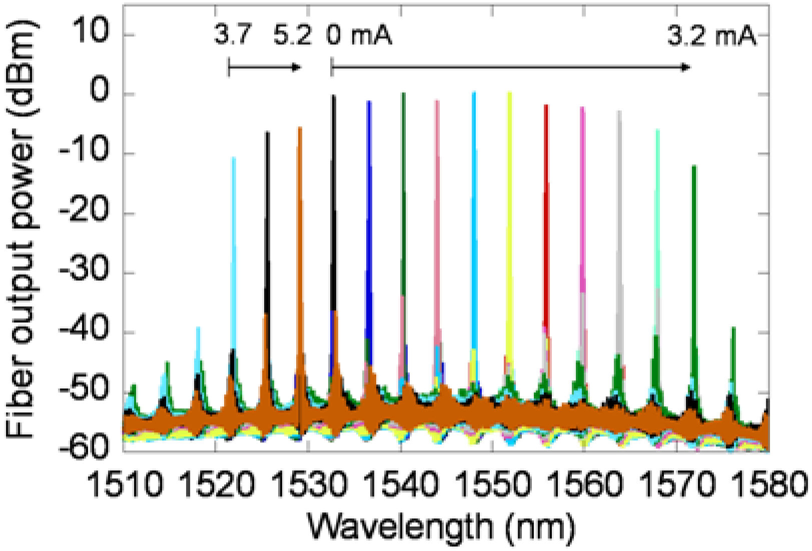
Double-Ring-Resonator Tunable LD



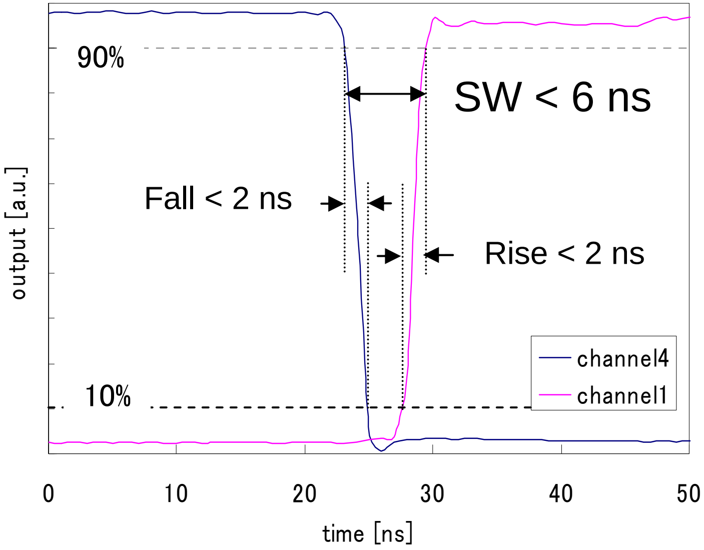
Characteristics

- ◆ Fast switching time (< 6 ns)
- ◆ Wide tuning range (> 50 nm)
- ◆ Low driving current (< 7 mA)
- ◆ Low wavelength drift (< 5 GHz)

Wavelength tuning



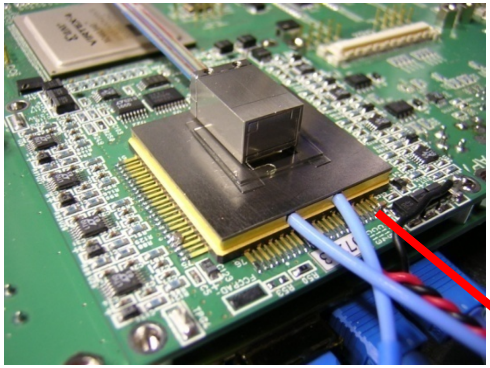
Wavelength switching



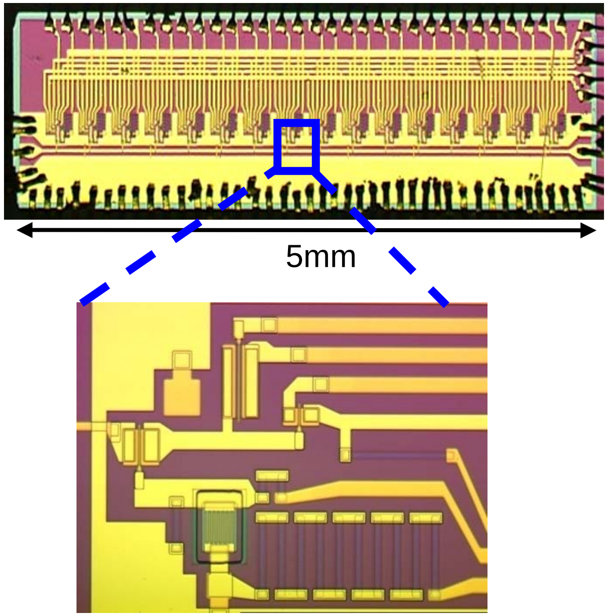
Label Processor & Optical Switch

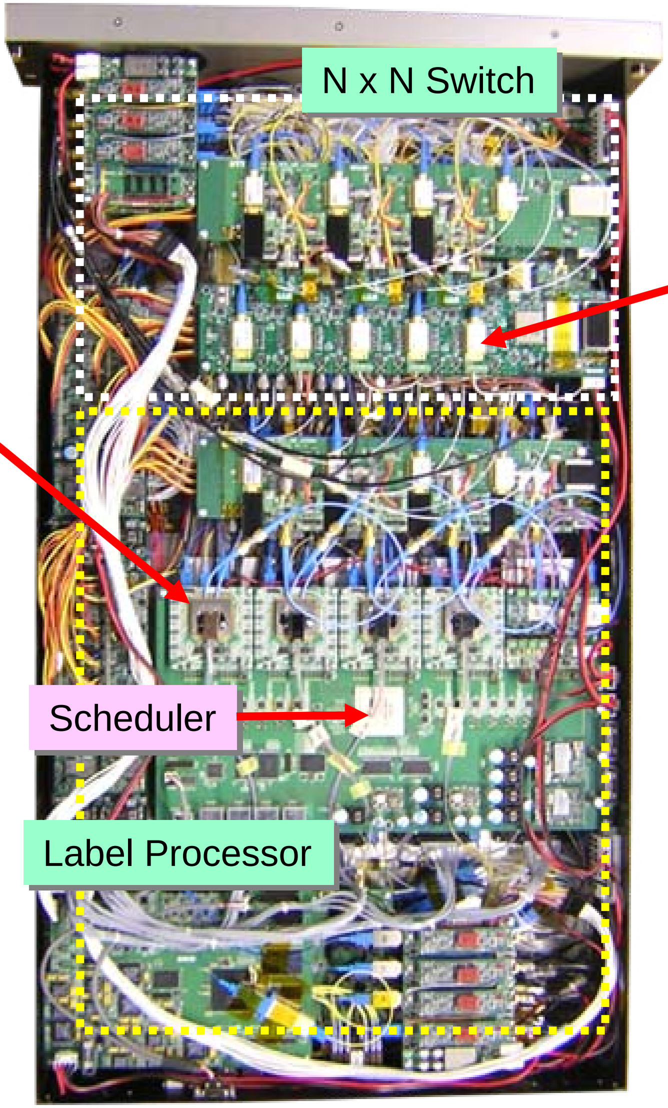
Label Processor

OCTA module



16-ch OCTA

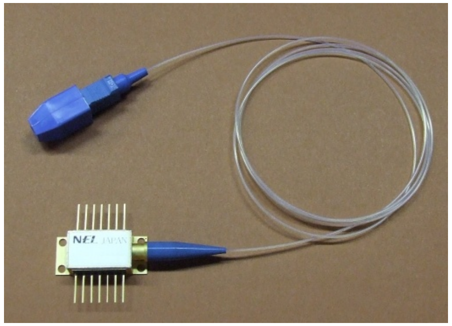


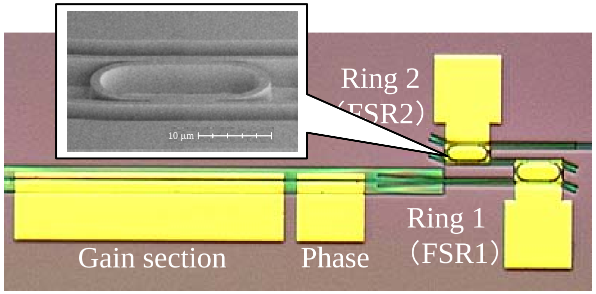


43 x 76 x 8.5 cm³（19-inch, 2U）

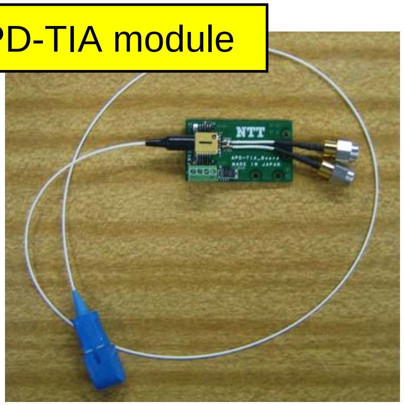
N x N Switch

TLD module

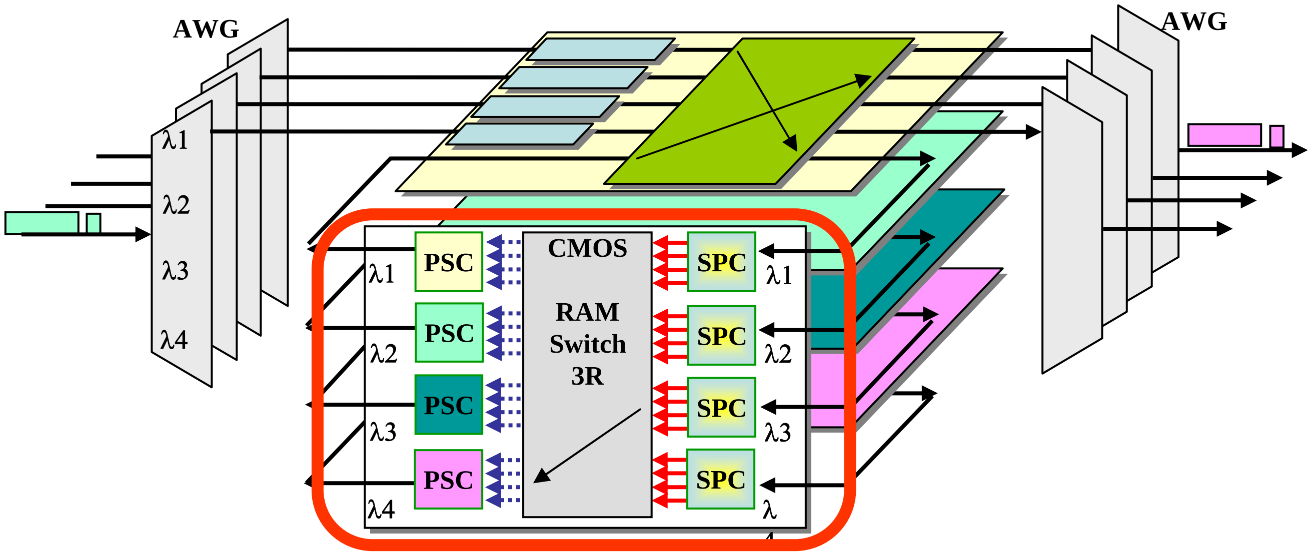




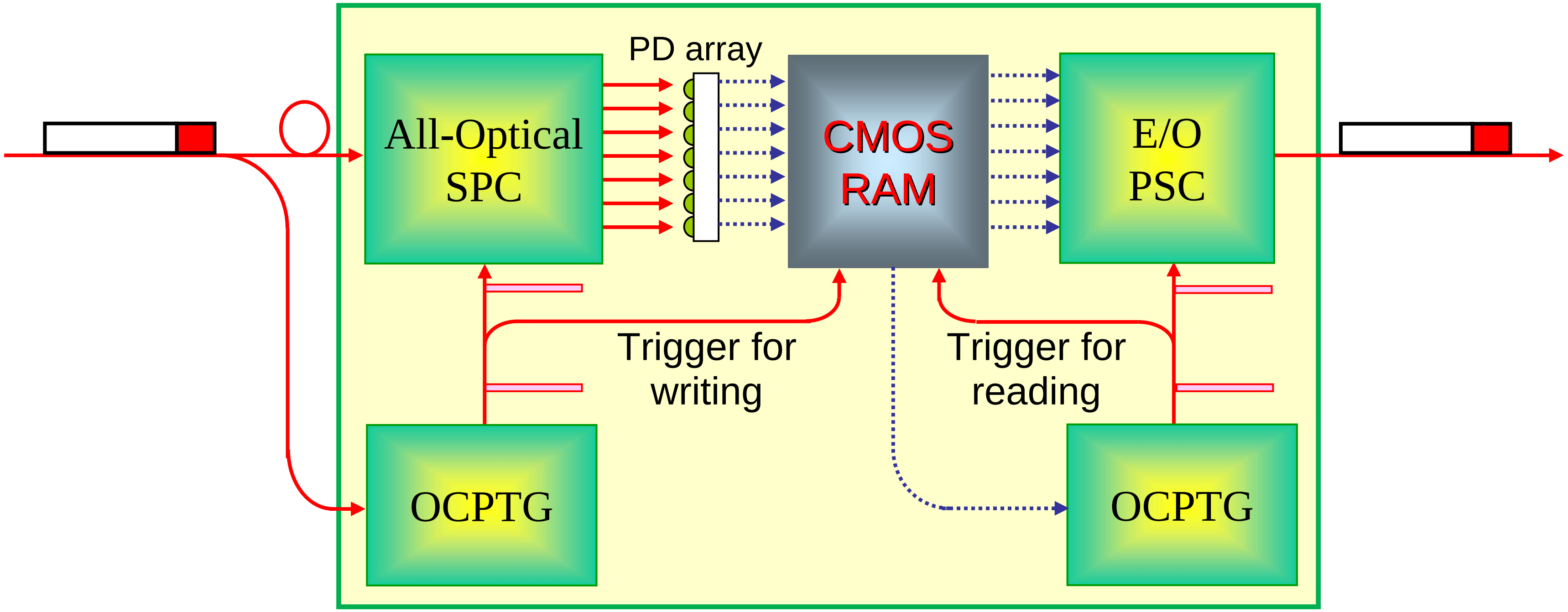
APD-TIA module



Shared Buffer



Shared Buffer Subsystem

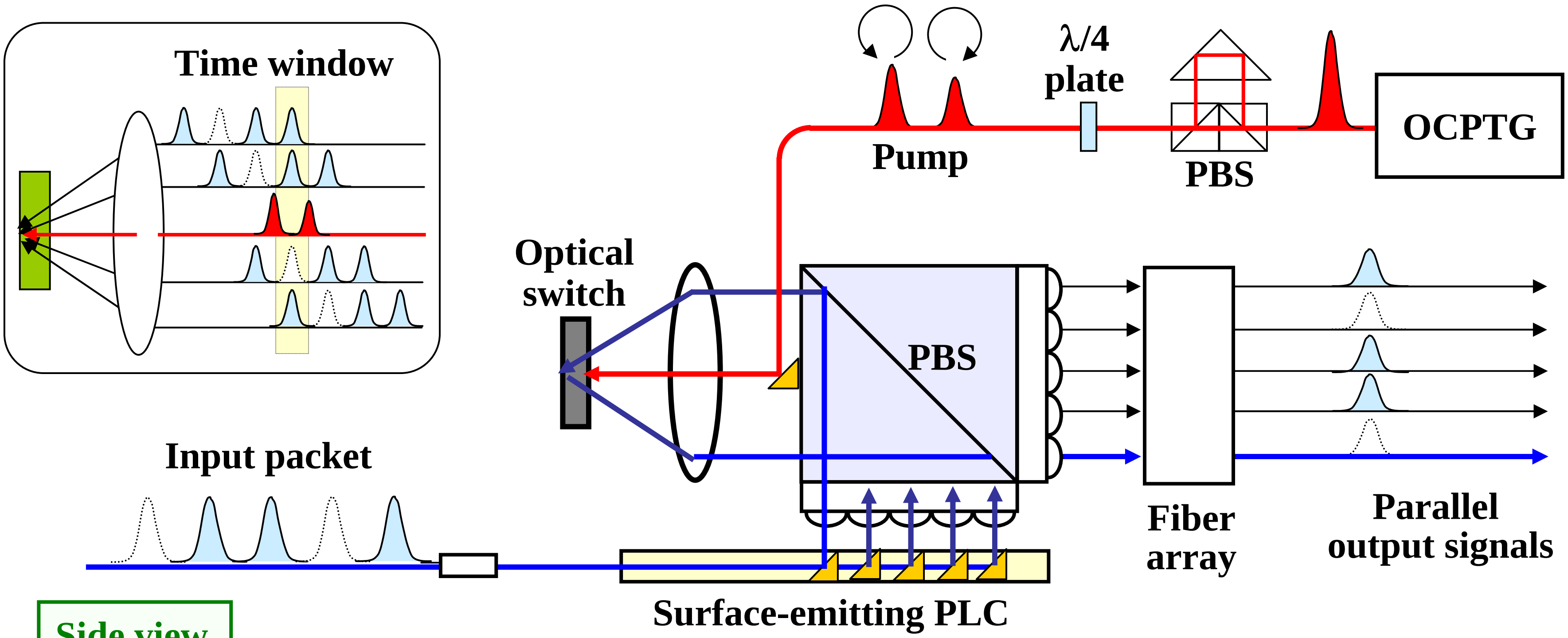


SPC : Serial-to-Parallel Converter
PSC : Parallel-to-Serial Converter
OCPTG: Optical Clock-Pulse Train Generator

Selective buffering, high-level packet functions

Asynchronous burst mode compliant, low power, CMOS functionality

All-Optical Serial-Parallel Converter



Time window

Optical switch

Pump

λ/4 plate

PBS

OCPTG

PBS

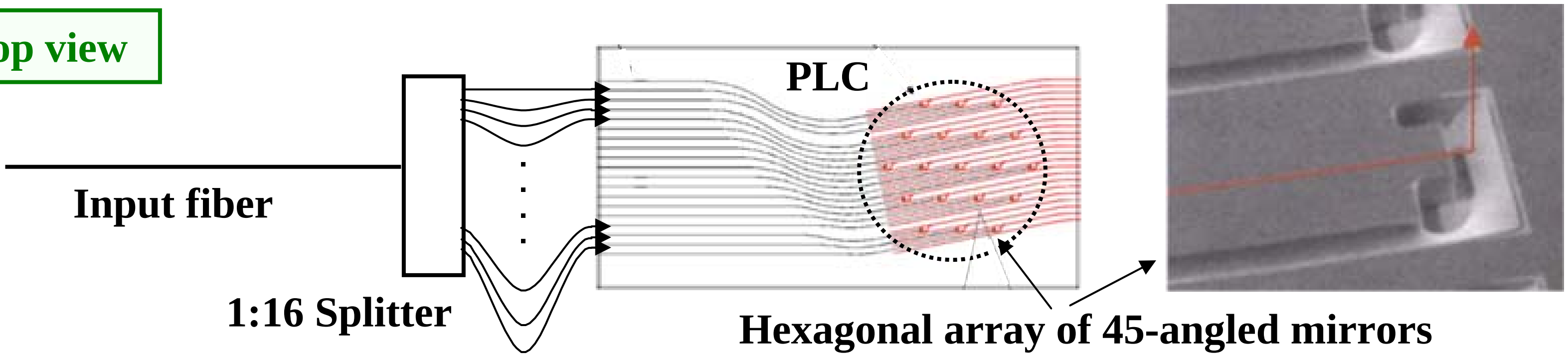
Input packet

Fiber array

Parallel output signals

Surface-emitting PLC

Side view



Top view

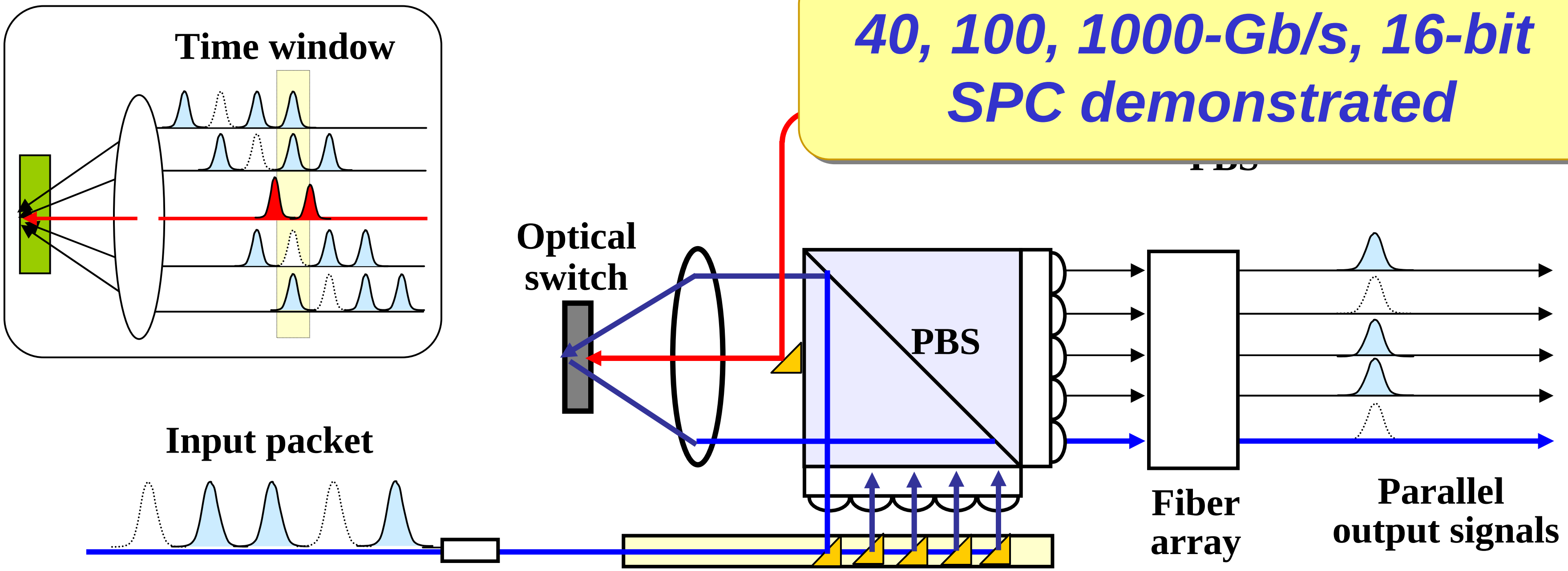
PLC

Input fiber

1:16 Splitter

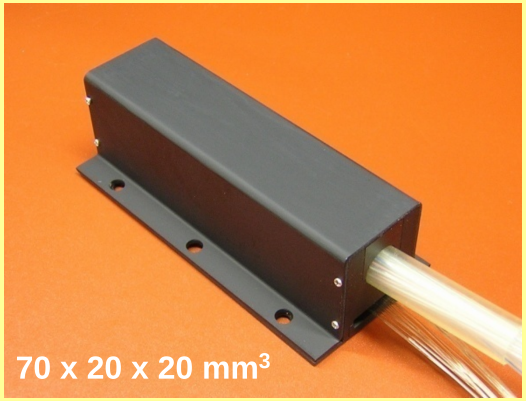
Hexagonal array of 45-angled mirrors

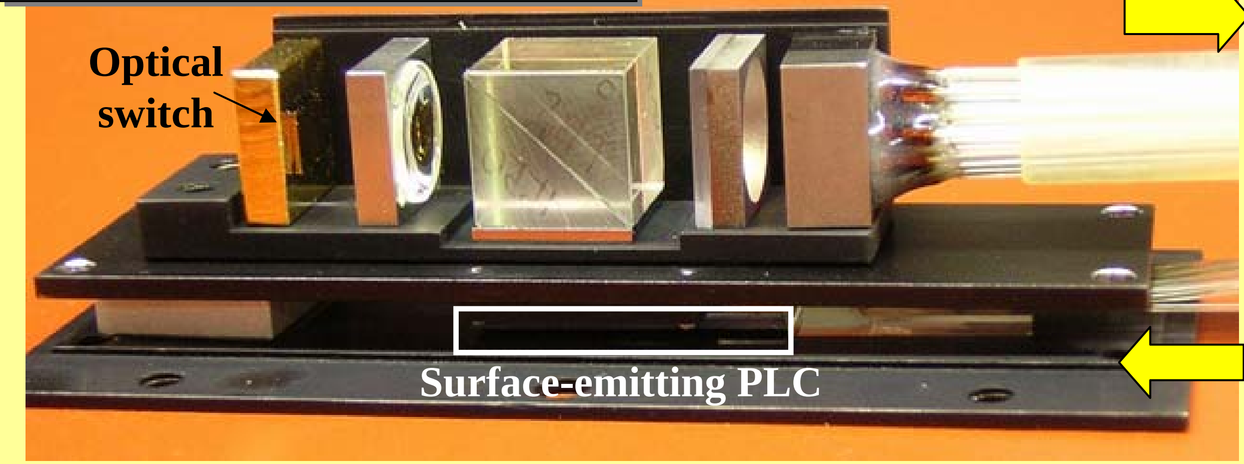
All-Optical Serial-Parallel Converter



40, 100, 1000-Gb/s, 16-bit SPC demonstrated

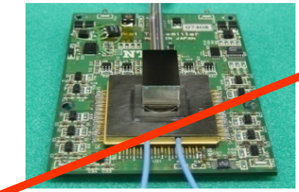
All-Optical SPC Module

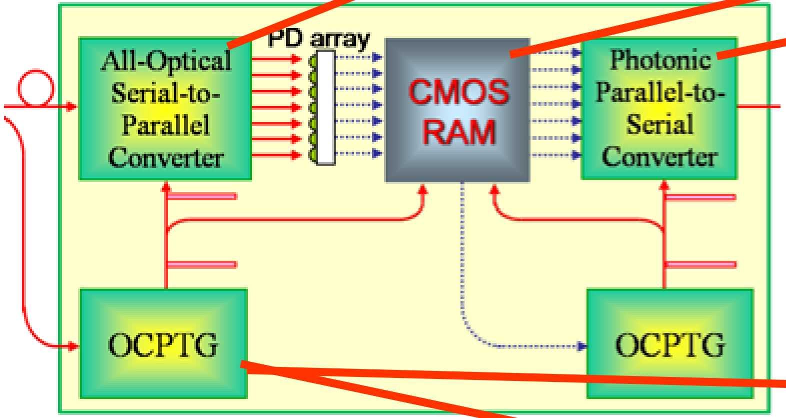




Shared Buffer & OCPTG

Shared Buffer





All-Optical Serial-to-Parallel Converter

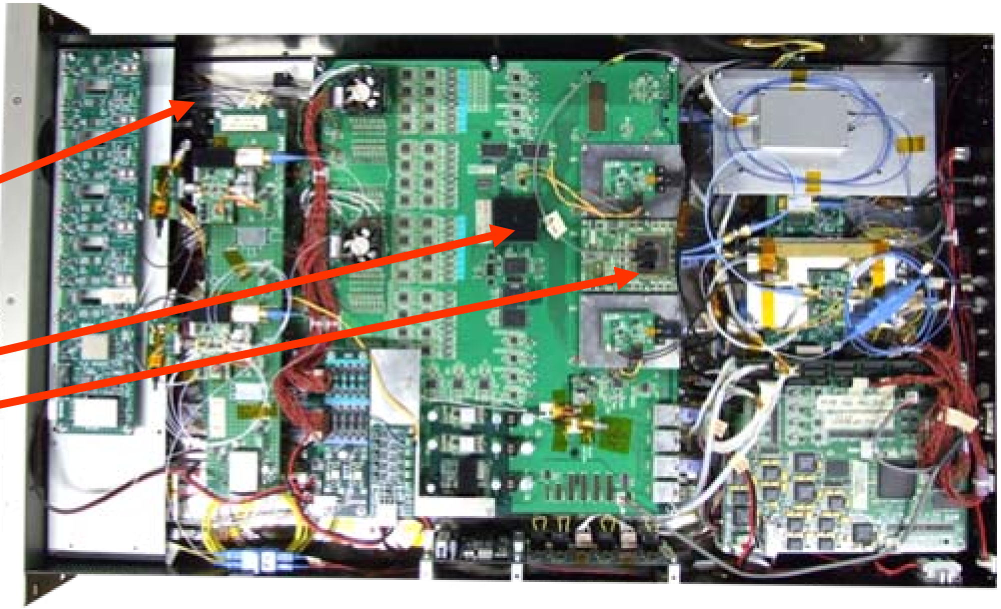
PD array

CMOS RAM

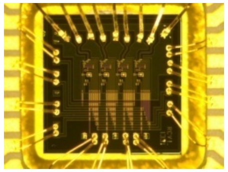
Photonic Parallel-to-Serial Converter

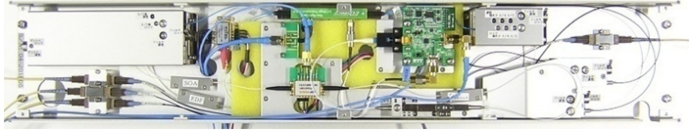
OCPTG

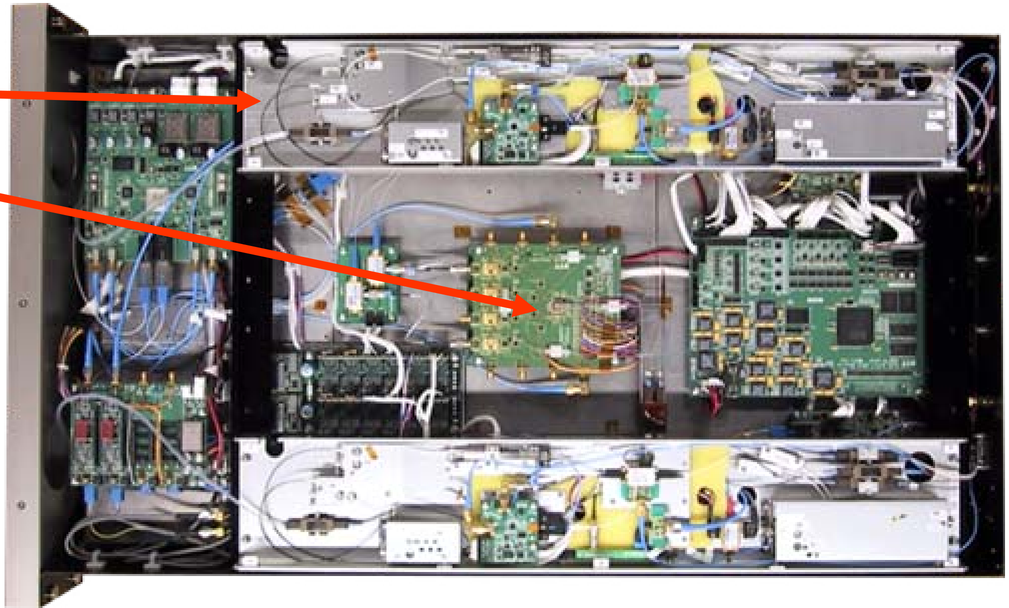
OCPTG



OCPTG

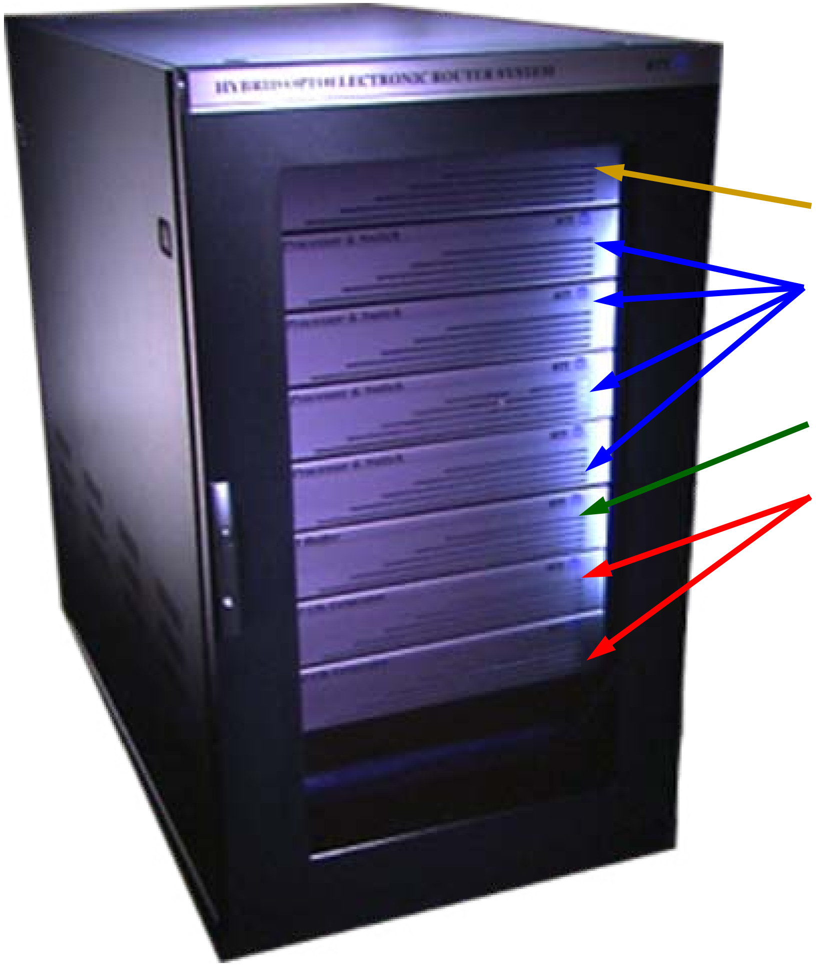






Prototype Router

8x8 (4x4, 2λs) packet switching capability for 10-Gbps, variable-length, asynchronous optical packets (scalable to 16x16 (4λs))



Optical Input/Output

Label Processor & Switch
(Two layers implemented)

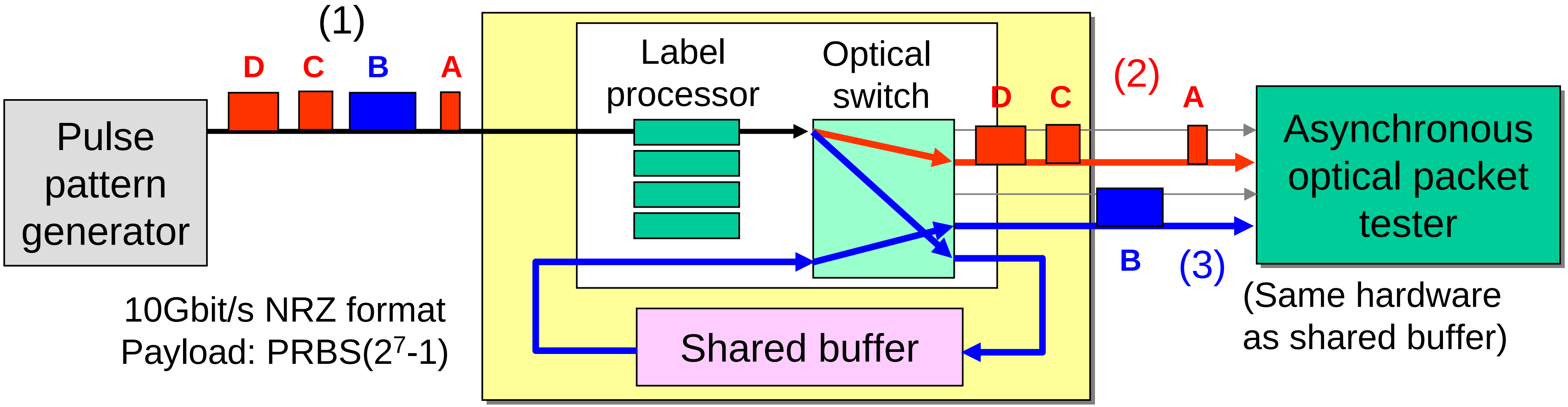
Shared Buffer

Optical Clock Generator

Performance

- **Throughput:** **160 Gbps**
- **Power:** **~360 W**
- **Latency:** **~1.4 μs (contention)**
  ~380 ns (no contention)
- **Functions**:
  16-bit label swapping, 2-line QoS, Multicast, TTL-based 3R regeneration
- **Size**: **100 x 60 x 100 cm^3**

Performance of Prototype



Pulse pattern generator

10Gbit/s NRZ format

Payload: PRBS(2^7-1)

Label processor

Optical switch

Shared buffer

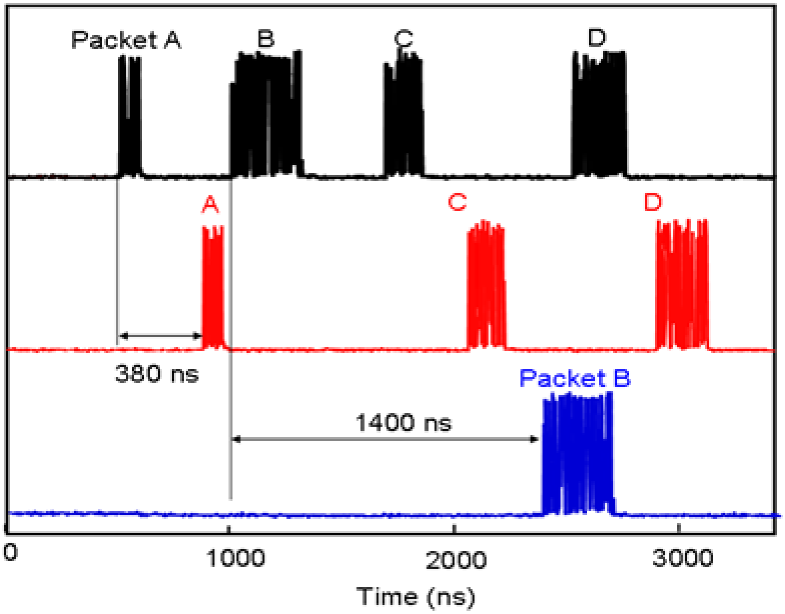
Asynchronous optical packet tester

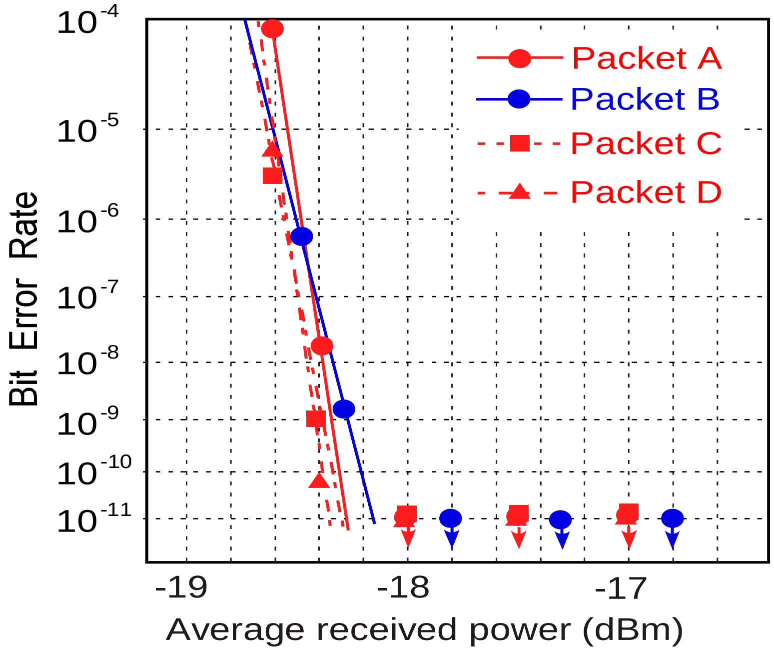
(Same hardware as shared buffer)

(1) Input

(2) Output （without contention)

(3) Output （with contention)



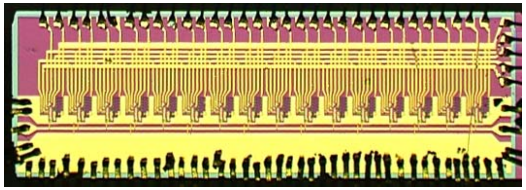


Summary

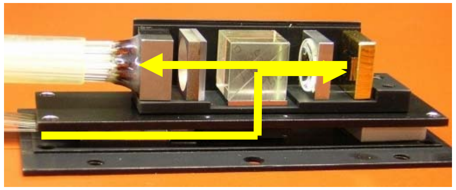
NTT

Devices

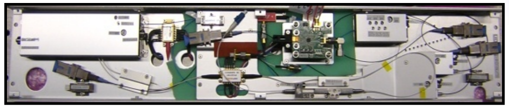
Optically Clocked Transistor Array（OCTA）



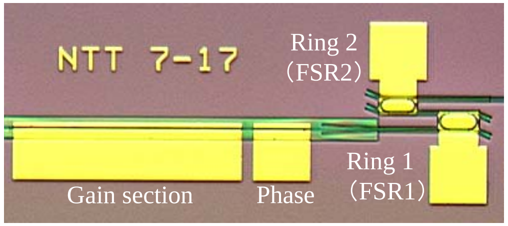
All-optical SPC



OCPTG

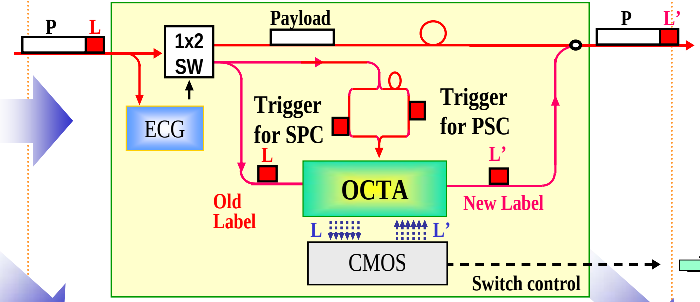


DRR-TLD

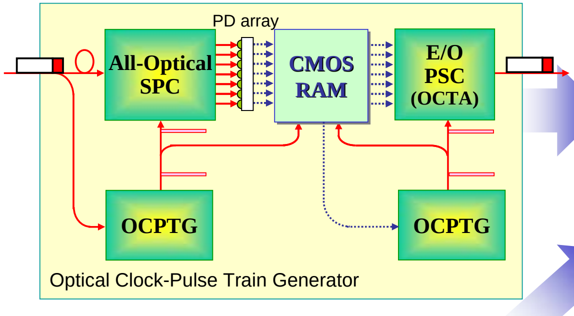


Sub-systems

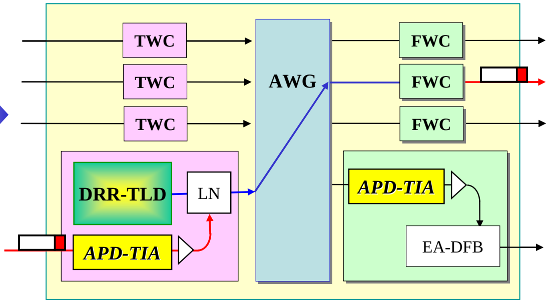
Label processor



Shared Buffer

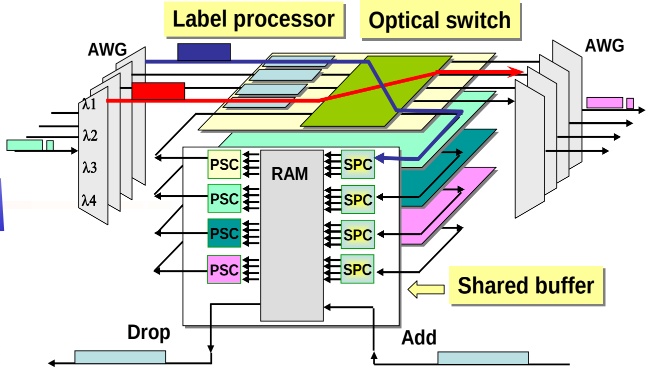


N x N Switch



Prototype

Hybrid Optoelectronic Router



Low power
Low latency
High functionality

Photonics in Switching Workshop on Energy Efficient Networking '10

A Researcher's Perspective on the Energy Issue:

"*How do I decide whether to pursue a given photonics switching project?*"

Alan E. Willner

University of Southern California
Los Angeles, CA 90089-2565

USC Optical Communications Laboratory

USC Viterbi School of Engineering

Thank You!!

… to Antonella, Dominique and June-Koo for their gracious and kind invitation.

… to Antonella, Moshe and my students for very helpful discussions.

… and for the generous support of Cisco, DARPA, HP, Intel, NSF, Packard Foundation.

The Three Most Important Words

“I DON’T KNOW”

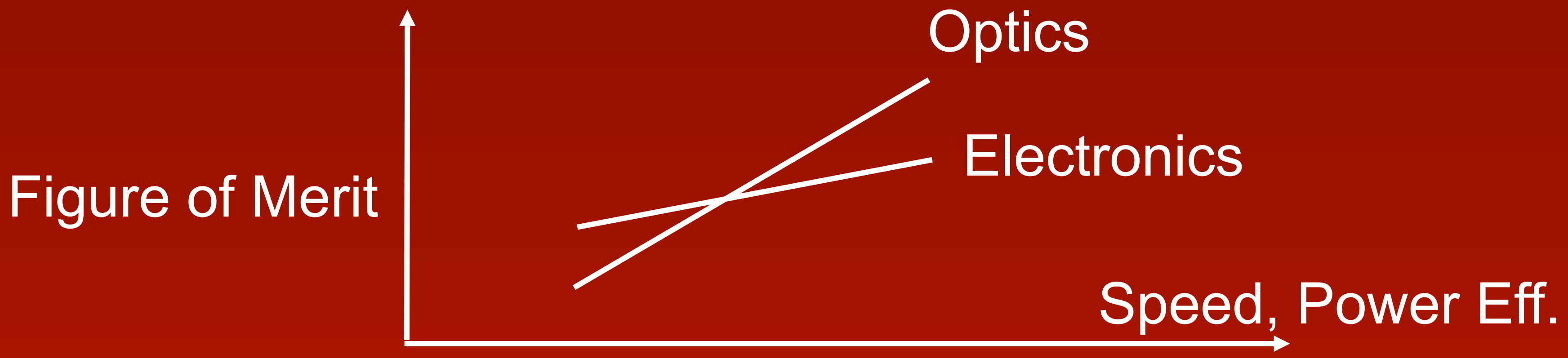
- We are, ***in general***, not experts at determining “true” power consumption.
- Power consumption of our competition (i.e., electronics) is a continuously moving target due to an army of R&D folks.
- Are we sure how we will ultimately accomplish functions optically? Probably not.
- Easier for us to compare two ***optical*** techniques.

11 Orders of Magnitude

- ***The size of an ant vs. the distance to the moon.***
- ***Rough cost comparison for electrical vs. optical transistor.***

Where, O' where, is the cross-over?

- The assumption is that optics should be better than electronics for speed, power efficiency, and transparency to bit-rate and format.
- Depends on the "function" (*simple & fast*). Very hard to latch.
- Is now the time for optical switching and signal processing applications? *"Lap(top) Burning"*



“Optics has more BW than electronics.”

- Yes, but this can’t be the only driver.
- Must be far beyond the BW of electronics, which is increasing all the time.
- Who would have predicted that computer chips would “stall” at <5-GHz clock speeds?
- What about dynamic range and reconfigurability?
- In research, we all place bets. Important to place “smart” bets.

Competing Forces:

✓*Moore’s Law: electronics is getting cheaper all the time*

✓*Jobs’ Law: BW needs are growing all the time*

Who will win? Both? Place your bets.

The Fourier Transform

Lens Design for Optical Fourier Transform Systems

K. von Bieren December 1971 / Vol. 10, No. 12 / APPLIED OPTICS 2739

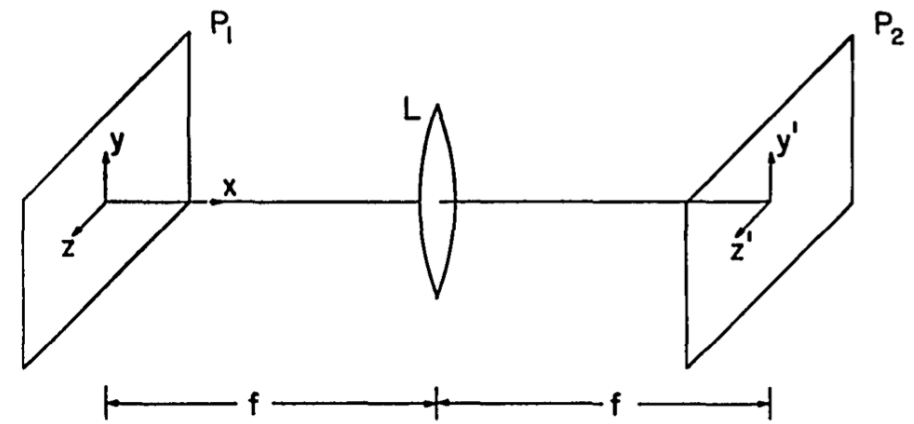
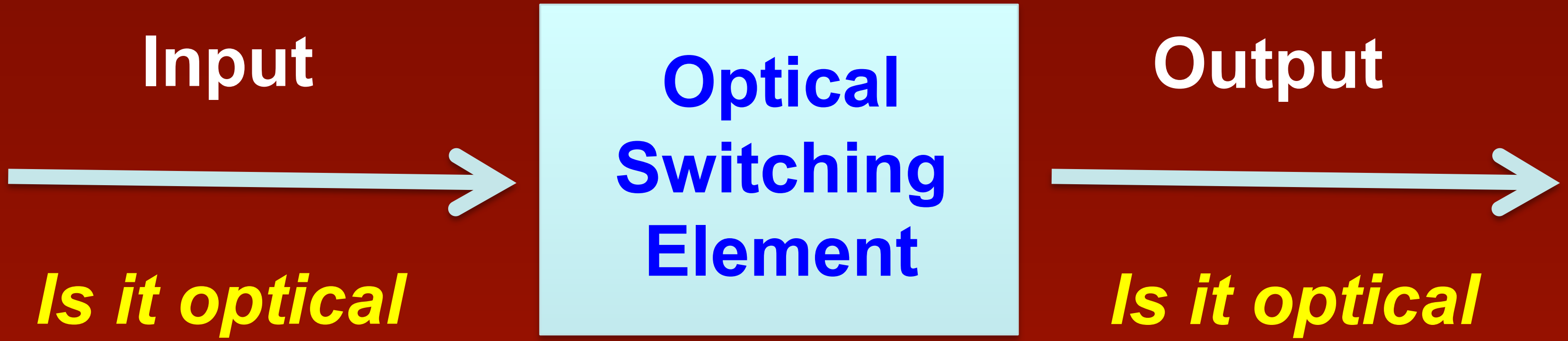


Fig. 1. Fourier transform geometry.

A lens can’t be beat for performing the most energy efficient Fourier Transform, yet ….

Boundary Conditions

Key question: Where does the signal come from and where is it going, i.e., will there be a requirement for EO or OE converters?



Input

Optical Switching Element

Output

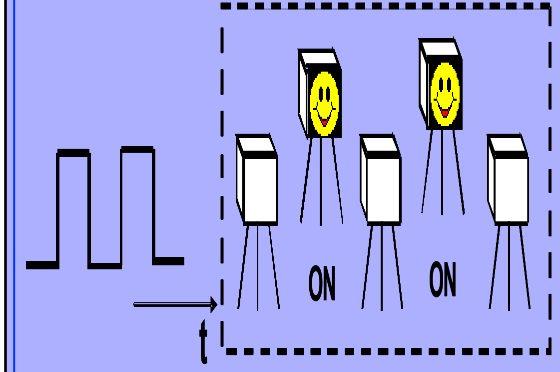
Is it optical or electrical?

Is it optical or electrical?

Electrical in and electrical out will be a hard sell.

Optics for *Select* Signal Processing Functions

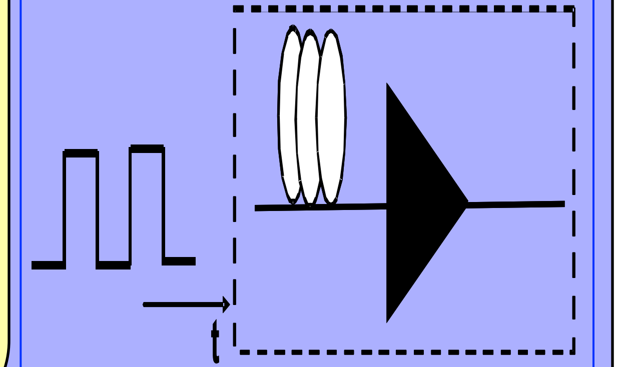
Electronics



Each bit is “seen”

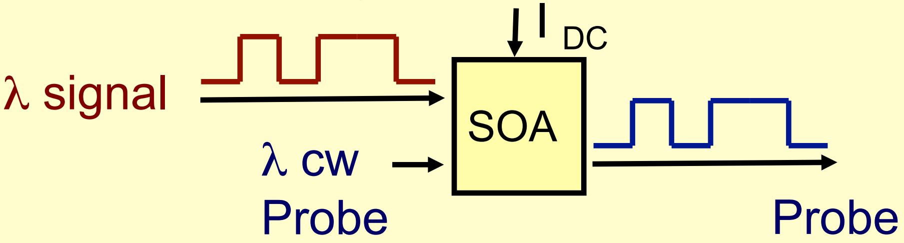
- Unlike electronics, optics doesn’t need to “touch” each bit, i.e., “switching event.”
- Good to accommodate multiple functions, multiple λ’s and reconfigurability.

Optics



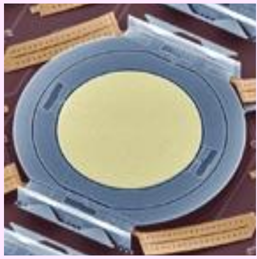
High BW pass-through

Wavelength Conversion



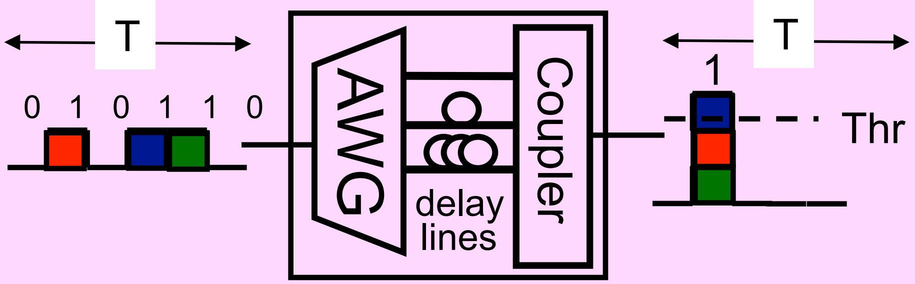
Speed limited only by carrier dynamics

Switching

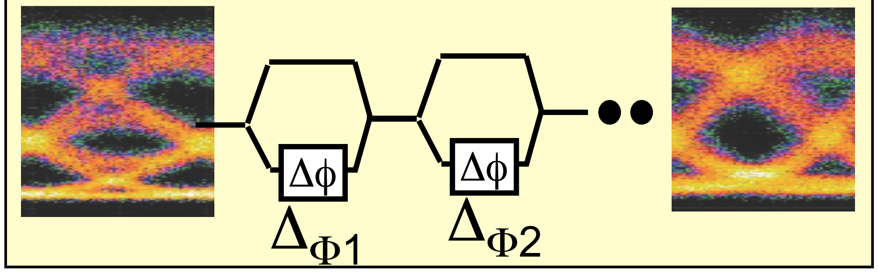


- Optical switch only alters the light path.
- Oblivious to the bit-rate.

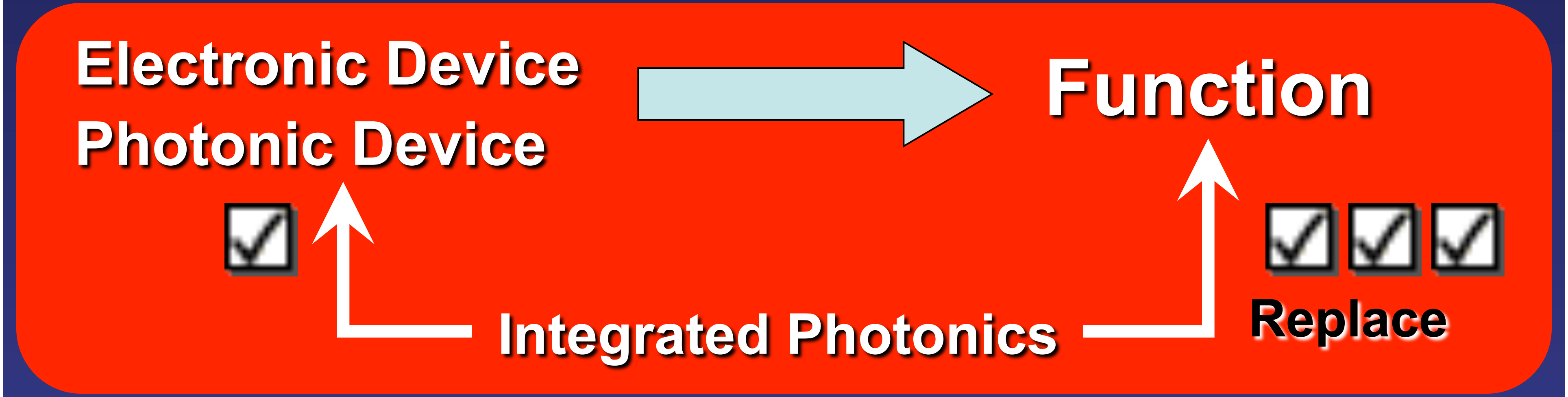
Optical Correlator



Optical Tap Delay Line Equalizer



Replace Function, Not Device



Electronic Device

Photonic Device

☑

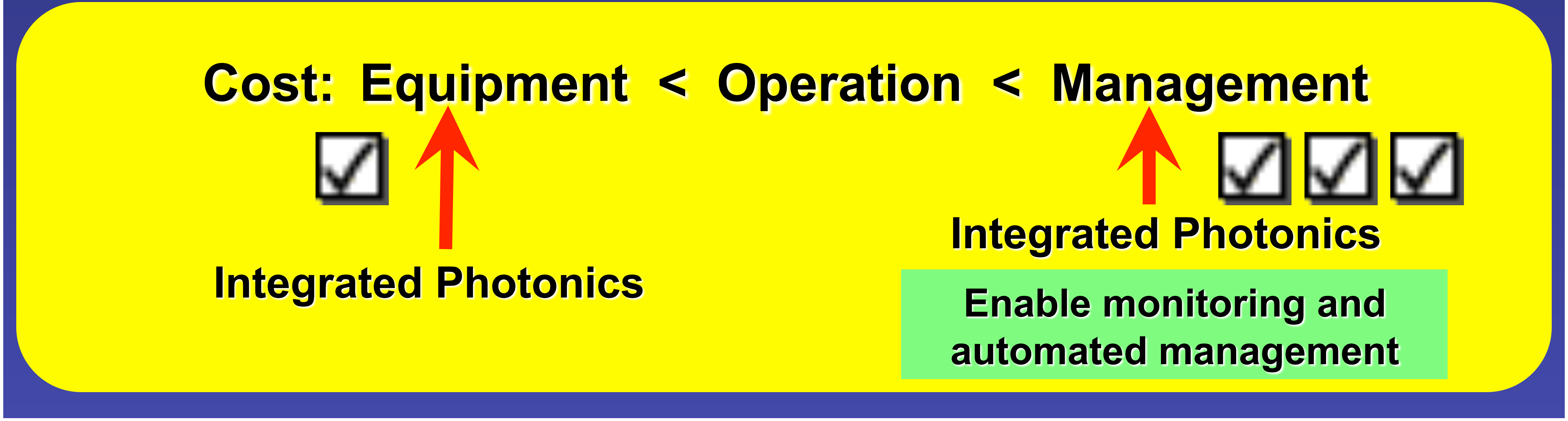
Function

☑☑☑

Integrated Photonics

Replace

Nick Tabellion, CTO, Fujitsu Softek: "The commonly used number is: For every $1 to purchase storage, you spend $9 to have someone manage it."



Cost: Equipment < Operation < Management

☑

Integrated Photonics

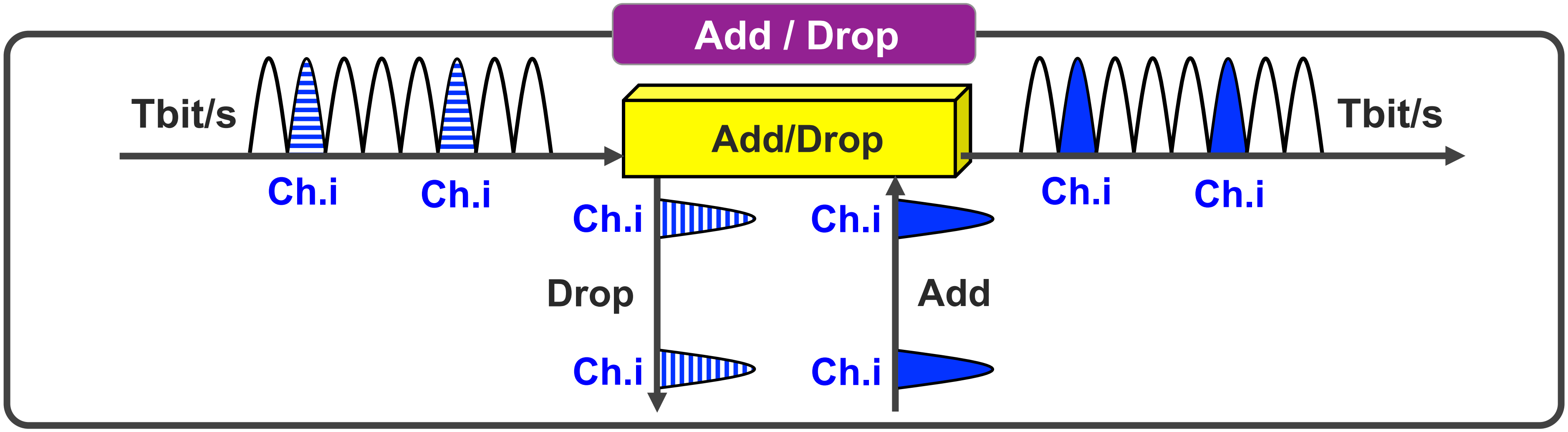
☑☑☑

Integrated Photonics

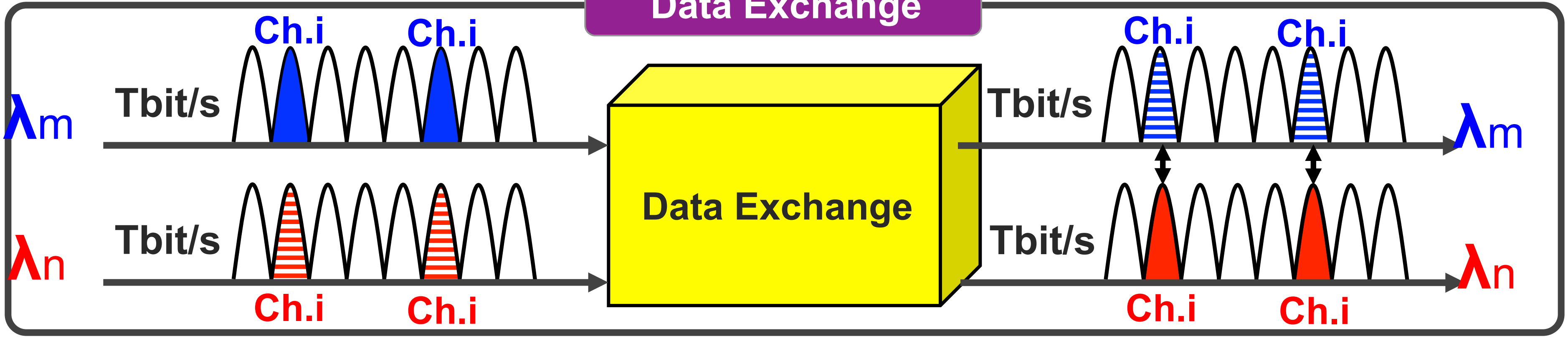
Enable monitoring and automated management

Tbit/s Grooming in Optical Domain (A. Saleh)

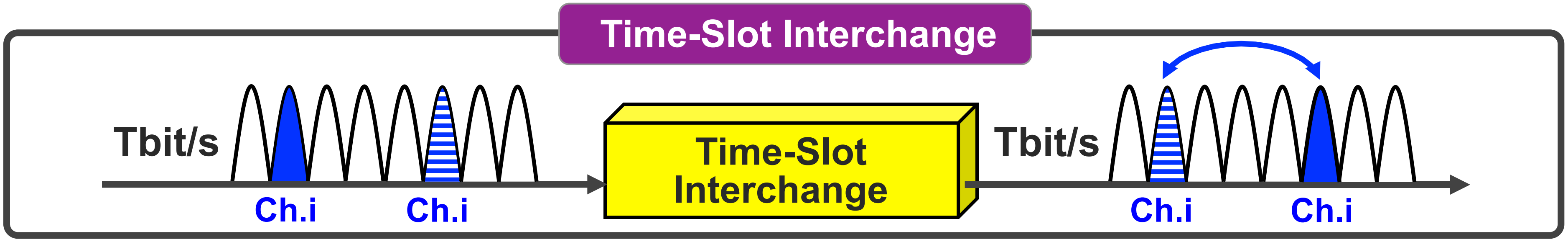
Add / Drop



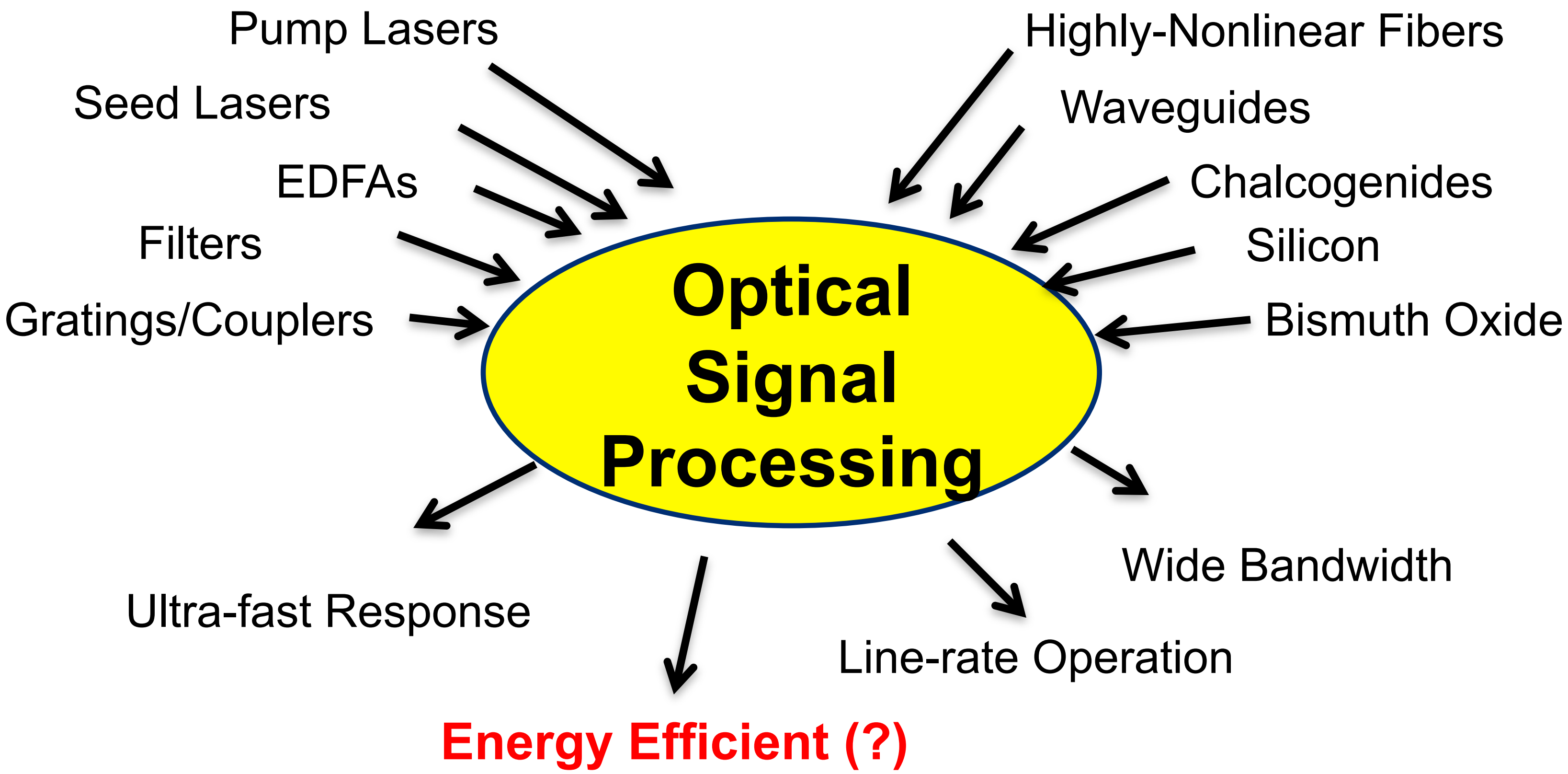
Data Exchange



Time-Slot Interchange



Energy Efficient Methods for Signal Processing



Pump Lasers

Seed Lasers

EDFAs

Filters

Gratings/Couplers

Highly-Nonlinear Fibers

Waveguides

Chalcogenides

Silicon

Bismuth Oxide

Optical Signal Processing

Ultra-fast Response

Wide Bandwidth

Line-rate Operation

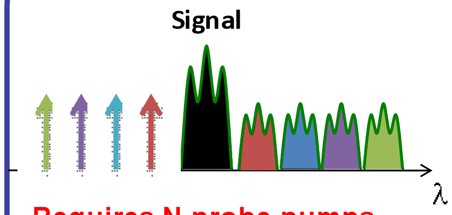
Energy Efficient (?)

Can optical signal processing be energy efficient by controlling the (i) the nonlinear medium properties, and (ii) the nonlinear process chosen for the signal processing?

Energy Efficient Methods for Signal Processing: Multicasting

Wavelength Multicasting

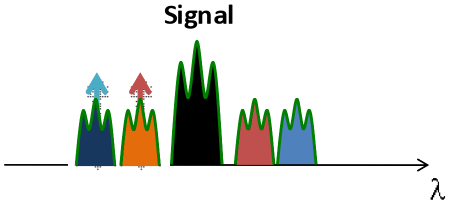
Degenerate FWM



Requires N probe pumps for N-fold multicasting

Pump powers ~N × 0.1 W

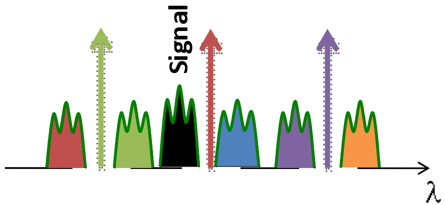
Single-Pump Parametric Amp.



Requires N/2 probe pumps for N-fold multicasting

Pump Powers ~ 1 W

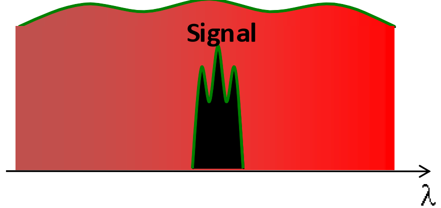
Multi-Pump FWM



Requires (N+1)/2 pumps for N-fold multicasting

Pump Powers ~ N × 0.2 W

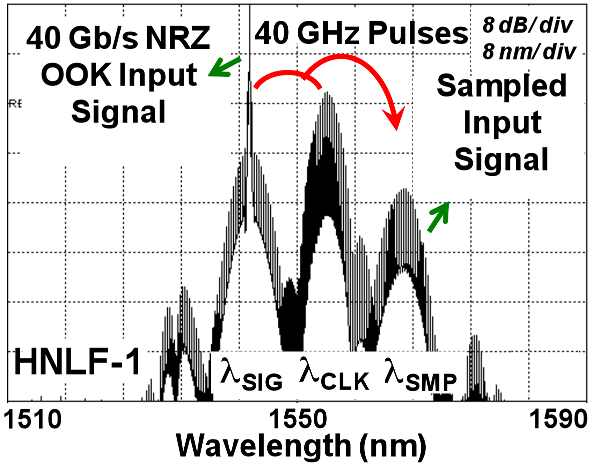
Supercontinuum Generation

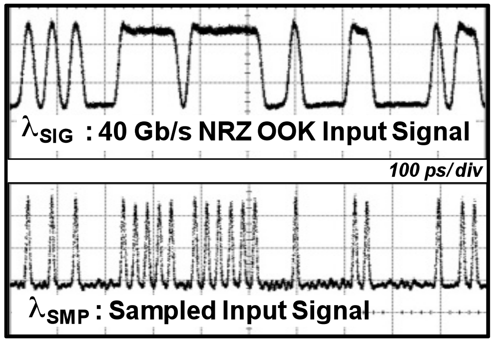


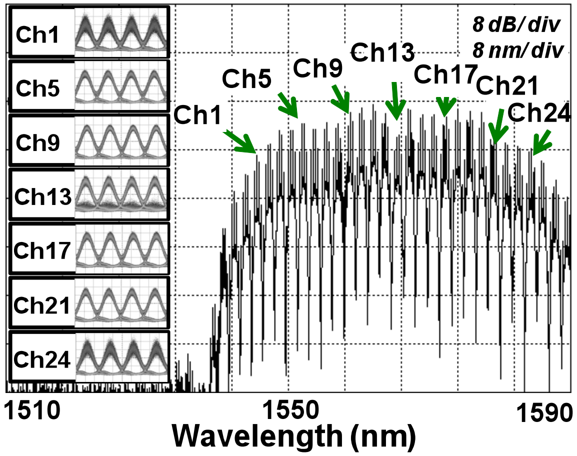
Requires a single short pulse signal and a periodic filter

Pump Power ~ 0.2 W
(Independent of N)

Wavelength multicasting with optical energy consumption of ~0.2 pJ/bit/channel can be achieved by supercontinuum generation*, while still supporting PSK based signals.







Up to 24-fold multicasting is achieved by broadcasting the a signal to a >4-THz bandwidth by supercontinuum generation using a single pump laser.

**O. Yilmaz et al. NLO PDP 2009, CLEO 2010*

Fundamental Motivation

Key question: Is your “photonics in switching” project meant to show feasibility of a function, or is it meant to show better energy efficiency than electronics?

Summary

- ✓ There are a set of key questions a researcher can ask before starting a “photonics in switching” project.
- ✓ Our competition represents an ever-moving target.
- ✓ We all place bets in research.
- ✓ There are a rich set of research problems that must be pursued to even determine if photonics can be used for certain functions, much less if it can beat electronics.

ENERGY EFFICIENCY AND GREEN NETWORKING

Mauro Macchi

July 25, 2010

OUTLINE

Energy consumption in telecom networks

Network design and energy efficiency

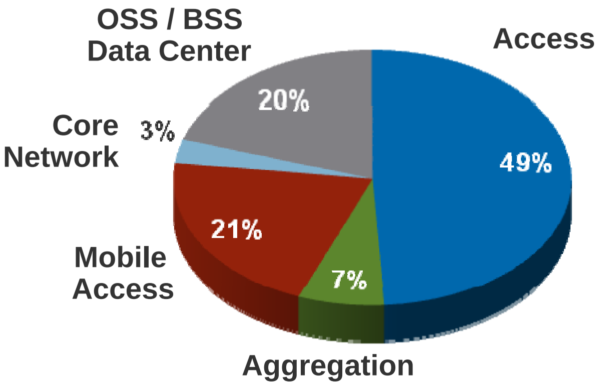
Historycal energy consumption reduction

Energy efficiency basics

Summary

ENERGY CONSUMPTION IN TELECOM NETWORKS

Where do networks consume energy?



- F.CUCCHIETTI Energy efficiency – an enabler for the Next Generation Network, Brussels 2006
- Tomas Edler EC JRC CoC Meeting 2007-04-01

Where do networks induce energy consumption?

→All connected equipment!

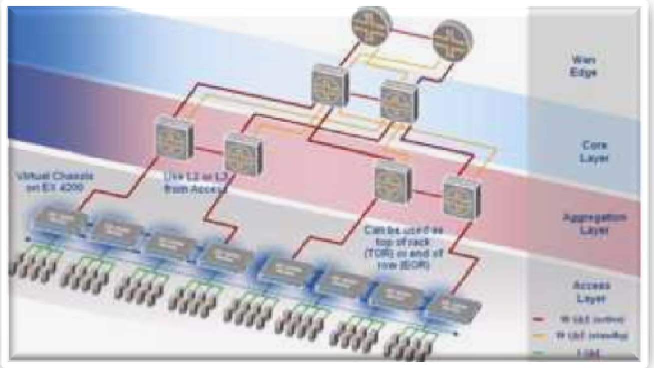
Strategies for energy savings

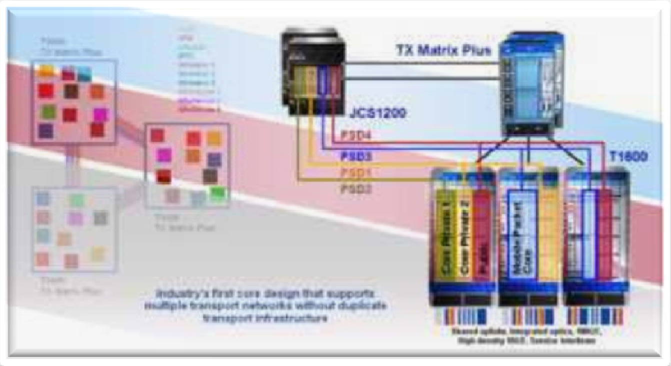
Strategy	Where
Virtualization	Data center, network
Collapsed architectures	Data center, POP
Application-specific hardware	Network core
Software-defined functionality on universal hardware	Edge and aggregation networks, Security
Energy Efficient Ethernet	Everywhere

NETWORK DESIGN AND ENERGY EFFICIENCY

Three concepts launched into market place

- EX: Virtual chassis – collapsing layers (datacenter)
- JCS/T-series: Virtualization (core network/POP)
- MX 3D/Falcon: Software-defined functionality on common hardware (edge)





Other opportunities

- Application specific hardware (e.g., Sangria)
- Capacity Management / System Utilization
- JUNOS SDK: further converging applications on fewer network elements
- Stratus: Data Center Fabric (massive simplification, single layer)

TECHNOLOGY SELECTION AND DESIGN PRINCIPLES
TECHNOLOGY AND ARCHITECTURE DRIVE ENERGY EFFICIENCY

Custom ASIC Based Design

- General purpose CPU
- NPU – fully configurable CPU arrays
- Juniper ASICs
  - Custom designed for specified feature and speed goals
  - High performance and services
  - <10 W per Gbps link

Component selection

- No TCAM
- Sub-peak power behavior part of the selection criteria
- Drive supplier roadmaps to meet our power monitoring/ control objectives
- Focus on power supply selection (ideally gold 87% efficiency)

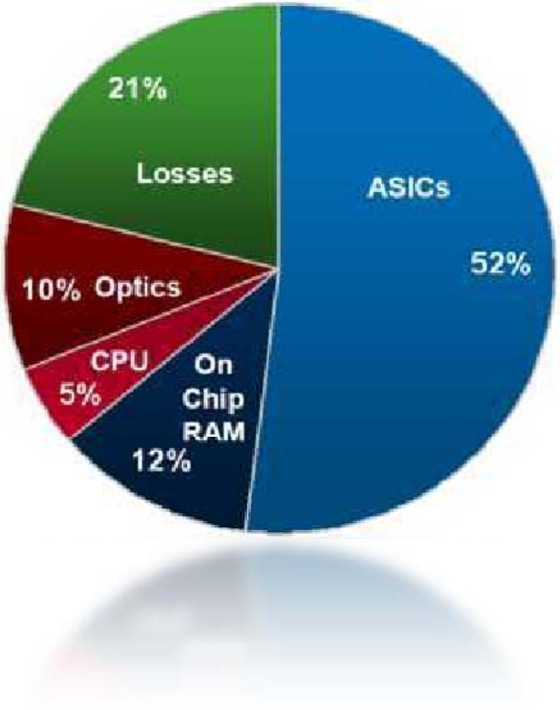
Power Management

- Enable low power system states
- Enable voltage control of ASICs at power-up

System Design

- Application-specific hardware
- Software defined functionality

Energy Consumers



www.juniper.net

ENERGY EFFICIENCY BASICS

Energy Efficiency (def.) :

Using less energy to provide the same service

(source: Wikipedia)

Network devices provide service in form of moving data

Therefore, network energy efficiency is a relation between effective throughput (in bits) and consumed energy (in Joules)

This relation exists at various levels – network element, POP design, network architecture, end-to-end network service

Question: What affects energy efficiency?

ENERGY EFFICIENCY VS OPERATIONS PER SECOND

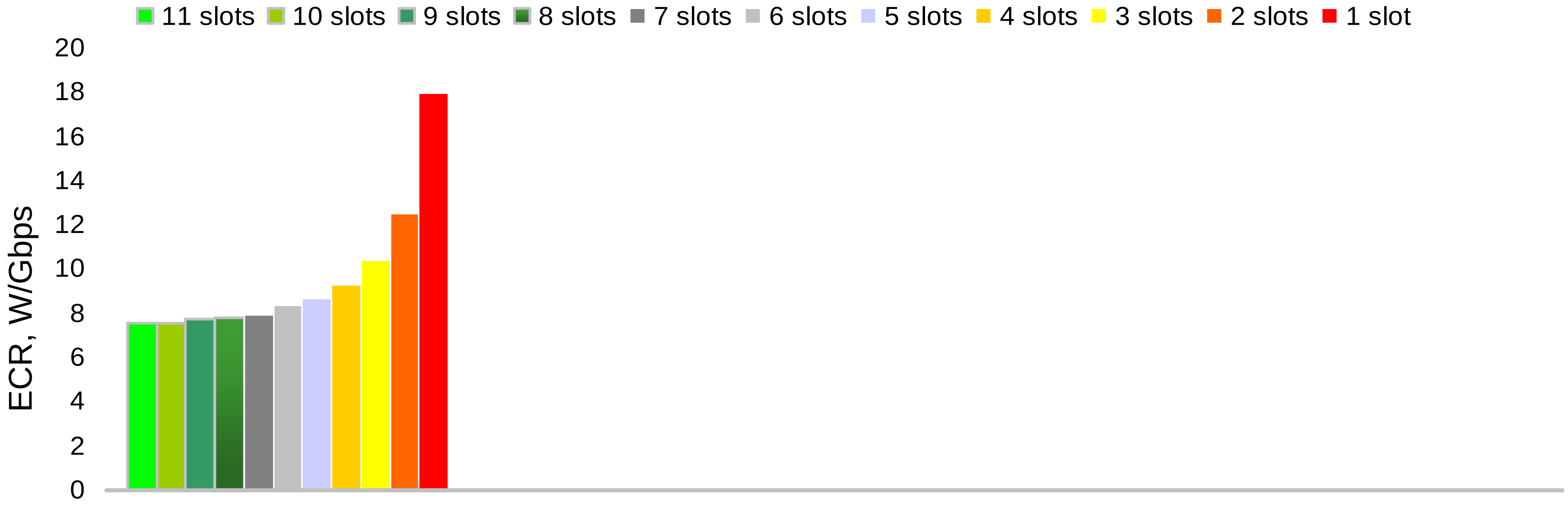
On platforms with hardware forwarding planes, packet rate and packet policy together determine the number of lookup operations per second required to maintain line-rate forwarding

Source: T1600 ECR stats for IPv4 lookups, 23x effective lookup speed change from left to right

Lookup speed does not affect efficiency significantly

ELEMENT EFFICIENCY AS FUNCTION OF CHASSIS FILL

On modular platforms, common infrastructure (power, fabric, control plane) is shared

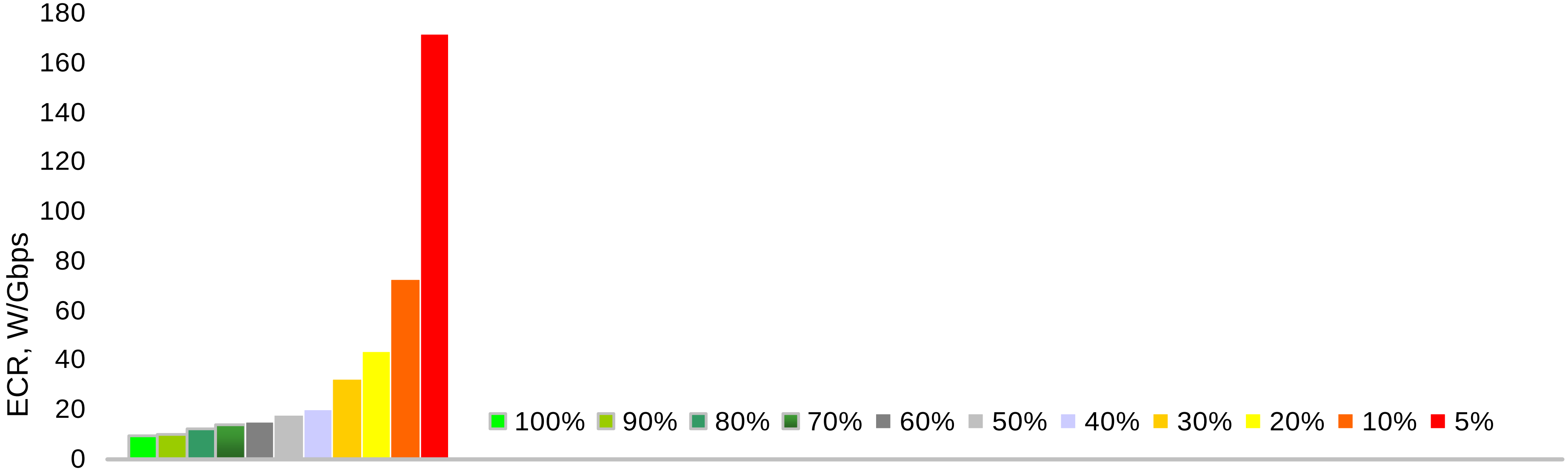


Source: MX960 chassis measured for progressively less linecards installed (11 down to 1)
Traffic is forwarded at 100% line rate (256B packet size) across all linecards in the test

Chassis utilization below 30% significantly affects ECR

ELEMENT EFFICIENCY AS FUNCTION OF UTILIZATION

In the field, a network device may have variable utilization levels, dependent on service type and network activity.

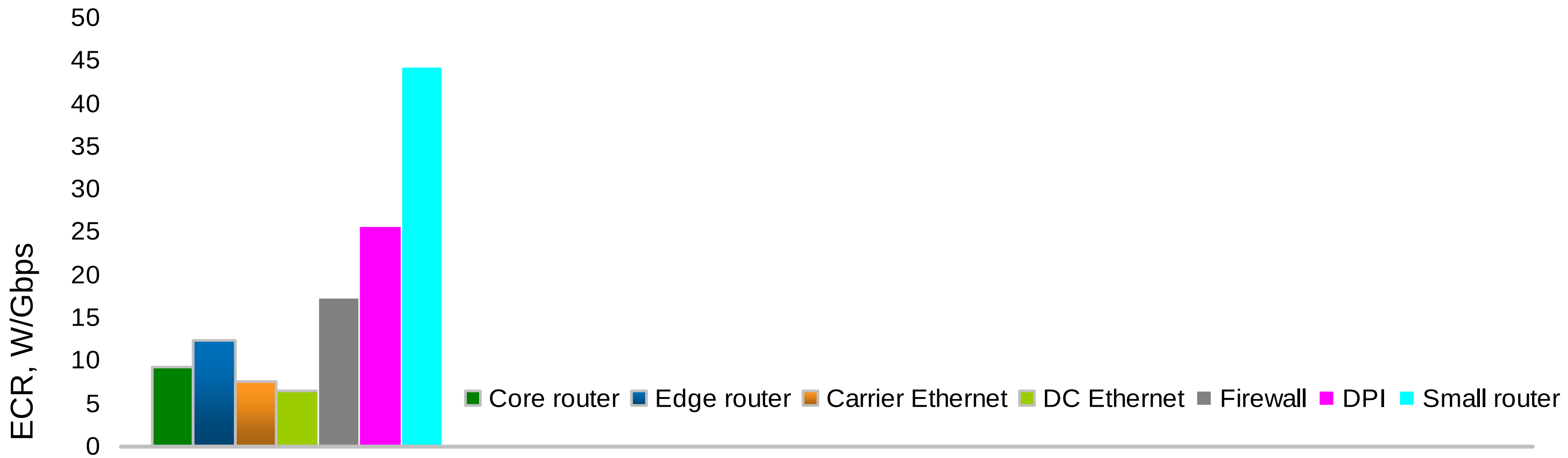


Source: T1600 ECR vs effective utilization (offered load varies from 100 to 5 percent)

Traffic utilization below 40% significantly affects ECR

ELEMENT EFFICIENCY AS FUNCTION OF DEVICE ROLE

On platforms with hardware forwarding planes, packet size and packet policy determines the number of lookup operations per second (in Mpps)



Sample efficiency ratings for various network product classes (projected data)

Efficiency improves with scale and lower packet touch

ELEMENT EFFICIENCY AS FUNCTION OF TECHNOLOGY

	M40	M160	T640	T1600
Year	1998	2000	2002	2007
Slot Bandwidth	3Gbps	10Gbps	40Gbps	100Gbps
System Throughput	40Gbps	160Gbps	640Gbps	1600Gbps
Fabrication	180nm	180nm	130nm	90nm
ECR, Watts/Gbps	76.9	33.3	14.08	9.34

Historical improvements in parallel with silicon progress (Dennard's Scaling Theory)

PHOTONIC MODULES EFFICIENCY

	MSA 300 Tunable	10 Tunable XFP	10x10G DWDM CFP	100G ULH DP-QPSK
Year	2005	2008	2010	2011
Technology	Discrete laser + LiNbO3 mod	Integrated laser+mod InP	Integrated 10Tx + 10 Rx InP over SiO2	Discrete laser + LiNbO3 mod
ASIC	N.A.	N.A.	N.A.	40nm
Reach	1000km	700km	500km	2000km
Power consumption	8W	3.5W	25W	50W
Power/ 100km*10Gbs	0.8	0.5	0.5	0.025

- Enabler for power reduction
  - Photonic integration
  - Increase bit rate

SUMMARY – NETWORK ELEMENT LEVEL

The following variables affect platform efficiency:

- Technology and architecture (vendor-dependent)
- Chassis fill level (higher is better)
- Traffic utilization (higher is better)
- Platform role (the simpler the function the better)
- Photonic integration and high bit rate
- Packet size does not affect efficiency significantly

Vendor selection and capacity planning are most critical

SUMMARY

Energy consumption and energy efficiency in telecom networks and equipment is a complex issue

Way to improve energy efficiency

- Enabling new architectures to reduce energy consumption
- System architecture and design
- Technology selection and design principles
- Driving standards and awareness

everywhere

Energy Footprint and Opportunities of ICT Networks.

Loukas Paraschis
Cisco

Abstract

The global energy consumption of the ICT networks, despite the significant global IP traffic growth (> 50% CAGR), has remained relatively small (2-3%), primarily dominated by access networks, and the increasingly computationally-intensive data-centers.

Electronic-IC and optical technology, and network architectural advancements have helped, and could further help the ICT energy footprint containment.

Moreover, “smart” networking, primarily advancements in “smart-grid” power distribution, transportation, and buildings, promises significant (> 10%) improvements in the overall energy consumption.

Cisco, for further details contact loukas@cisco.com

Outline

- **ICT Network Energy Footprint**

  Still small (<3 % of global) and mostly due to access, and DC

- **NGN Technology & Architecture Advancements**

  CMOS, Optical, IP-over-DWDM, FTTH

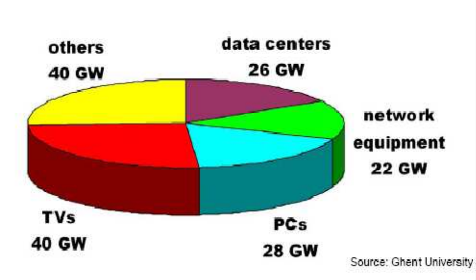
- **“Smart” NGN Energy efficiencies**

  Smart-grid, transportation, buildings

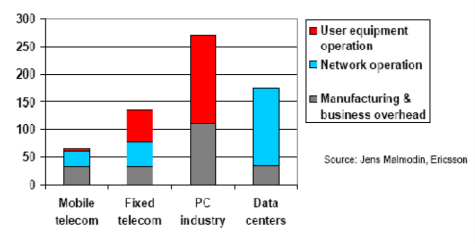
- **Summary**

ICT Energy Footprint

2006 USA	GW
All Electricity	350
Building	250
Electronics	25
Telecom Network	*20*



Source: Ghent University



Source: Jens Malmodin, Ericsson

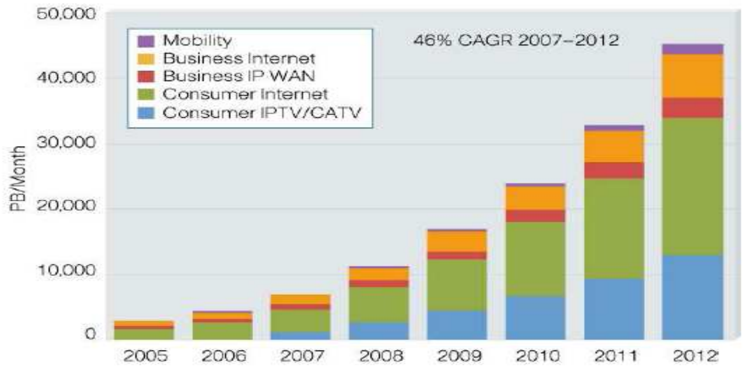
ICT ~ 8% Energy Footprint

Network around 1% mainly from Access Network (> 60% today).

Data Centers 1-2% (mainly from servers).

IP Networks Growth to the Zettabyte Era

Figure 1. Cisco Forecasts 44 Exabytes per Month of IP Traffic in 2012



For more details, see the paper entitled "Cisco Visual Networking Index – Forecast and Methodology 2007–2012."

Source: Cisco, 2008

http://www.cisco.com/en/US/netsol/ns827/networking_solutions_sub_solution.html

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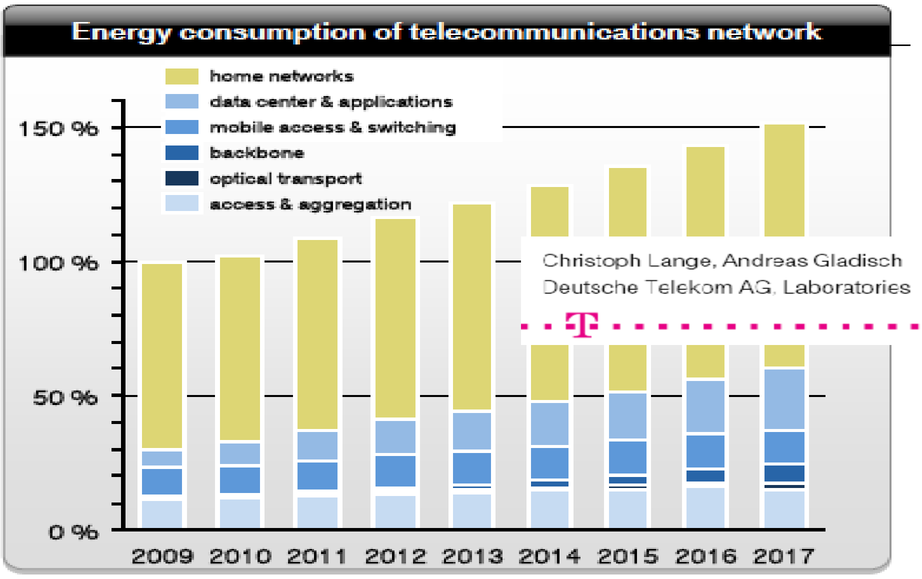
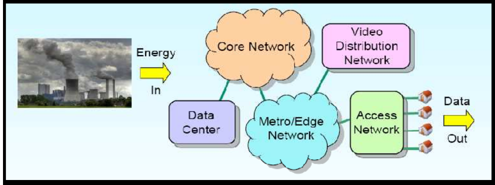
Deutsche Telecom Analysis *(IEEE OFC March 2010)*

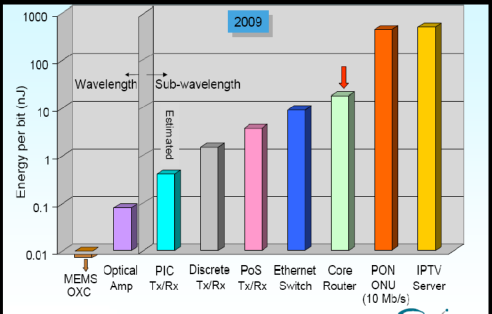


Christoph Lange, Andreas Gladisch
Deutsche Telekom AG, Laboratories

Telecom Energy Analysis

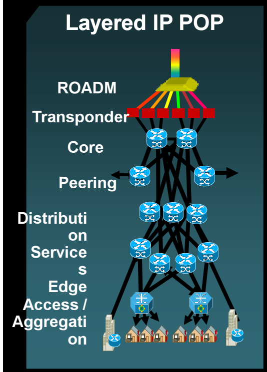
R. Tukcer et. al. IEEE OFC 2009

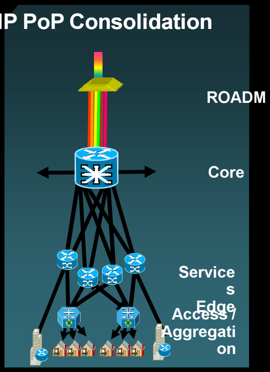


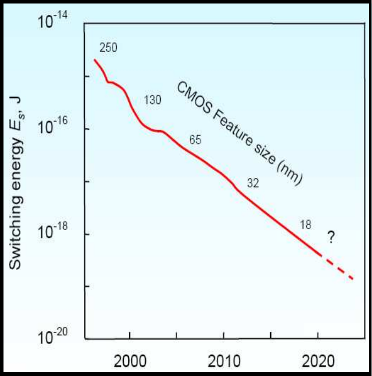


- **Optical better than Electronics**
- **Servers (500 nJ/bit) 10x more**
- **Planning very critical;**
  - **– Scalable platforms and capacity utilization (ASICs, interconnects, chassis fill factor)**
  - **– Converged architectures**
- **Access > 60% of consumption**

Technology Benefits for Network Systems

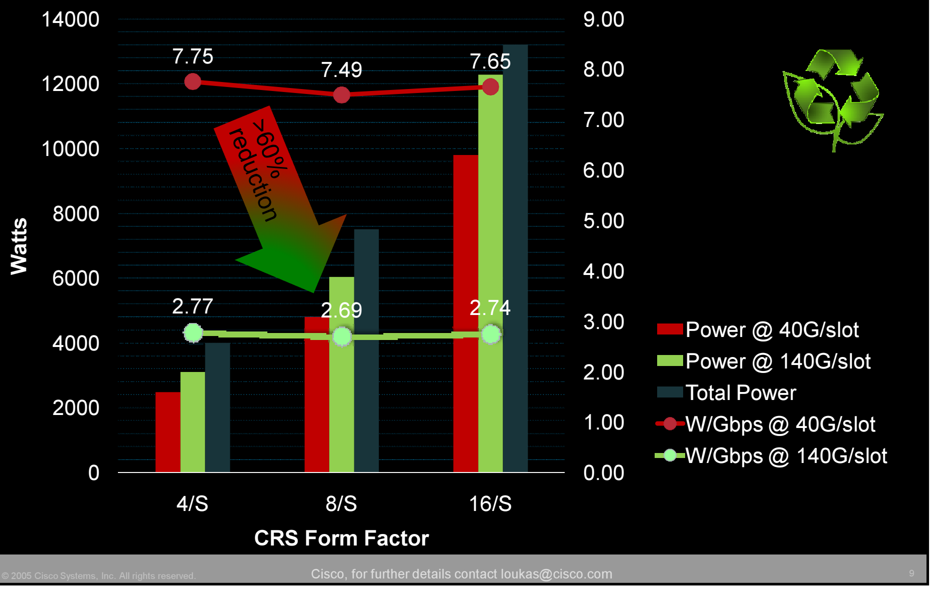






Technology advancements = Energy benefits in Scaling Network Systems:
- Electronics: CMOS 40% CAGR, ASIC
- DWDM (EDFA, ROADM, PIC, 100G, WC) > 50% CAGR
- System Innovation (sleep mode, green mode etc)

CMOS Advancement - Core Routing System



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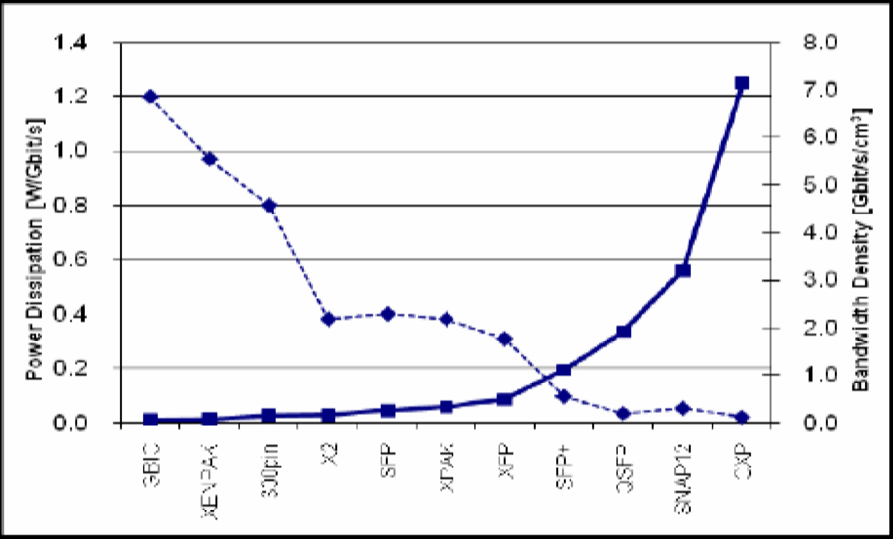
Optics energy and density Innovation

J. Eng, Finisar, OIDA Annual Forum, San Jose, CA December 2009



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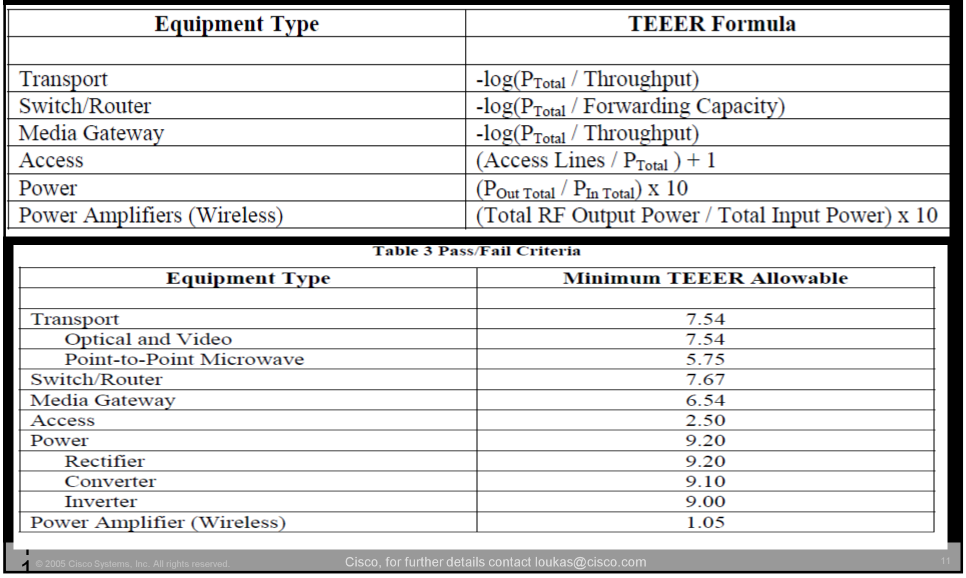
VZ TEEER “benchmarking’



Equipment Type	TEEER Formula
Transport	-log(P_{Total} / Throughput)
Switch/Router	-log(P_{Total} / Forwarding Capacity)
Media Gateway	-log(P_{Total} / Throughput)
Access	(Access Lines / P_{Total}) + 1
Power	($P_{Out\ Total}$ / $P_{In\ Total}$) x 10
Power Amplifiers (Wireless)	(Total RF Output Power / Total Input Power) x 10

Table 3 Pass/Fail Criteria

Equipment Type	Minimum TEEER Allowable
Transport	7.54
Optical and Video	7.54
Point-to-Point Microwave	5.75
Switch/Router	7.67
Media Gateway	6.54
Access	2.50
Power	9.20
Rectifier	9.20
Converter	9.10
Inverter	9.00
Power Amplifier (Wireless)	1.05

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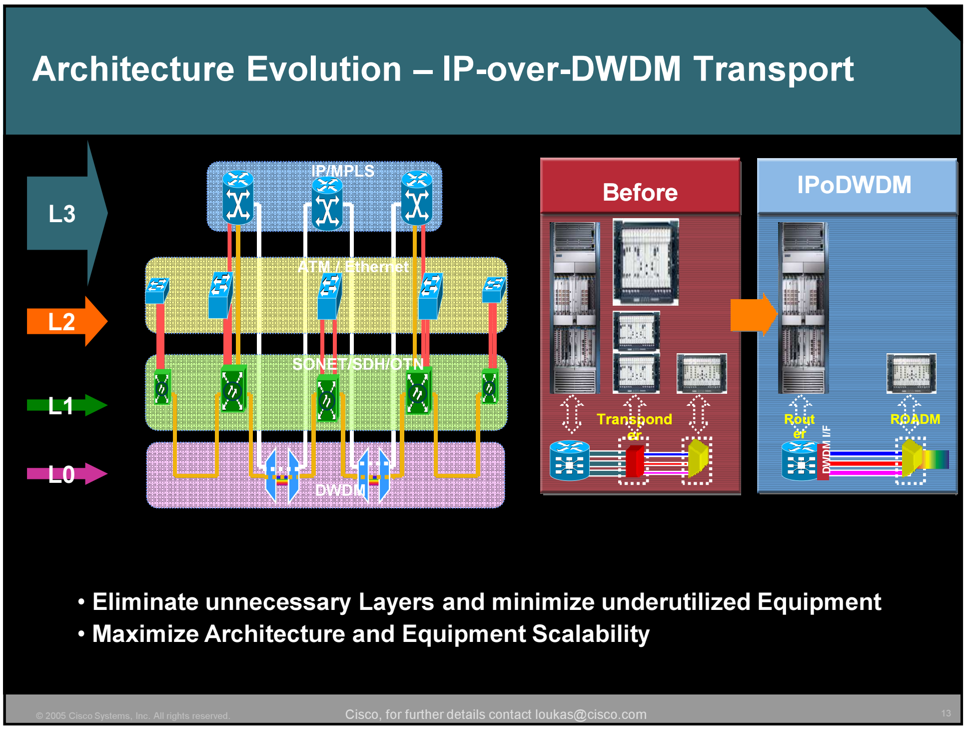
Benchmarking ‘Green Networks’

- Bit-level efficiency (e.g. nJ/bits): this is most often used
  - E.g. TEERS VZ.TPR.9205 (Issue 4, August 2009)
  - BUT often incorrectly bias the efficiency towards ‘wasted bits’
- Energy/Throughput: this is a better definition than above, but also counts wasted packets (e.g. TCP resend).
- Energy/Goodput: this is most accurate definition by including what application sees as useful work for the given amount of energy; *however still lacks the lifetime analysis.*



Architecture Evolution – IP-over-DWDM Transport

- Eliminate unnecessary Layers and minimize underutilized Equipment
- Maximize Architecture and Equipment Scalability

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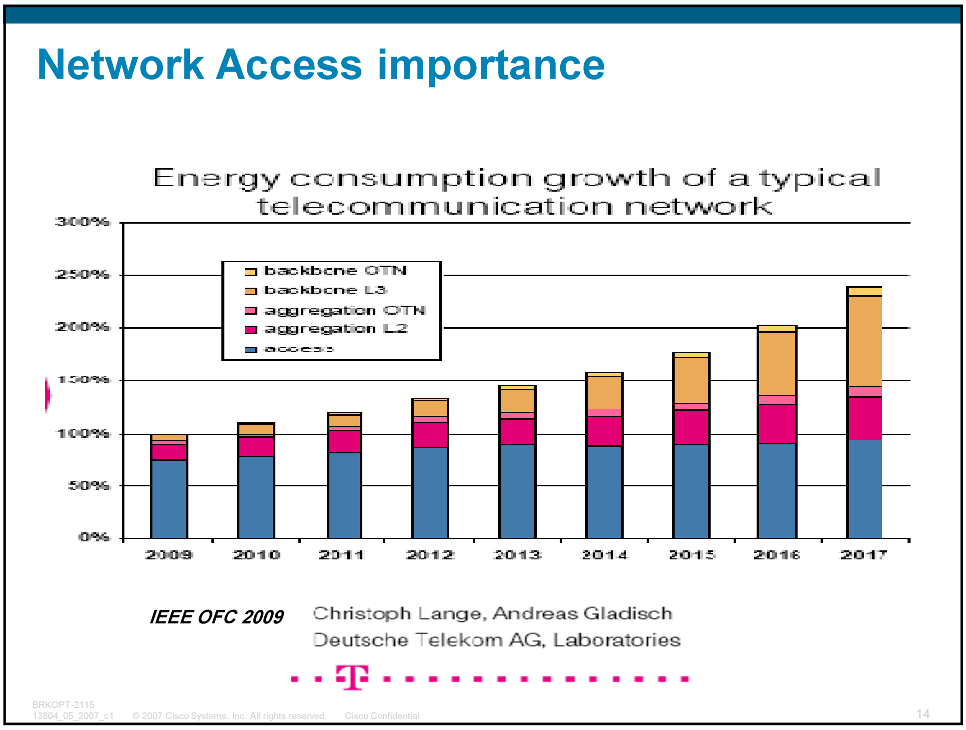


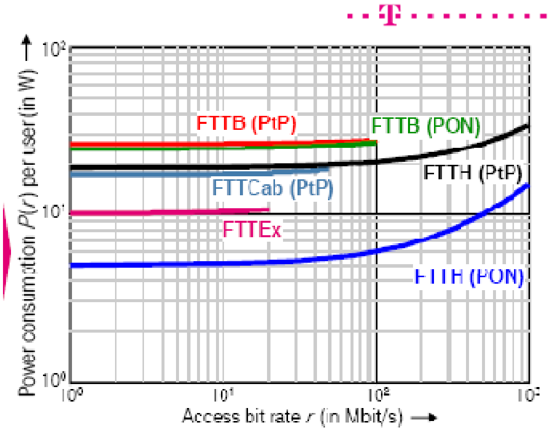
Network Access importance

IEEE OFC 2009

Christoph Lange, Andreas Gladisch
Deutsche Telekom AG, Laboratories

Architecture Evolution – FTTH Access

Christoph Lange, Andreas Gladisch
Deutsche Telekom AG, Laboratories



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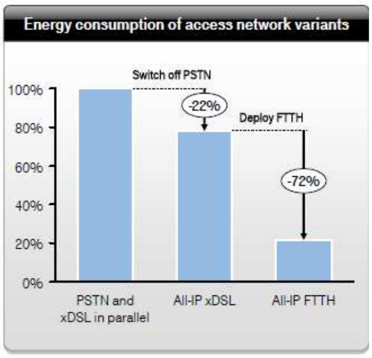
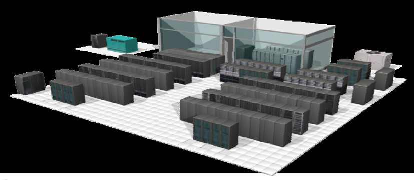
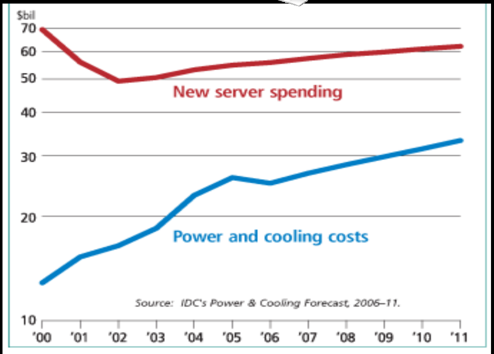


IEEE OFC 2010

Data Center Power & Cooling Cost raises fast





Source: IDC's Power & Cooling Forecast, 2006–11.

- **Servers (500 nJ/bit) 10x more than other equipment**
- **High Power & cooling cost (often exceeding server cost)**
- **Value of DC-3.0 advancements:**
  - **– Architectures Convergence**
  - **– Consolidation, Virtualization**
  - **– Scalable platforms**
  - **– *Use of OPTICS as much as possible; optical interconnects!***

Motivation for Data Center Evolution

- Scaling
- *Efficiency utilization (CapEx)*
- Operational simplicity (OpEx)
- *Power management (CapEx/OpEx)*
- Interconnectivity
- Flexible Service Delivery

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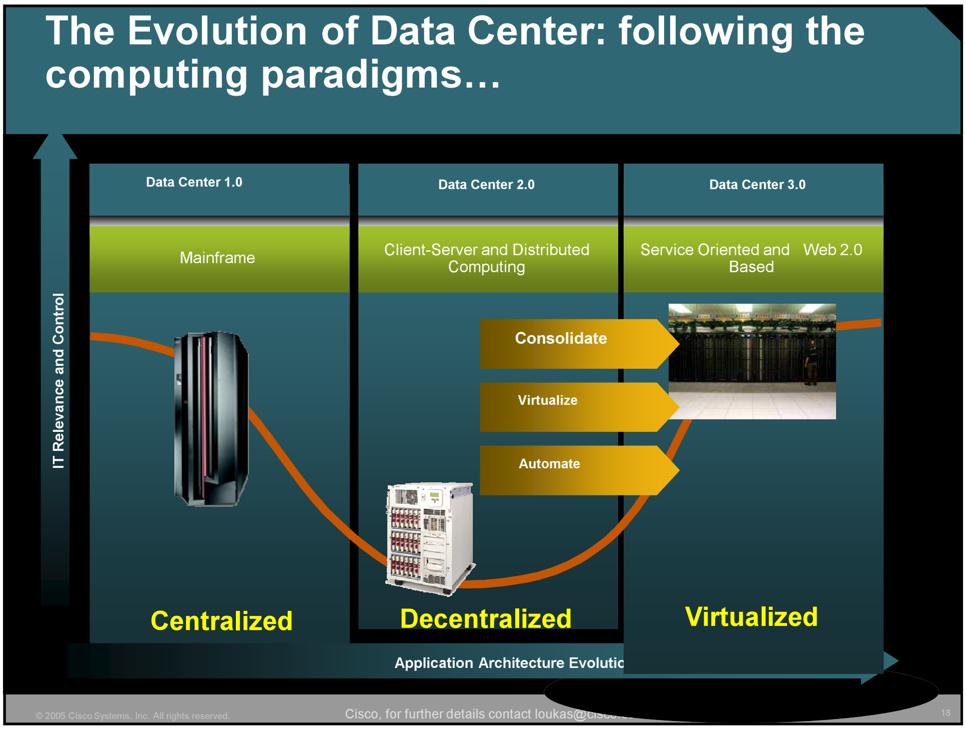


The Evolution of Data Center: following the computing paradigms…

Data Center 1.0	Data Center 2.0	Data Center 3.0
Mainframe	Client-Server and Distributed Computing	Service Oriented and Web 2.0 Based
Centralized	Decentralized	Virtualized

Consolidate

Virtualize

Automate

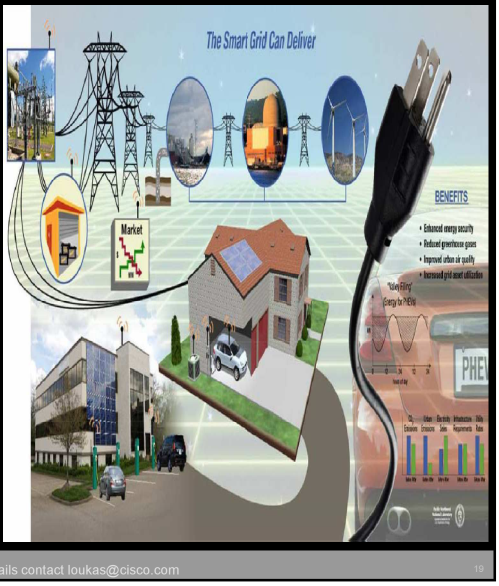
IT Relevance and Control

Application Architecture Evolutio

Cisco, for further details contact loukas@cisc

“Intelligent” NGN Efficiencies

- **“Smart” NGN efficiencies up to 30% of Energy Footprint**
- Power distribution “Smart-Grid”
- Transportation, and Buildings
- **“Intelligent Urbanization”**
  - **Top 20 Cities use 75% of WW energy**
- **Network as the 4th utility**



Summary

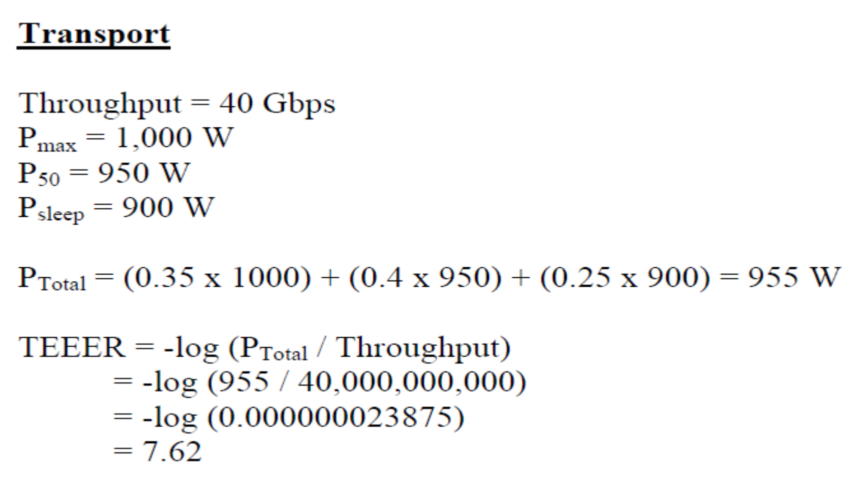
- **ICT Networking Energy still small (<3 %), mostly due to access and growth in Data-Centers**
- **NGN Technology & Architecture Advancements (CMOS, Optical, IP-over-DWDM, FTTH) have helped Energy footprint, in spite the > 50% Traffic CAGR**
- **“Smart” NGN, mostly in Power distribution (Smart-Grid), transportation, and buildings, could enable significant energy efficiencies (> 10%)**

Thank you

Looking forward to your questions/comments

Please contact:
Loukas Paraschis loukas@cisco.com
Business Development Manager, Emerging Markets

Calculation Examples of EEI (TEEER)-Transport



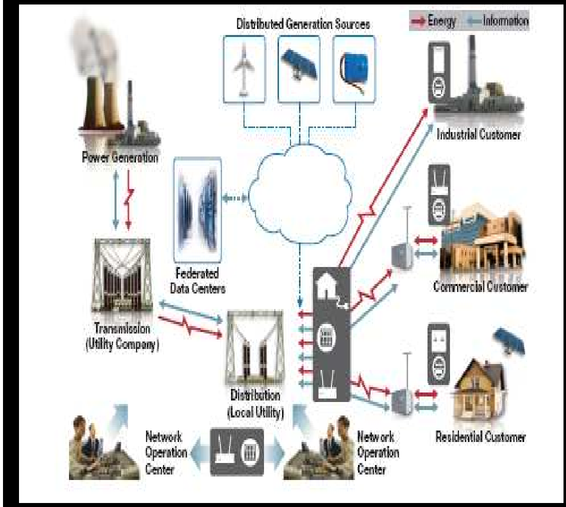
Transport

Throughput = 40 Gbps
P_{max} = 1,000 W
P_{50} = 950 W
P_{sleep} = 900 W

P_{Total} = (0.35 x 1000) + (0.4 x 950) + (0.25 x 900) = 955 W

TEEER = -log (P_{Total} / Throughput)
= -log (955 / 40,000,000,000)
= -log (0.000000023875)
= 7.62

Smart Grid Infrastructure



- Advanced connectivity and intelligence/control of Power Distribution network (100Ks nodes)
- Connect 200M C&I and 2B residential nodes
- Multiple Applications:
  - Monitoring
  - Metering
  - Renewable management
  - Demand side management

Integrated Photonics Research, Silicon and Nano Photonics (IPR)/Photonics in Switching (PS) Agenda of Sessions

Sunday, July 25	**Cypress I & II**	**Big Sur**	**Cypress III**	**Cypress IV**
1:00 p.m.–6:30 p.m.	**Registration Open,** *Steinbeck Foyer*			
2:00 p.m.–4:00 p.m.			**Energy Efficient Networking and Systems Workshop**	**Integrated Photonic Technologies and Systems: Current Status, Future Prospect, and Enabling Applications Workshop**
4:00 p.m.–4:30 p.m.	**Coffee Break,** *Cypress Foyer*			
4:30 p.m.–6:30 p.m.			**Energy Efficient Networking and Systems Workshop (continued)**	**Integrated Photonic Technologies and Systems: Current Status, Future Prospect, and Enabling Applications Workshop (continued)**
6:30 p.m.–7:30 p.m.	**Get-Together Party,** *Location to Be Announced On-Site*			
Monday, July 26				
7:30 a.m.–6:30 p.m.	**Registration Open,** *Steinbeck Foyer*			
8:30 a.m.–8:45 a.m.	**Opening Remarks,** *Dolphins Ballroom*			
8:45 a.m.–10:25 a.m.	**JMA • Joint Plenary Session I,** *Dolphins Ballroom*			
10:30 a.m.–11:00 a.m.	**Coffee Break/Exhibits Open,** *Cypress Foyer*			
11:00 a.m.–12:30 p.m.	**IMA • Quantum Nanophotonics**	**IMB • CMOS-Compatible Laser Sources**	**PMA • Symposium on Optics in Computing I,** *Cypress III & IV*	
12:30 p.m.–2:00 p.m.	**Lunch (on your own)**			
2:00 p.m.–4:00 p.m.	**IMC • Nanocavities and Nanoresonators**	**IMD • Modeling and Simulation I: Methods (ends at 3:30 p.m.)**	**PMB • Symposium on Optics in Computing II,** *Cypress III & IV*	
4:00 p.m.–4:30 p.m.	**Coffee Break/Exhibits Open,** *Cypress Foyer*			
4:30 p.m.–6:30 p.m.	**IME • Applications of Resonator Devices**	**IMF • Special Symposium on Optomechanics (starts at 4:00 p.m.)**	**PMC • Optical Interconnects**	**PMD • Grooming and Flow Switching**
6:30 p.m.–7:30 p.m.	**Welcome Reception,** *Dolphins Ballroom*			
Tuesday, July 27				
7:45 a.m.–6:00 p.m.	**Registration Open,** *Steinbeck Foyer*			
8:45 a.m.–10:25 a.m.	**JTuA • Joint Plenary Session II,** *Dolphins Ballroom*			
10:30 a.m.–11:00 a.m.	**Coffee Break/Exhibits Open,** *Cypress Foyer*			
11:00 a.m.–12:30 p.m.	**ITuA • Nanophotonic Lasers and Photodetectors**	**ITuB • Plasmonics and Applications**	**PTuA • Silicon Photonics (ends at 12:45 p.m.)**	**PTuB • Energy Efficient Net (ends at 12:45 p.m.)**
12:30 p.m.–2:00 p.m.	**Lunch (on your own)**			
2:00 p.m.–4:00 p.m.	**ITuC • Monolithic Photonic Integration in Indium Phosphide**	**ITuD • Modeling and Simulation II: Nanophotonics and Plasmonics**	**PTuC • Optical Packet Switching, Memory, Flip-Flops**	**PTuD • High Capacity Transparent Network Architecture**
4:00 p.m.–4:30 p.m.	**Coffee Break/Exhibits Open,** *Cypress Foyer*			
4:00 p.m.–6:00 p.m.	**JTuB • Joint Poster Session,** *Dolphins Ballroom*			
6:00 p.m.	**Off-Site Dinner**			

	Cypress I & II	Big Sur	Cypress III	Cypress IV
Wednesday, July 28				
7:30 a.m.–6:00 p.m.	**Registration Open,** *Steinbeck Foyer*			
8:30 a.m.–10:30 a.m.	**IWA • Optical Modulators**	**IWB • Modeling and Simulation III: Photonic-Crystal and Waveguide Devices**	**PWA • Signal Processing I**	**PWB • Optical Switches, Wavelength Conversion**
10:30 a.m.–11:00 a.m.	**Coffee Break/Exhibits Open,** *Cypress Foyer*			
11:00 a.m.–12:30 p.m.	**IWC • All-Optical Signal Processing**	**IWD • Modeling and Simulation IV: Optoelectronics**	**PWC • Terabit/s, OFDM**	**PWD • Signal Processing II**
12:30 p.m.–2:00 p.m.	**Lunch (on your own)**			
2:00 p.m.–4:00 p.m.	**IWE • Photonic Nanowires and Crystals**	**IWF • Monolithic and Hybrid Photonic Integration in Silicon**	**PWE • Nanophotonics, Lasers, Flip-Flops**	**PWF • RF/Optical, PON, WAN Testbed**
4:00 p.m.–4:30 p.m.	**Coffee Break/Exhibits Open,** *Cypress Foyer*			
4:30 p.m.–6:30 p.m.	**IWG • Nonlinear Nanophotonics**	**IWH • Modeling and Simulation V: Waveguides**	**PWG • Closing Session**	
6:30 p.m.–7:30 p.m.	**IWI • IPR Postdeadline Session,** *Cypress I & II*			

• Sunday, July 25 •

1:00 p.m.–6:30 p.m., Registration Open, *Steinbeck Foyer*

Cypress III

2:00 p.m.–4:00 p.m.

Energy Efficient Networking and Systems Workshop

Cypress IV

2:00 p.m.–4:00 p.m.

Integrated Photonic Technologies and Systems: Current Status, Future Prospect, and Enabling Applications Workshop

4:00 p.m.–4:30 p.m., Coffee Break, *Cypress Foyer*

Cypress III

4:30 p.m.–6:30 p.m.

Energy Efficient Networking and Systems Workshop (continued)

Cypress IV

4:30 p.m.–6:30 p.m.

Integrated Photonic Technologies and Systems: Current Status, Future Prospect, and Enabling Applications Workshop (continued)

6:30 p.m.–7:30 p.m., Get-Together Party, ***Location to Be Announced On-Site***

• Monday, July 26 •

7:30 a.m.–6:30 p.m., Registration Open, *Steinbeck Foyer*

Dolphins Ballroom

8:30 a.m.–8:45 a.m.

Opening Remarks

Andrea Melloni; Politecnico di Milano, Italy, **IPR General Chair**
Liming Zhang; Bell Labs, Lucent Technologies, USA, **IPR General Chair**
Ken-ichi Kitayama; Osaka Univ., Japan, **PS General Chair**
David T. Neilson; Bell Labs, Alcatel-Lucent, USA, **PS General Chair**
S. J. Ben Yoo; Univ. of California at Davis, USA, **PS General Chair**

8:45 a.m.–10:25 a.m.

JMA • Joint Plenary Session I

Andrea Melloni; Politecnico di Milano, Italy, Presider
Liming Zhang; Bell Labs, Lucent Technologies, USA, Presider
Ken-ichi Kitayama; Osaka Univ., Japan, Presider
David T. Neilson; Bell Labs, Alcatel-Lucent, USA, Presider
S. J. Ben Yoo; Univ. of California at Davis, USA, Presider

JMA1 • 8:45 a.m. **Plenary**

Future Computing Systems, ***Terry Morris;*** *Hewlett-Packard Co., USA.* Radical departures from traditional photonic packaging concepts are indicated when considering photonic interconnections within high-volume, low-cost data center products. Cost considerations dictate a very different photonic infrastructure, while volume opportunities abound.

JMA2 • 9:35 a.m. **Plenary**

Recent Advances in Plasmonic Device Technologies, ***Mark Brongersma;*** *Stanford Univ., USA.* Plasmonics is a new field of science and technology in which the flow of light can be molded at the nanoscale using metals. The limitations and advantages of plasmonics for on-chip applications will be discussed.

10:30 a.m.–11:00 a.m., Coffee Break/Exhibits Open, *Cypress Foyer*

11:00 a.m.–12:30 p.m.

IMA • Quantum Nanophotonics

Anatoly V. Zayats; Queen's Univ. Belfast, UK, Presider

IMA1 • 11:00 a.m. Invited

Quantum Dot-Nanocavity Devices for Information Processing, *Jelena Vučković*[1], *Arka Majumdar[1], Kelley Rivoire[1], Erik Kim[1], Andrei Faraon[1], Dirk Englund[1], Ilya Fushman[1], Hyochul Kim[2], Pierre Petroff[2]; [1]Edward L. Ginzton Lab, Stanford Univ., USA, [2]Univ. of California at Santa Barbara, USA.* A combination of a single quantum emitter (a semiconductor quantum dot) with a semiconductor optical nanocavity has been employed to demonstrate devices ranging from optical switches and modulators controlled with sub-fJ energies, to quantum gates.

IMA2 • 11:30 a.m.

Advances in Photonic Quantum Information Science, *Alberto Politi*[1], *Jonathan C. F. Matthews[1], Anthony Laing[1], Alberto Peruzzo[1], Pruet Kalasuwan[1], Xiao-Qi Zhou[1], Maria Rodas Verde[1], Martin J. Cryan[1], John G. Rarity[1], Andre Stefanov[2], Timothy C. Ralph[3], Siyuan Yu[1], Mark G. Thompson[1], Jeremy L. O'Brien[1]; [1]Univ. of Bristol, UK, [2]Federal Office of Metrology METAS, Switzerland, [3]Univ. of Queensland, Australia.* Quantum technologies based on photons will likely require integrated optics architectures for improved performance, miniaturization and scalability. We demonstrate high-fidelity silica-on-silicon integrated optical realizations of key quantum photonic circuits and the

11:00 a.m.–12:30 p.m.

IMB • CMOS-Compatible Laser Sources

Valery Tolstikhin; OneChip Photonics Inc., Canada, Presider

IMB1 • 11:00 a.m. Invited

Hybrid Silicon-AlGaInAs Lasers and Optical Modulators, *John Bowers*[1], *Hui-Wen Chen[1], Di Liang[2], Hsu-Hao Chang[1], Richard Jones[3], Alex Fang[4]; [1]Univ. of California at Santa Barbara, USA, [2]HP Labs, USA, [3]Photonics Technology Lab, Intel Corp., USA, [4]Aurrion, USA.* A number of important breakthroughs in the past decade have focused attention on Si as a photonic platform. We review here recent progress on efforts to make lasers on or in silicon and on silicon optical modulators.

IMB2 • 11:30 a.m. Invited

Optical Gain and Lasing in Ge-on-Si, *Lionel Kimerling*; *MIT, USA.* Monolithic Ge-on-Si laser arrays are candidates for integrated, WDM optical power. Optical gain and lasing from the *direct* gap transition of band-engineered Ge-on-Si has been achieved using tensile strain and *n*-type doping. The edge-emitting laser device exhibits a gain spectrum of 1590-1610 nm.

11:00 a.m.–12:30 p.m.

PMA • Symposium on Optics in Computing I

Keren Bergman; Columbia Univ., USA, Presider

PMA1 • 11:00 a.m. Invited

What is the Right Layer for Switching? Layer-1? Layer-3? Or Packet Optical? *Bikash Koley*; *Google, USA.* As computation and storage continues to move from desktops to large internet services, computing platforms running such services are transforming into warehouse-scale computers (WSCs). This paper will address switching layer optimizing for interconnecting globally distributed WSCs.

PMA2 • 11:30 a.m. Invited

Optically Interconnected Supercomputing, *Jeffrey Kash*; *IBM Res., USA.* Optical interconnects are now used extensively in Petascale supercomputers. Technological and economic requirements for optics in future supercomputers through the Exascale are considered, and the optics technologies that can meet these requirements are reviewed.

first integrated quantum algorithm.

IMA3 • 11:45 a.m.
Enhanced Amplified Spontaneous Emission in III-V Semiconductor Photonic Crystal Waveguides, *Sara Ek*, *Martin Schubert, Kresten Yvind, Jesper Mørk; Dept. of Photonics Engineering, DTU Fotonik, Denmark.* We experimentally demonstrate enhanced amplified spontaneous emission in the slow light regime of an active photonic crystal waveguide slab. This promises great opportunities for future devices such as miniaturized semiconductor optical amplifiers and mode-locked lasers.

IMA4 • 12:00 p.m.
Enhancing Optical Switching with Coherent Control, *Sunil Sandhu*[1], *M. L. Povinelli[2], Shanhui Fan[1]; [1]Stanford Univ., USA, [2]Univ. of Southern California, USA.* We show that coherent control can enhance the peak energy coupled into a photonic crystal (PC) resonator system. We then demonstrate two applications of this coherent control technique in a bistable PC device.

IMB3 • 12:00 p.m.
High Speed Silicon Carrier-Depletion Mach-Zehnder Modulator with 1.4V-cm $V_{\pi}L$, *Ning-Ning Feng*[1], *Shirong Liao[1], Dazeng Feng[1], Po Dong[1], Dawei Zheng[1], Hong Liang[1], Roshanak Shafiiha[1], Guoliang Li[2], John E. Cunningham[2], Ashok V. Krishnamoorthy[2], Mehdi Asghari[1]; [1]Kotura Inc., USA, [2]Oracle America Inc., USA.* We demonstrate a very efficient high speed silicon carrier-depletion Mach-Zehnder (MZ) modulator with an ultralow π-phase-shift voltage-length product $V_{\pi}L$=1.4V-cm. The 3dB bandwidth of a typical 1mm long device was measured to be more than 12GHz.

PMA3 • 12:00 p.m. Invited
The Integration of Silicon Photonics and VLSI Electronics for Computing and Switching Systems, *Ashok Krishnamoorthy*[1], *R. Ho[1], X. Zheng[1], G. Li[1], D. Feng[2], P. Dong[2], T. Pinguet[3], A. Mekis[3], H. Schwetman[1], J. Lexau[1], D. Patil[1], F. Liu[1], P. Koka[1], M. McCracken[1], I. Shubin[1], H. Thacker[1], Y. Luo[1], K. Raj[1], M. Asghari[2], J. G. Mitchell[1], J. E. Cunningham[1]; [1]Oracle Corp., USA, [2]Kotura Inc., USA, [3]Luxtera Inc., USA.* We review the potential benefits and challenges for achieving optical-interconnects to the chip via the native integration of silicon photonics components with VLSI electronics; and review the “macrochip” - a collection of contiguous silicon chips enabled by optical proximity communication. We summarize recent progress towards achieving low-power photonic links for the macrochip.

IMA5 • 12:15 p.m.
Spontaneous Emission Dynamics and Purcell Enhancement in Si-nc-Based Microdisk Resonators, ***Mher Ghulinyan***[1], *Alessandro Pitanti*[2], *Daniel Navarro-Urrios*[3], *Georg Pucker*[1], *Lorenzo Pavesi*[2]; [1]*Fondazione Bruno Kessler, Italy,* [2]*Univ. of Trento, Italy,* [3]*Univ. de Barcelona, Spain.* We report on measurements of spontaneous emission rate enhancement of Si-ncs embedded in a WGM resonator at room temperature. We demonstrate experimentally emission lifetime reduction of 70% for Si-ncs coupled to cavity resonances.

IMB4 • 12:15 p.m.
Study of Hybrid Silicon Microring Lasers with Undercut Active Region, ***Di Liang***[1], *Marco Fiorentino*[1], *John E. Bowers*[2], *Raymond G. Beausoleil*[1]; [1]*HP Labs, USA,* [2]*Univ. of California at Santa Barbara, USA.* We report a study of hybrid silicon microring lasers with undercut active region, showing threshold reduction and output power enhancement due to better gain/optical mode overlap. Negative effects from excessive undercutting are also discussed.

12:30 p.m.–2:00 p.m., Lunch (on your own)

2:00 p.m.–4:00 p.m.

IMC • Nanocavities and Nanoresonators

Jelena Vuckovic; Edward L. Ginzton Lab, Stanford Univ., USA, Presider

IMC1 • 2:00 p.m. Invited
Ultra-High-Rate Modulation of High-*Q* Optical Cavities, ***Joyce Poon***, *W. D. Sacher; Univ. of Toronto, Canada.* By modulating the output coupler of a microcavity, the traditional limits in resonant modulators and laser modulation can be circumvented. High-*Q* microcavity modulators and lasers can be ultra- high-speed, low-power, and compact.

2:00 p.m.–3:30 p.m.

IMD • Modeling and Simulation I: Methods

Presider to Be Announced

IMD1 • 2:00 p.m. Invited
Advances in Modelling 3-D Resonators, ***Ana Vukovic***, *Phillip Sewell, Trevor Benson; Univ. of Nottingham, UK.* This paper presents an analytical approach to modelling 3-D resonators possessing axial symmetry. The analysis combines a Body of Revolution approach with the Method of Analytical Regularisation resulting in a more robust numerical algorithm.

2:00 p.m.–4:00 p.m.

PMB • Symposium on Optics in Computing II

John Bowers; Univ. of California at Santa Barbara, USA, Presider

PMB1 • 2:00 p.m. Invited
Large-Scale Integrated Photonics for High-Performance Computer Networks, ***Ray Beausoleil****; Hewlett-Packard Labs, USA.* We describe Si-compatible photonic interconnect components that could precipitate an "optical Moore's Law" and allow exponential performance gains until the transistors themselves become the bottleneck in datacenter-scale communications.

IMC2 • 2:30 p.m.

Resonant Optical Modulators beyond Conventional Energy-Efficiency and Modulation Frequency Limitations, *Miloš A. Popović*; *Univ. of Colorado at Boulder, USA.* Modulator designs are proposed that can employ arbitrarily high-Q resonators to simultaneously achieve high energy efficiency and distortionless modulation at all (low/high) frequencies by completely decoupling optical cavity dynamics from the modulation frequency response.

IMC3 • 2:45 p.m.

Complex Scissor Device Characterization and All-Optical Tuning of Single Resonant Cavity, *Paolo Bettotti*[1], *Mattia Mancinelli[1], Manga Rao[1], Marco Masi[1], Romain Guider[1], Lorenzo Pavesi[1], Jean Marc Fedeli[2]; [1]Nanoscience Lab, Dept. of Physics, Univ. di Trento, Italy, [2]CEA-LETI, MINATEC, France.* Optical characterization of complex coupled microring system is performed. Advanced optical effects as optical equivalent of electromagnetic induced transparency and all-optical tuning of single cavity are achieved and complex data transformation processes are envisaged.

IMC4 • 3:00 p.m.

Dynamical Slow Light Cell Based on Controlled Far-Field Interference of Microring Resonators, *Marcus S. Dahlem*[1], *Charles W. Holzwarth[1], Henry I. Smith[1], Erich P. Ippen[1], Miloš A. Popović[2]; [1]MIT, USA, [2]Univ. of Colorado, USA.* A novel dynamical slow light cell with a tunable group delay, fabricated in silicon-on-insulator, is

IMD2 • 2:30 p.m.

Multiscale and Accurate Modeling of High Permittivity and Plasmonic Nanostructures, *Benjamin Gallinet*, *Olivier J. F. Martin; Nanophotonics and Metrology Lab, Switzerland.* The surface integral formulation is a flexible, multiscale and accurate tool used to simulate light scattering on periodic nanostructures. Discretization and computations are reduced to the surface of the scatterers in the unit cell.

IMD3 • 2:45 p.m.

Improved Least Squares Method for Analyzing Layers of Spheres, *Huan Xie*[1,2], *Ya Yan Lu[1]; [1]City Univ. of Hong Kong, Hong Kong, [2]Univ. of Science and Technology of China, China.* An improved least squares method is presented to calculate transmission spectra for periodic layers of spheres. Spherical waves are used in unit cells containing spheres. The method does not require the evaluation of lattice sums.

IMD4 • 3:00 p.m.

Analyzing Diffraction Gratings in Conical Mounting by a Boundary Integral Equation Neumann-to-Dirichlet Map Method, *Yumao Wu*[1,2], *Ya Yan Lu[1]; [1]City Univ. of Hong Kong, Hong Kong, [2]Univ. of Science and Technology of China, China.* For diffraction gratings, a boundary integral equation Neumann-to-Dirichlet map (BIE-NtD) method is developed for problems in conical mounting. The method

PMB2 • 2:30 p.m. Invited

Optical Interconnected Computing Systems, *Keren Bergman*; *Columbia Univ., USA.* As chip multiprocessors (CMPs) scale, the gap between the on-chip computation and the available off-chip bandwidth continues to widen. We examine photonic networks-on-chip architectures that support both on-chip communication and off-chip memory access in an energy efficient manner.

PMB3 • 3:00 p.m. Invited

Device Requirements for Optical Interconnects to CMOS Silicon Chips, *David Miller*; *Stanford Univ., USA.* Optics could solve key interconnect problems in future electronic machines especially in interconnect density and energy. We project the requirements for the necessary optoelectronic and optical devices and prospects for hybrid optical/electronic processing systems.

demonstrated. It provides a tuning range of more than 1 ns, with a usable group delay of about 0-24 ps.

IMC5 • 3:15 p.m.
Athermal Silicon Ring Resonators, ***Vivek Raghunathan***[1], *Juejun Hu*[1], *Winnie N. Ye*[2], *Jurgen Michel*[1], *Lionel C. Kimerling*[1]; [1]*MIT, USA*, [2]*Carleton Univ., Canada.* We demonstrate athermal amorphous Si (a-Si) ring resonators using a top polymer cladding. We observe near complete thermo-optic (TO) compensation, and a temperature dependent resonant wavelength shift (TDWS) as low as 0.5 pm/K is achieved.

IMC6 • 3:30 p.m.
Athermal Performance in Titania-Clad Microring Resonators on SOI, ***Payam Alipour***, *Amir Hossein Atabaki, Ali Asghar Eftekhar, Ali Adibi; Georgia Tech, USA.* We propose the use of titanium dioxide as cladding material to reduce the temperature sensitivity of silicon-based microresonators. The advantages of using titanium dioxide over the conventional alternatives are discussed, and experimental results are presented.

IMC7 • 3:45 p.m.
Low-Loss Microdisk-Based Delay Lines for Narrowband Optical Filters, ***Qing Li***, *Siva Yegnanarayanan, Ali Eftekhar, Ali Adibi; Georgia Tech, USA.* We propose to use over-coupled microdisk resonators with high intrinsic Qs as delay lines for narrowband optical filters. Design issues including coupling method, uniformity and nonlinearity are investigated. Preliminary experimental work is also presented.

performs equally well for dielectric or metallic gratings.

IMD5 • 3:15 p.m.
A Finite Element Approach to Maxwell's Equations in Two Dimension, *S. M. Raiyan Kabir,* ***B.M.A. Rahman***, *Arti Agrawal, Anita Quadir, K.T.V. Grattan; City Univ. London, UK.* A finite element based time domain method is proposed to solve the Maxwell's curl equations. This technique can handle irregular mesh. The method also utilises less node to store all field components.

3:30 p.m.–4:00 p.m.
Coffee Break
Cypress Foyer

PMB4 • 3:30 p.m. Invited
Networking Content-Rich Data Centers, ***Donn Lee***; *Facebook, USA.*
Abstract not available.

4:00 p.m.–4:30 p.m., Coffee Break/Exhibits Open, *Cypress Foyer*

4:30 p.m.–6:30 p.m.

IME • Applications of Resonator Devices

Ray Beausoleil; Hewlett-Packard Labs, USA, Presider

IME1 • 4:30 p.m. Invited
C and L Bands Wavelength Tunable Laser with Silicon Photonic-Wire Waveguide Micro-Ring Resonators, ***Tao Chu***[1], *N. Fujioka*[2,3], *M. Tokushima*[1], *S. Nakamura*[2], *M. Ishizaka*[2,3]; [1]*Nanodevice Innovation Res. Ctr., AIST, Japan,* [2]*Green Innovation Labs, NEC Corp., Japan,* [3]*Optoelectronic Industry and Technology Development Association, Japan.* Using photonic-wire-waveguide-based silicon micro-ring resonators, we demonstrate the first C and L bands wavelength tunable laser module. The laser hybrid integrated on SOI substrate is compact and lower power consumption.

4:00 p.m.–6:30 p.m.

IMF • Special Symposium on Optomechanics

Anatoly V. Zayats; Queen's Univ. Belfast, UK, Presider

Dan-Xia Xu; Natl. Res. Council Canada, Canada, Presider

IMF1 • 4:00 p.m. Invited
Cooling of a Micromechanical Oscillator Close to the Quantum Ground State, ***Tobias J. Kippenberg****; Max-Planck-Inst. für Quantenoptik, Germany.* Abstract not available.

IMF2 • 4:30 p.m. Invited
Cavity Optomechanics and Optomechanical Crystals, *Amir H. Safavi-Naeini, Thiago P. Mayer Alegre,* ***Oskar Painter****; Caltech, USA.* We propose, analyze, design, and take the first experimental steps towards the demonstration of optomechanical crystals capable of converting photons to phonons, and vice versa, in a quantumlimited setting.

4:30 p.m.–6:30 p.m.

PMC • Optical Interconnects

Madeleine Glick; Intel, USA, Presider

PMC1 • 4:30 p.m. Invited
Silicon Photonics in High Performance Computing, ***Michael Watts****; Sandia Natl. Labs, USA.* Recent results in the application of silicon photonics to high performance computer networks are reviewed including sub-10fJ/bit modulator demonstrations, high-speed bandpass switches, tunable filters, actively stabilized resonators, and low dark current germanium detectors.

4:30 p.m.–6:30 p.m.

PMD • Grooming and Flow Switching

Takaya Miyazawa; NICT, Japan, Presider

PMD1 • 4:30 p.m.
Dual Routing Architecture in Multi-Layer and Multi-Domain GMPLS/ASON Networks, ***Yongli Zhao****, Jie Zhang, Min Zhang, Yuefeng Ji, Wanyi Gu; Beijing Univ. of Posts and Telecommunications, China.* A novel PCE-based routing architecture entitled DREAMSCAPE is proposed in multi-layer and multi-domain GMPLS/ASON networks, the performance of which is simulated and compared with hierarchical routing and backward recursive PCE-based computation on the DRE testbed.

PMD2 • 4:45 p.m.
Synchronization and NRZ-to-RZ Format Conversion of 10 G Ethernet Packet Based on a Time Lens, ***Hao Hu****, Janaina Laguardia Areal, Evarist Palushani, Michael Galili, Anders Clausen, Michael Stübert Berger, Leif Katsuo Oxenløwe, Palle Jeppesen; DTU Fotonik, Denmark.* 10 G Ethernet packet with maximum frame size

of 1518 bytes is synchronized to a global clock using a time lens. The 10 Gb/s NRZ signal is converted into RZ signal at the same time.

IME2 • 5:00 p.m.

In-Plane Thermally Tuned Silicon-on-Insulator Wavelength Selective Reflector, ***Lawrence S. Stewart****, P. Daniel Dapkus; Univ. of Southern California, USA.* A wavelength selective reflector thermally tuned by semiconductor resistors placed in proximity to the microring elements is proposed. The Vernier effect is utilized to increase device free spectral range and decrease required temperature shifts.

IME3 • 5:15 p.m.

Optimizing ARROW Transitions by Selective Deposition of Thin Films, ***Brian S. Phillips****[1], Jared Keeley[1], Mikhail Rudenko[2], Kaelyn Leake[2], Philip Measor[2], Aiqing Chen[2], Shuo Liu[2], Evan Lunt[1], Holger Schmidt[2], Aaron R. Hawkins[1]; [1]Brigham Young Univ., USA, [2]Univ. of California at Santa Cruz, USA.* Selective deposition of dielectric thin films on an optofluidic sensor provides the means for low loss in hollow-core waveguides and increased solid- to hollow-core interface transmission. This method promises significant throughput improvement over previous devices.

IMF3 • 5:00 p.m. Invited

Nano-Optomechanical Photonic Circuits Based on Light Forces, ***Milos Popovic****[1], Peter T. Rakich[2], Zheng Wang[3]; [1]Univ. of Colorado at Boulder, USA, [2]Sandia Natl. Labs, USA, [3]MIT, USA.* We describe novel functionalities in photonics enabled by incorporating nanomechanics and light-force actuation, and their application in data communication, from ultra-wide resonator tuning to all-optical feedback control that may alleviate fundamental problems in integrated nanophotonics.

PMC2 • 5:00 p.m.

Towards Scalable, Contention-Free Data Center Networking with All-Optical Switching Fabric, ***Yawei Yin****, Xiaohui Ye, Dan Ding, Samuel Johnson, Venkatesh Akella, S. J. Ben Yoo; Dept. of Electrical and Computer Engineering, Univ. of California at Davis, USA.* We propose a scalable optical switching architecture towards contention-free interconnection for data center networks. The arrayed-waveguide-grating router (AWGR) based switching fabric utilizes wavelength parallelism to alleviate contention, to reduce latency, and to improve scalability.

PMC3 • 5:15 p.m.

Low-Power, Fast Hybrid Silicon Switches for High-Capacity Optical Networks, ***Hui-Wen Chen****, John E. Bowers; Univ. of California at Santa Barbara, USA.* We draw a comparison between the energy utilization of electronic and optical routers. A hybrid silicon switch was demonstrated with low power consumption and fast switching speed. Its potential in high-capacity optical networks is discussed.

PMD3 • 5:00 p.m. Invited

Flexible Use of Spectrum and Photonic Grooming, ***Ori A. Gerstel****; Cisco Systems, USA.* We discuss the motivation and new concepts arising from a new DWDM architecture that uses the available spectrum in a flexible way - with no fixed grid, as well as some of the enabling technologies.

Cypress I & II	Big Sur	Cypress III	Cypress IV

IME4 • 5:30 p.m.
High-Q Microresonators: Characterization Method and Application to Amplifying Optical Delay Lines, *Stéphane Trebaol, **Yannick Dumeige**, Patrice Féron; ENSSAT FOTON, France.* We present ringing phenomenon in coupled resonators and in high-Q amplifying whispering gallery mode resonators. This effect can be used to measure the gain and the group delay of optical integrated delay lines.

IME5 • 5:45 p.m.
Extreme Miniaturization of Silicon Add-Drop Microring Filters for WDM Applications, ***Ashok P. Masilamani**, Zhanghua Han, Alan Tsay, Vien Van; Univ. of Alberta, Canada.* We explore the potential for extreme miniaturization of silicon microring filters by experimentally demonstrating wideband add-drop filters with bending radii scaled down to 1um, achieving insertion loss as low as 1.0dB and FSR exceeding 80nm.

IME6 • 6:00 p.m.
Near Infrared Absorption Sensor Based on Large-Scale Array of Miniaturized Microdonut Resonators, ***Zhixuan Xia**, Ali Asghar Eftekhar, Mohammad Soltani, Qing Li, Maysam Chamanzar, Siva Yegnanarayanan, Babak Momeni, Ali Adibi; Georgia Tech, USA.* An optical integrated absorption sensor based on a multichannel, high resolution (<0.6 nm) near-infrared spectrometer is proposed. Miniaturized microresonators (radius < 2μm) with high intrinsic Q enable the on-chip spectroscopy

IMF4 • 5:30 p.m. Invited
Integrated Optomechanical Circuits, ***Joris Roels**, Bjorn Maes, Roel Baets, Dries Van Thourhout; Photonics Res. Group, INTEC Dept., Ghent Univ., Belgium.* Optomechanical circuits are a promising candidate to realize various signal processing functions on a chip. In this paper we review several different NOMS structures fabricated in a silicon-on-insulator platform.

IMF5 • 6:00 p.m. Invited
Phonon Lasers in Cavity Optomechanics, ***Kerry Vahala**, Ivan Grudinin, Oskar Painter, Hansuek Lee; Caltech, USA.* The possibility of a phonon laser, the analog of an optical laser except for vibronic motion, has been considered since the earliest days of the optical laser.

PMC4 • 5:30 p.m. Invited
Scaled CMOS Photonics, ***Jason Orcutt**; MIT, USA.* Photonic devices integrated within existing state-of-the-art CMOS foundries are subject to many design constraints. In this work we present designs for waveguides, modulators and photodiodes suitable for integration within both bulk- and SOI-CMOS processes.

PMC5 • 6:00 p.m.
Experimental Demonstration of Optically-Connected SDRAM, ***Daniel Brunina**, Ajay S. Garg, Howard Wang, Caroline P. Lai, Keren Bergman; Columbia Univ., USA.* A four-channel, 2.5-Gb/s, all-optical WDM link is established between SDRAM and an emulated CPU. Data integrity and error-free performance are verified with a sequence of SDRAM write and read operations.

PMD4 • 5:30 p.m.
An Evaluation of Effects on Packet Loss Rate by Optical Packet Multiplexing Based on BGP Flow Aggregation, ***Yuki Okamura**[1], Hideaki Imaizumi[1], Kenji Hisadome[2], Osamu Ishida[2], Yuji Sekiya[1], Hiroyuki Morikawa[1]; [1]Univ. of Tokyo, Japan, [2]NTT Network Innovation Labs, Japan.* We apply our proposed packet multiplexing mechanism with BGP flow aggregation to asynchronous OPS networks and evaluate packet loss ratio in a FDL buffer through simulation based on real traffic trace data.

PMD5 • 5:45 p.m.
8-Degree 96-Wavelength ROADM with 100% Fully Flexible Add-Drop Access, ***Shifu Yuan**, David Altstaetter, John E. Bowers, Volkan Kaman, Chris Lee; Calient Networks, USA.* In this paper, we proposed an approach that uses 3-D MEMS based 320x320 optical switches to achieve 100% fully flexible add-drop access for an 8-degree 96 wavelength reconfigurable optical add drop multiplexer (ROADM).

PMD6 • 6:00 p.m. Invited
Optical Flow Switching, ***Vincent Chan**; Lab for Information and Decision Systems, MIT, USA.* Present-day networks are being challenged by dramatic increases in bandwidth demand of emerging applications. We will explore a new network transport, ”optical flow switching”, that will enable significant data rate growth, power-efficiency and cost-effective scalability of next-generation networks.

with low insertion loss.

IME7 • 6:15 p.m.

Silicon Wire Waveguide Label-Free Biosensor Arrays, *D.-X. Xu*[1], *A. Densmore[1], R. Ma[1], M. Vachon[1], S. Janz[1], Y.-H. Li[2], G. Lopinski[2], J. Lapointe[1], A. Delage[1], C. Luebbert[3], Q.-Y. Liu[3], J. H Schmid[1], P. Cheben[1]; [1]Inst. for Microstructural Sciences, Natl. Resource Council Canada, Canada, [2]Steacie Inst. for Molecular Sciences, Natl. Resource Council Canada, Canada, [3]Inst. for Biological Sciences, Natl. Resource Council Canada, Canada.* We report silicon wire evanescent field biosensor arrays, addressed using WDM and broadcasting approaches. Simultaneous and real-time monitoring of different antibody-antigen reactions can resolved an adsorption of 0.25 pg/mm^2. The two addressing approaches are compared.

PMC6 • 6:15 p.m.

Improving the SOA Switching Speed of Wavelength-Striped Optical Packets Using Multipulse Current Injection, *Caroline P. Lai*, *Martha A. Koroshetz, Keren Bergman; Columbia Univ., USA.* A reduced semiconductor optical amplifier switching speed is demonstrated for 8x10-Gb/s wavelength-striped optical packets using multipulse pre-emphasis current injection. The scheme yields a 20% improvement in switching speed; the power penalty performance is also characterized.

6:30 p.m.–7:30 p.m., Welcome Reception, *Dolphins Ballroom*

NOTES

• Tuesday, July 27 •

7:45 a.m.–6:00 p.m., Registration Open, *Steinbeck Foyer*

Dolphins Ballroom

JTuA • Joint Plenary Session II

8:45 a.m.–10:25 a.m.
Thomas Koch; Lehigh Univ., USA, Presider
Ken-ichi Kitayama; Osaka Univ., Japan, Presider

JTuA1 • 8:45 a.m. **Plenary**

The Future of Silicon Photonics, Justin Rattner; *Intel Corp., USA.* In his Plenary Talk, Intel Chief Technology Officer Justin Rattner will explore recent advances in silicon photonics research and discuss potential applications and future opportunities for this technology in a variety of computing devices and systems.

JTuA2 • 9:35 a.m. **Plenary**

The Path to Energy Efficient Optical Networking, ***Ken-ichi Sato;*** *Nagoya Univ., Japan.* Considering the bandwidth demands of future video-oriented services, the bottleneck of IP transport, and known limitations of silicon-based technologies, photonic technologies are shown to be the best path to creating bandwidth-abundant and energy efficient networks.

NOTES

Cypress I & II	Big Sur	Cypress III	Cypress IV

10:30 a.m.–11:00 a.m., Coffee Break/Exhibits Open, *Cypress Foyer*

11:00 a.m.–12:30 p.m.

ITuA • Nanophotonic Lasers and Photodetectors

Tao Chu; NEC Corp., Japan, Presider

ITuA1 • 11:00 a.m. **Invited**
Progress in Electrically Pumped Plasmonic Nano-Lasers at near Infrared Wavelengths, ***Martin T. Hill****; Eindhoven Univ. of Technology, Netherlands.* We will present our latest results on further miniaturization of electrically pumped plasmonic nano-lasers and also DFB Plasmon mode devices. In particular we are focusing on metal-insulator-metal waveguide structures as a basis for our lasers.

ITuA2 • 11:30 a.m.
Short Pulse Generation in a Passively Mode-Locked Photonic Crystal Semiconductor Laser, ***Mikkel Heuck****, Søren Blaaberg, Jesper Mørk; Dept. of Photonics Engineering, DTU Fotonik,*

11:00 a.m.–12:30 p.m.

ITuB • Plasmonics and Applications

Alexander Gaeta; Cornell Univ., USA, Presider

ITuB1 • 11:00 a.m. **Invited**
Nano-Biophotonics, ***Romain Quidant***[1,2]; [1]*ICFO, Spain,* [2]*ICREA, Spain.* In this talk, we describe our recent advances in the engineering of both the optical and thermal properties of plasmonic nanosystems and discuss their respective applications to biosciences.

ITuB2 • 11:30 a.m.
Sub-λ Plasmon Laser, ***Volker J. Sorger***[1]*, Rupert F. Oulton*[1]*, Thomas Zentgraf*[1]*, Chris Gladden*[1]*, Guy Bartal*[1]*, Ren-Min Ma*[2]*, Lun Dai*[2]*, Xiang Zhang*[1,3]*;* [1]*Univ. of California at Berkeley, USA,* [2]*State Key Lab for*

11:00 a.m.–12:45 p.m.

PTuA • Silicon Photonics

Katsunari Okamoto; AiDi Corp., Japan, Presider

PTuA1 • 11:00 a.m. **Invited**
Switching to Low-Cost Integration Technology for Switching, ***Meint Smit****; Eindhoven Univ., Netherlands.* Research on photonic switching is hampered by the high entry costs for developing integrated devices. Generic Photonic Integration Technologies offer novel opportunities for developing advanced integrated switching devices at low cost.

PTuA2 • 11:30 a.m.
A Fast and Comprehensive Microdisc Laser Model Applied to All-Optical Wavelength Conversion, ***Jens Hofrichter***[1]*, Oded Raz*[2]*, Folkert Horst*[1]*, Nikolaos Chrysos*[1]*, Cyriel Mi=nkenberg*[1]*,*

11:00 a.m.–12:45 p.m.

PTuB • Energy Efficient Net

June-Koo Rhee; KAIST, Republic of Korea, Presider

PTuB1 • 11:00 a.m.
Energy-Efficient Long-Reach Passive Optical Network: A Dynamic Wavelength Allocation Scheme, ***Lei Shi***[1]*, Sang-Soo Lee*[2]*, Biswanath Mukherjee*[1]*;* [1]*Univ. of California at Davis, USA,* [2]*Electronics and Telecommunications Res. Inst., Republic of Korea.* We investigate a dynamic wavelength allocation scheme for "ring-and-spur" long-reach PON. By enabling wavelength sharing among multiple remote nodes, significant energy is saved by reducing wavelengths needed and putting idle transmitters into sleep mode.

PTuB2 • 11:15 a.m.
Time-Aware Energy Conservation in IP-over-WDM Networks, ***Yi Zhang***[1,2]*, Massimo Tornatore*[1]*, Pulak Chowdhury*[1]*, Biswanath Mukherjee*[1]*;* [1]*Univ. of California at Davis, USA,* [2]*Tsinghua Univ., China.* We propose a novel approach to save energy in IP-over-WDM networks by shutting down idle line cards and chassis of routers based on time-of-the-day network traffic variation.

PTuB3 • 11:30 a.m. **Invited**
Technologies and Approaches for Improving Energy Efficiency of Network Elements, ***Slaviša Aleksić****; Vienna Univ. of Technology, Austria.* Technologies and approaches for implementing

Denmark. We present a new type of passively mode-locked laser with quantum wells embedded in photonic crystal waveguides operating in the slow light regime, which is capable of emitting sub picosecond pulses with widely controllable properties.

ITuA3 • 11:45 a.m.
Wavelength Tunable Lasers Incorporating Flexible Polymer Waveguide with Bragg Grating, ***Kyung-Jo Kim****, Jun-Whee Kim, Min-Cheol Oh; Pusan Natl. Univ., Republic of Korea.* A wavelength tunable laser is demonstrated in terms of the external feedback from a flexible polymeric Bragg reflector. The extraordinary elastic property enables the tuning of wavelength over 100 nm proportional to the imposed strain.

ITuA4 • 12:00 p.m.
Cavity-Enhanced Multispectral Photodetector on a Si Platform: Theory, Materials, and Devices, ***Jianfei Wang****, Juejun Hu, Xiaochen Sun, Piotr Becla, Anu Agarwal, Lionel Kimerling; MIT, USA.* We report the design and fabrication of a novel multispectral photodetector capable of detecting multiple wavebands in a single

Mesoscopic Physics and School of Physics, Peking Univ., China, [3]Materials Sciences Div., Lawrence Berkeley Natl. Lab, USA. We report a plasmonic laser device exhibiting strong sub-wavelength confinement. These nanowire-based plasmonic lasers are not subjected to diffraction limitations, hence can operate below the photonic mode cut-off diameter of purely dielectric nanowire lasers.

ITuB3 • 11:45 a.m.
Nanoscale Si-SPP Waveguides, ***Alexey V. Krasavin****, Anatoly V. Zayats; Queen's Univ. Belfast, UK.* We propose a highly efficient dielectric-loaded plasmonic waveguide based on a Al/Si material platform. It provides a subwavelength localization of the mode along with high photonic integration density and is fully compatible with CMOS fabrication.

ITuB4 • 12:00 p.m.
Characterization of the Localized Surface Plasmon Ploariton Mode in Ag/SiO_2/Ag T-Shaped Array, ***Cheng-Wen Cheng*[1,2,3]*, Zi-Chang Chang[2,4], Mohammed Nadhim Abbas[2,3,5], Min-Hsiung Shih[2], Chih-Ming Wang[2], Meng-Chyi Wu[4], Yia-Chung Chang[2]; [1]Dept. of Physics, Natl. Taiwan Univ., Taiwan, [2]Res. Ctr. for Applied Sciences, Taiwan,*

Tjibbe De Vries[2], Harm J. S. Dorren[2], Rajesh Kumar[3], Liu Liu[3], Bert-Jan Offrein[1]; [1]IBM Res. - Zurich, Switzerland, [2]Cobra Res. Inst., Eindhoven Univ. of Technology, Netherlands, [3]Photonics Res. Group, INTEC Dept., Ghent Univ. / IMEC, Netherlands. Microdisc lasers (MDLs) are an attractive option for on-chip laser sources, wavelength converters and even all-optical optical memory. We have developed a comprehensive model for wavelength conversion in MDLs which is compared with measurements.

PTuA3 • 11:45 a.m.
Digital All-Optical Signal Processing Using Microdisc Lasers, ***Jens Hofrichter*[1]*, Folkert Horst[1], Nikolaos Chrysos[1], Cyriel Minkenberg[1], Rajesh Kumar[2], Liu Liu[2], Geert Morthier[2], Tjibbe de Vries[3], Bert-Jan Offrein[1]; [1]IBM Res. - Zurich, Switzerland, [2]Photonics Res. Group, INTEC Dept., Ghent Univ. / IMEC, Belgium, [3]COBRA Res. Inst., Eindhoven Univ. of Technology, Netherlands.* Microdisc lasers (MDLs) are an attractive option for on-chip laser sources, wavelength converters and all-optical memory. We have developed a comprehensive model for MDL flip-flops and numerically investigate their switching properties in comparison with experiments.

PTuA4 • 12:00 p.m. Invited
Silicon Photonics: The Enabling Technology for Green Optical Processing, ***Giorgio Grasso*[1]*, Marco Romagnoli[2], Andrea Melloni[3]; [1]Pirelli, Italy, [2]Independent Consulting, Italy, [3]DEI - Politecnico di Milano, Italy.* Terabit Ethernet is the next challenge for coping with Internet bandwidth increase. Recent advances show that silicon

energy-efficient network elements are briefly reviewed. Optical transmission and switching together with an optimized network concept including power-aware routing, dynamic resource control and power management can significantly improve energy efficiency.

PTuB4 • 12:00 p.m.
Power Management in Mixed Line Rate Optical Networks, ***Avishek Nag*[1]*, Massimo Tornatore[2], Biswanath Mukherjee[1]; [1]Univ. of California at Davis, USA, [2]Politecnico di Milano, Italy.* We present a sensitivity study on how launch optical power can be managed to control the CAPEX of a mixed line rate (i.e., 10/40/100 Gbps wavelengths on same fiber)

pixel. Our prototypical device demonstrates spectral selectivity with a peak responsivity of 65.4V/W at 3.9μm wavelength.

ITuA5 • 12:15 p.m.
Three-Dimensional Thermal Analysis of a Waveguide Ge/Si Photodiode, *Molly Piels*[1,2,3], *Anand Ramaswamy[1], John E. Bowers[1], Dustin Kendig[2], Ali Shakouri[2], Tao Yin[3]; [1]Univ. of California at Santa Barbara, USA, [2]Univ. of California at Santa Cruz, USA, [3]Intel Corp., USA.* The spatial temperature distribution of a high power Ge/Si waveguide n-i-p photodiode is experimentally obtained using a time-domain thermoreflectance imaging technique. Measurement results are shown to be in good agreement with simulated values.

[3]Taiwan Intl. Graduate Program, Academia Sinica, Taiwan, [4]Dept. of Electrical Engineering, Natl. Tsing Hua Univ., Taiwan, [5]Dept. of Engineering and System Science, Natl. Tsing Hua Univ., Taiwan. The localized surface plasmon polariton mode in T-shaped Ag/SiO_2/Ag array was demonstrated. The mode was characterized by a Fourier transform infrared spectrometer. The resonant wavelength can be manipulated by modifying the structure, broadening operation range.

ITuB5 • 12:15 p.m.
Racetrack Filters for Nanophotonic on-Chip Networks, *Xi Chen*[1], *Moustafa Mohamed[1], Brian Schwartz[2], Zheng Li[1], Li Shang[1], Alan Mickelson[1]; [1]Univ. of Colorado at Boulder, USA, [2]Tech-X Corp., USA.* Multistage racetrack-filters are theoretically and experimentally studied for application as wave-length division multiplexing components for on-chip networks. When demultiplexing from broad-band sources, salient features of components include bandwidth, passband and free spectral range.

photonics is the most promising platform for matching speed and power consumption requirements for linear and non-linear devices.

PTuA5 • 12:30 p.m.
Multi-Hop Characteristics of a Prototype Hybrid Optoelectronic Router, *Ryohei Urata*, *Tatsushi Nakahara, Yasumasa Suzaki, Toru Segawa, Hiroshi Ishikawa, Akira Ohki, Hiroki Sugiyama, Ryo Takahashi; NTT Photonics Labs, Japan.* We report the performance of a prototype-hybrid-optoelectronic-router for multi-

optical network.

PTuB5 • 12:15 p.m.
Would Energy Efficient Ethernet Be Effective on 10Gbps Optical Links? *Pedro Reviriego[1], **David Larrabeiti**[2], Juan Antonio Maestro[1]; [1]Univ. Antonio de Nebrija, Spain, [2]Univ. Carlos III de Madrid, Spain.* Energy Efficient Ethernet is being standardized for copper transceivers in IEEEP802.3az. The next step could be low power modes for optical transceivers. We analyze this possibility through impact analysis of transition times on energy savings.

PTuB6 • 12:30 p.m.
640 Gb/s All-Optical Add/Drop Multiplexing Based on Pump Depletion in a PPLN Waveguide, *Antonella Bogoni*[1,2], *Xiaoxia Wu[2], Zahra Bakhtiari[2], Scott Nuccio[2], Robert W. Hellwarth[2], Alan E. Willner[2]; [1]CNIT, Italy, [2]Univ. of Southern California, USA.* All-optical time-domain add/drop scheme based on pump depletion

hop-transmission. A packet-loss-rate$<10^{-10}$ due to label-processing-errors and BER$<10^{-9}$ are achieved for up-to four-hops. These results, combined with the proposed-TTL-based-multi-hop-transmission-scheme, allow unlimited multi-hop transmission through the OPS-network.

effect in a PPLN waveguide is demonstrated at 640 Gb/s. Less than 2 dB power penalty is for achieved for dropped, survived and added channels.

12:30 p.m.–2:00 p.m., Lunch (on your own)

2:00 p.m.–4:00 p.m.

ITuC • Monolithic Photonic Integration in Indium Phosphide

Meint Smit; Eindhoven Univ., Netherlands, Presider

ITuC1 • 2:00 p.m. **Invited**
Large-Scale Photonic Integration for Advanced All-Optical Routing Functions, ***Steven C. Nicholes****, Milan L. Mašanović, Biljana Jevremović, Erica Lively, Larry A. Coldren, Daniel J. Blumenthal; Univ. of California at Santa Barbara, USA.* We review the first InP monolithic tunable optical router chip, consisting of eight wavelength converters and an 8x8 AWGR. The device integrates more than 200 functional elements and operates at 40 Gbps per port.

2:00 p.m.–4:00 p.m.

ITuD • Modeling and Simulation II: Nanophotonics and Plasmonics

Hung-chun Chang; Natl. Taiwan Univ., Taiwan, Presider

ITuD1 • 2:00 p.m. **Invited**
Nanophotonic Theory and Modeling, ***Shanhui Fan****; Stanford Univ., USA.* We discuss some of our recent works in nanophotonic theory and modeling. Examples include development of a theory for fundamental limit in light trapping in nanophotonic solar cells, super scattering of light from sub-wavelength particles, as well as a photonic band theory for plasmonic meta-materials.

2:00 p.m.–4:00 p.m.

PTuC • Optical Packet Switching, Memory, Flip-Flops

Hiroyuki Uenohara; Tokyo Inst. of Technology, Japan, Presider

PTuC1 • 2:00 p.m. **Invited**
Hybrid Optoelectronic Router Prototype for Asynchronous Optical Packet Switched Networks, ***Tatsushi Nakahara****, Ryohei Urata, Toru Segawa, Yasumasa Suzaki, Hirokazu Takenouchi, Ryo Takahashi; NTT Photonics Labs, NTT Corp., Japan.* We describe a hybrid optoelectronic router that optimally utilizes both optical and electrical technologies to reduce power and latency while maintaining functionality. A prototype router which handles 10-Gbit/s asynchronous optical packets is demonstrated.

2:00 p.m.–4:00 p.m.

PTuD • High Capacity Transparent Network Architecture

David T. Neilson; Bell Labs, Alcatel-Lucent, USA, Presider

PTuD1 • 2:00 p.m.
Implementation of Automatic Resources Adjustment for Optical Integrated Path and Packet Networks, ***Takaya Miyazawa****, Hideaki Furukawa, Hiroaki Harai; NICT, Japan.* We implement a control function which automatically adjusts the amount of resources between path/packet according to the number of in-use lightpaths for optical integrated networks. The system achieves the automatic resources reallocation within 8 seconds.

PTuD2 • 2:15 p.m.
Dynamic Protection-Capacity Sharing for Survivable IP and Wavelength Services in Optical Backbone Networks, ***Chaitanya S. K. Vadrevu***[1]*, Massimo Tornatore*[2]*, Biswanath Mukherjee*[1]*;* [1]*Univ. of California at Davis, USA,* [2]*Politecnico di Milano, Italy.* Dynamic sharing of protection

ITuC2 • 2:30 p.m. Invited

Monolithically Integrated Wavelength-Routing Switch with Double-Ring-Resonator-Coupled Tunable Lasers, ***Toru Segawa****, Shinji Matsuo; NTT Photonics Labs, NTT Corp., Japan.* We present a compact wavelength-routing switch that monolithically integrates semiconductor-optical-amplifier-based wavelength converters and double-ring-resonator-coupled tunable lasers. A 1x8 high-speed wavelength routing operation of a non-return-to-zero signal at 10 Gbit/s is demonstrated.

ITuD2 • 2:30 p.m. Invited

Complex Eigenvalue Analysis of Plasmonic Waveguides, ***Jasmin Smajic***[1]*, Christian Hafner*[2]*;* [1]*ABB Corporate Res. Ltd., Switzerland,* [2]*Swiss Federal Inst. of Technology, ETH Zurich, Switzerland.* Complex eigenvalue problems of plasmonic waveguide nanostructures are solved using FEM and MMP solvers. For improving MMP performance, new eigenvalue search functions are studied. Several plasmonic structures are analyzed and the field solvers are compared.

PTuC2 • 2:30 p.m.

All-Optical Flip-Flop with Optical Clock Signal Using Mach-Zehnder Interferometer Bistable Laser Diode, ***Masaru Zaitsu****, Koji Takeda, Mitsuru Takenaka, Takuo Tanemura, Yoshiaki Nakano; Univ. of Tokyo, Japan.* We perform and demonstrate synchronous all-optical flip-flop operations with optical clock injection using Mach-Zehnder interferometer bistable laser diode. Saturable absorbers play the key role which allow broadband wavelength tuning of the clock wavelength.

PTuC3 • 2:45 p.m.

Investigation of Tunable Laser Diode Control with Built-in Wavelength Monitoring and Calibration Methods, *Junya Kurumida*[1]*, R. Yu*[2]*,* ***Aytug O. Karalar***[2]*, B. Guan*[2]*, S. J. Ben Yoo*[2]*;* [1]*NPRC, AIST, Japan,* [2]*Univ. of California at Davis, USA.* We investigate fast tunable wavelength laser control designed for optical switching system with built-in wavelength monitoring and calibration. The combination of the AWGR and photo detector array allows calibration and monitoring of fast switching TLDs.

capacity between connections at IP and optical layers can improve capacity utilization in optical backbone networks. We investigate how idle backup wavelengths can support IP services while ensuring survivability.

PTuD3 • 2:30 p.m. Invited

Impact of Switching Technologies on Resilience Mechanisms in Transparent and Translucent Networks, *Dimitri Staessens, Maarten De Groote, Matthias Gunkel, Didier Colle,* ***Mario Pickavet****, Piet Demeester; Ghent Univ., Belgium.* Transparent optical cross connects based on Wavelength-Selective Switches using the broadcast-and-select principle are very cost efficient for switching trunk traffic. In this paper, we study the impact of the directionality of this architecture on restoration.

Cypress I & II	Big Sur	Cypress III	Cypress IV
ITuC3 • 3:00 p.m. **Programmable Photonic Filters from Monolithically Cascaded Filter Stages, *Erik J. Norberg***, *Rob S. Guzzon, John S. Parker, Larry A. Coldren; Univ. of California at Santa Barbara, USA.* A monolithic programmable photonic filter structure is constructed from cascaded single filter stages individually capable of producing poles or zeros. Flat-topped 2nd and 3rd order filters with pass-band rejection exceeding 30 dB are demonstrated.	**ITuD3 • 3:00 p.m.** **C-Shaped Subwavelength Apertures for Silicon Photonics Applications,** *Olena Lopatiuk-Tirpak, **Sasan Fathpour**; CREOL, College of Optics and Photonics, Univ. of Central Florida, USA.* Optical transmission properties of C-shaped apertures in silver films on silicon are studied for subwavelength integrated photonic applications. The fundamental Fabry-Perot-like mode is recognized to attain the highest power throughput at the telecommunication wavelengths.	**PTuC4 • 3:00 p.m. Invited** **Recent Advances on Colored Optical Packet Switching Systems, *Hideaki Furukawa***[1], *Satoshi Shinada*[1], *Szilárd Zsigmond*[2], *Hiroaki Harai*[1], *Naoya Wada*[1]; [1]*NICT, Japan*, [2]*Budapest Univ. of Technology and Economics, Hungary.* Over 1 Tbit/s/port wide-colored optical packet switching technologies are described. We demonstrate transparent operation of an optical packet switch system for various format and bit-rate, and presents its energy efficiency and network scalability.	**PTuD4 • 3:00 p.m.** **Management of Excess Capacity for Path-Oriented Differentiated Services Optical Networks, *Ferhat Dikbiyik***[1], *Biswanath Mukherjee*[1], *Massimo Tornatore*[2], *Laxman Sahasrabuddhe*[3]; [1]*Univ. of California at Davis, USA*, [2]*Politecnico di Milano, Italy*, [3]*Park, Vaughan & Fleming LLP, USA.* A path-oriented differentiated services optical network has demands which require different types of expectations from the network. Exploiting excess capacity which the network already has to meet these different expectations is investigated.
ITuC4 • 3:15 p.m. **Highly Programmable Optical Filters Integrated in InP-InGaAsP with Tunable Inter-Ring Coupling, *Robert S. Guzzon***, *Erik J. Norberg, John S. Parker, Larry A. Coldren; Univ. of California at Santa Barbara, USA.* A highly programmable optical filter architecture incorporating tunable inter-ring coupling is designed. The basic unit cell building block consisting of 3 coupled rings is fabricated in InP-InGaAsP, and bandpass filter results are presented.	**ITuD4 • 3:15 p.m.** **Inverse Design of Nanophotonic Structures Using Complementary Convex Optimization, *Jesse Lu***, *Jelena Vuckovic; Stanford Univ., USA.* We present a computationally-fast inverse design method for nanophotonic structures, based on the complementary optimization of both dielectric structure and resonant-field variables.variables. This method is used to efficiently design multi-objective nanophotonic resonators in two dimensions.		**PTuD5 • 3:15 p.m.** **Dynamic Quality of Transmission Optimization for Impairment Controllable WSON, *Guanjun Gao***[1], *Jie Zhang*[1], *Wanyi Gu*[1], *Daobin Wang*[1], *Sai Chen*[1], *Zhiyong Feng*[2], *Yabin Ye*[3]; [1]*Beijing Univ. of Posts and Telecommunications, China*, [2]*Huawei Technologies Co., Ltd., China*, [3]*Huawei Technologies, Deutschland GmbH, Germany.* Two novel dynamic Quality of Transmission (QoT) optimization schemes are proposed for improving the lightpath QoT in WSON. Significant QoT improvements and relevant attenuation tuning costs of different schemes have been analytically and numerically compared.

Cypress I & II

ITuC5 • 3:30 p.m.
Transmitter and Receiver Solutions ror Regrowth-Free Multi-Guide Vertical Integration in InP, *Scott B. Kuntze*, *Valery Tolstikhin, Fang Wu, Yury Logvin, Chris Watson, Kirill Pimenov, Ron Moore, Alan Moore, Huiling Wang, Tania Oogarah; OneChip Photonics, Canada.* We present the design and characterization of generic transmitter and receiver building blocks developed for a multi-guide vertical integration platform and implementable in a one-step growth process in InP.

ITuC6 • 3:45 p.m.
Compact Bandstop Filters with Semiconductor Optical Amplifier, Etched Beam Splitters and Total Internal Reflection Mirrors, *Byungchae Kim*, *Nadir Dagli; Univ. of California at Santa Barbara, USA.* Compact bandstop filters based on conventional waveguides, etched beam splitters, total internal reflection mirrors and integrated SOAs were demonstrated. 8.2(14.5) nm FSR and 18(12) dB ER are obtained for resonator of circumference 75(45) μm.

Big Sur

ITuD5 • 3:30 p.m.
Metallic-Dielectric Lenses Chromatic Aberration Analysis, *V. F. Rodríguez-Esquerre*[1], *C. E. Rubio-Mercedes[2], H. E. Hernandez-Figueroa[3]; [1]Federal Univ. of Bahia, UFBA, Brazil, [2]State Univ. of Mato Grosso do Sul, UEMS, Brazil, [3]State Univ. of Campinas, UNICAMP, Brazil.* Metallic-dielectric lenses permit sub-wavelength focusing of light in the visible and near-infrared. The chromatic aberration of these nanoslits lenses by using the finite-element method in conjunction with the perfectly matched layers is analyzed in detail.

ITuD6 • 3:45 p.m.
Accurate Analysis of Plasmonic Structures Using the Multidomain Pseudospectral Frequency-Domain (PSFD) Method, *Po-Jui Chiang*[1], *Yao-Wen Chung[1], Fang-Chi Lin[2], Nai-Hsiang Sun[2], Hung-chun Chang[3]; [1]Natl. Kaohsiung Univ. of Applied Sciences, Taiwan, [2]I-Shou Univ., Taiwan, [3]Natl. Taiwan Univ., Taiwan.* The high-accuracy multidomain pseudospectral frequency-domain (PSFD) method is formulated to simulate the interaction of light and plasmonic structures. The excited electric field on a sinusoidal metallic surface by a transverse-electric optical wave is particularly studied.

Cypress III

PTuC5 • 3:30 p.m.
Variable Optical Buffer Using Integrated 1×8 Optical Phased-Array Switch, *Tomofumi Oyama*[1], *Takuo Tanemura[1], Ibrahim Murat Soganci[1], Takaharu Ohyama[2], Shinji Mino[2], Yoshiaki Nakano[1]; [1]Res. Ctr. for Advanced Science and Technology, Univ. of Tokyo, Japan, [2]NTT Photonics Labs, NTT Corp., Japan.* We demonstrate variable all-optical buffering based on InP 1x8 optical phased-array switch and fiber delay lines. Low-loss 8-channel simultaneous coupling between the switch and fiber array is achieved by using a silica-based planer-lightwave-circuit pitch converter.

PTuC6 • 3:45 p.m.
All-Optical Flip-Flop-Based Square-Wave Clock, *Aaron M. Kaplan[1], Govind P. Agrawal[2],* ***Drew N. Maywar*[3]**; *[1]Heriot-Watt Univ., UK, [2]Inst. of Optics, USA, [3]Rochester Inst. of Technology, USA.* We experimentally demonstrate the generation and phase control of a square-wave optical clock signal emitted from a semiconductor-optical-amplifier-based all-optical flip-flop. All electrically driven components require only dc current, and phase control is performed optically.

Cypress IV

PTuD6 • 3:30 p.m. Invited
Dynamic O-O-O Switching in Large Scale Core Optical Networks, *Jeff Jian Chen*, *Cesar Santivanez, Kristin Rauschenbach; Raytheon BBN Technologies, USA.* We present systematic analysis of all optical dynamic switching in large scale core optical networks including theoretical studies, network level simulations using novel topology abstraction, as well as analysis in switching technologies and cost efficiencies.

4:00 p.m.–4:30 p.m., Coffee Break/Exhibits Open, *Cypress Foyer*

JTuB • Joint Poster Session

4:00 p.m.–6:00 p.m.

JTuB1

Realistic Squared-Rods Circular F-Doped Large-Mode-Area Leakage Channel Fibers with Low Bending Loss, *Lorenzo Rosa*[1], *Kunimasa Saitoh[1], Masanori Koshiba[1], Mrinmay Pal[2], Mukul Paul[2], Debashri Ghosh[2], Tarun Mahanty[2], Shyamal Bhadra[2], Luca Vincetti[3], Stefano Selleri[4]; [1]Hokkaido Univ., Japan, [2]Central Glass & Ceramic Res. Inst., India, [3]Univ. of Modena e Reggio Emilia, Italy, [4]Univ. of Parma, Italy.* We investigate realistic all-glass large-mode-area leakage channel fibers (LCFs) with a single down-doped-silica circular flattened-rod ring, engineering the silica bridge width for effectively single-mode behavior and reduced bending loss.

JTuB2

Numerical Modeling of Optical Pulse Propagation in Silicon Waveguides: The Finite-Difference Time-Domain Approach, *Chethiya M. Dissanayake*[1], *Ivan D. Rukhlenko[1], Malin Premaratne[1], Govind P. Agrawal[2]; [1]Monash Univ., Australia, [2]Univ. of Rochester, USA.* We study the propagation of two optical pulses through silicon-on-insulator (SOI) waveguides, using an extended finite-difference time-domain (FDTD) model, which allows for linear dispersion and stimulated Raman scattering.

JTuB3

A Method for Direct Synthesis of Optimal Microring Ladder Filters, *Ashok P. Masilamani*, *Vien Van; Univ. of Alberta, Canada.* A filter synthesis method based on the sum-difference all-pass decomposition of the filter transfer matrix is presented for directly obtaining the optimal canonical design of microring ladder filters for realizing general optical transfer functions.

JTuB4

Negative Feedback Semiconductor Optical Amplifier Using Fiber Bragg Gratings, *Yoshinobu Maeda*, *Tatsuya Matsuo, Koichi Tanimoto, Masakazu Takagi, Hideki Nakayama; Kinki Univ., Japan.* A negative feedback semiconductor optical amplifier was realized in an InGaAsP-InP amplifier using a fiber Bragg grating. The negative feedback optical amplification effect can be utilized to recover signal loss with a lower error probability.

JTuB5

Femtosecond Pump and Probe Pulse Propagation in a Filtered SOA-Based Configuration Exploiting Optical Gain Enhancement Induced by Spectral Red-Shift, *Claudio Crognale*[1], *Antonella Di Giansante[1], Mario Frezzini[2]; [1]Technolabs S.p.A., Italy, [2]Technolabs S.p.A. (Consultant), Italy.* This paper numerically shows how a proper management of the nonlinear gain saturation dynamics and a correct exploitation of the gain filtering mechanism can strongly enhance the performances of a femtosecond SOA-based pump-probe scheme.

JTuB6

Experimental Demonstration of Wavelength Channel Switching in V-Coupled Cavity Semiconductor Laser, *Jialiang Jin*, *Dekun Liu, Lei Wang, Jian-Jun He; Zhejiang Univ., China.* A simplified cleaved-facet version of the V-coupled cavity semiconductor laser is fabricated and tested. The wavelength switching over 8 consecutive channels by Vernier effect is demonstrated for channel spacing of 50GHz and 100GHz.

JTuB7

Multi-Wavelength Blue Light Generation by Frequency Doubling of the Output of Stacked Grating Coupled Surface Emitting Lasers, *Yigit O. Yilmaz*, *Viktor O. Smolski, Oleg V. Smolski, Pradeep Srinivasan, Eric G. Johnson; Univ. of North Carolina at Charlotte, USA.* We report on a compact multi-wavelength blue light source by frequency doubling of the vertically stacked grating coupled surface emitting lasers. The maximum second harmonic peak power of 0.97 W was obtained in pulse operation.

JTuB8

A New Spatio-Temporal Finite-Element Propagator for Plasmonic Waves in Nanostructures, *Hugo E. Hernandez Figueroa*, *Lorenzo L. Bravo-Roger, Marcos S. Goncalves, Francisco J. Arnold, Marli de F. G. Hernandez; UNICAMP, Brazil.* A new model to simulate the propagation of long-range Surface-Plasmon-Polariton waves based on the Finite Element Method is proposed. This spatio-temporal approach allows one to simulate very long devices, nanostructures, in particular.

JTuB9

On the Optimum Design for 1xN Multimode Interference Coupler Based Beam Splitters, *Amir Hosseini*, *David Kwong, Yang Zhang, Yazhao Liu, Ray T. Chen; Univ. of Texas at Austin, USA.* An analytical formula for optimum 1xN multimode input/output channel width is derived for improved performance based on the insertion loss and output uniformity. Experimental investigation of a SOI based 1x12 MMI confirms the analytical results.

JTuB10

Optical Add-Drop Filter Design Incorporating Mode Conversion in a Shifted Grating Cavity, *Marcel W. Pruessner*[1], *Jacob B. Khurgin[2], Todd H. Stievater[1], William S. Rabinovich[1], Vincent J. Urick[1]; [1]NRL, USA, [2]Johns Hopkins Univ., USA.* We design an add-drop filter incorporating a mode conversion waveguide and high index contrast shifted grating Fabry-Perot mode-conversion cavity. Simulations indicate that this device demonstrates add-drop functionality with high Q-factor and finesse.

JTuB11

Hybrid Vertical Cavity Laser, *Il-Sug Chung*, *Jesper Moerk; DTU Fotonik, Denmark.* A new hybrid vertical cavity laser structure for silicon photonics is suggested and numerically investigated. It incorporates a silicon subwavelength grating as a mirror and a lateral output coupler to a silicon ridge waveguide.

JTuB12

UV Written Integrated Photonic Sensors Based on Bragg Gratings in Silica-on-Silicon, *Peter G.R. Smith*, *James C. Gates, Christopher Holmes, Benjamin D. Snow, Richard M. Parker, Dominic Wales, Dmytro Kundys, Chaotan Sima, Helen L. Rogers, Lewis G. Carpenter, Sumiaty Ambran, Martin C. Grossel; Univ. of Southampton, UK.* Integrated sensors exhibit surface detection limits of 1nm and sensitivity to a range of chemicals. UV writing of waveguides and Bragg gratings into patterned silica-on-silicon substrates offers unique advantages for both chemical and physical detection.

JTuB13

Tunable Frequency Comb Generator Based on a Nested Heterostructure Photonic Crystal Cavity, *Amin Khorshidahmad*, *Andrew G. Kirk; McGill Univ., Canada.* Tunable multiple wavelength comb generation is numerically demonstrated, based on dynamic reconfiguration of intermodal transitions in a nested photonic crystal cavity, with spatially uniform tuning and suppressed adiabatic conversion. 8 wavelengths spanning 1515-1560nm are generated.

JTuB14

Micro-Damage Induced Direct Written Waveguide Bragg Gratings in the Cumulative Heating Regime, *Christopher T. Miese*, *Michael J. Withford, Alexander Fuerbach; CUDOS, Macquarie Univ., Australia.* We exploited micro-damage effects to fabricate waveguides that incorporate Bragg gratings in a single process step. We utilized a 5.1 MHz femtosecond oscillator combined with a Pockels cell to modulate the pulse energy.

JTuB15

A Novel Semiconductor-on-Metal MSM Photodetector Design for Dark Current Reduction, *Salia Mirbaha*, *Niall Tait, S. P. McGarry, N. G. Tarr; Carleton Univ., Canada.* A novel design of semiconductor-on-metal MSM photodetector for reducing dark current is reported. Leakage of 11.6μA and responsivity of 2mA/W is shown, while conventional metal-on-semiconductor design shows leakage of 166μA, and responsivity of 2.5mA/W.

JTuB16

Modal Control of Broad Area Semiconductor Laser with Monolithically Integrated Feedback Gratings, *Oleg V. Smolski*, *Viktor O. Smolski, Yigit O. Yilmaz; Univ. of North Carolina at Charlotte, USA.* Varying the duty cycle of the grating used for wavelength locking enhanced their functionality by providing laterally variable feedback reflectivity. By controlling the amplitude of the highest-order modes, beam divergence from the laser was reduced.

JTuB17

Integrated Optical Gas Sensors on Silicon-on-Insulator Platform, *Nebiyu A. Yebo*[1], *Dirk Taillaert[1], Joris Roels[1], Driss Lahem[2], Marc Debliquy[2], Zeger Hens[3], Roel Baets[1]; [1] INTEC-Photonics, Gent Univ.-IMEC, Belgium, [2]Materia Nova ASBL, Belgium, [3] Physical Chemistry Lab, Gent Univ., Belgium.* We demonstrate highly sensitive micro-optical hydrogen and ethanol gas sensors using SOI microring resonators (MRR) coated with sensitive films. Hydrogen concentrations below the lower explosion limit and ethanol vapor concentration below 100ppm are detected.

JTuB18

Redundant Planar Lightwave Transceivers for Aerospace Applications, *Hua Zhang, Shiquan Yang, Ashok Balakrishnan, **Matt Pearson**, Serge Bidnyk; Enablence Technologies Inc., Canada.* The scalability of planar lightwave circuits (PLCs) has been leveraged to create ultra-reliable optical links carrying bi-directional mixed-signal traffic at speeds of 2.5 Gb/s per channel. Optical and RF characteristics of these components are discussed.

JTuB19

The Influence of Localized Surface Plasmon on Radiation Pattern of Optical Dipole Antennas, *Shuangfeng Jiang, Hui Gao, **Fanmin Kong**, Kang Li; Shandong Univ., China.* Two optical dipole antennas (ODA) are introduced in this paper. Their far-field directivities at 600nm are carefully studied by FDTD method. We explore the influence of localized surface plasmon on the radiation pattern of ODA.

JTuB20

Radiation Loss of Dislocation for Dielectric Waveguides Using Radiation Mode Coupling Technique, *Nai-Hsiang Sun*[1], *Min-Yu Tsai[1], Ru-Yen Ro[1], San-Liang Lee[2], Jerome K. Butler[3], Gary A. Evans[3]; [1]Dept. of Electrical Engineering, I-Shou Univ., Taiwan, [2]Dept. of Electronic Engineering, Natl. Taiwan Univ. of Science and Technolog, Taiwan, [3]Dept. of Electrical Engineering, Southern Methodist Univ., USA.* We present a simplified derivation of the normalization of radiation modes from Fourier transformation. The transmission and forward radiation efficiencies of the dislocation of a three-layer waveguide are analyzed.

JTuB21

Highly Efficient Quasi-Phase-Matched Wavelength Conversion in GaP/Alox Zigzag Waveguides, *Tomonori Matsushita*, *Hiroshi Ishikawa, Takashi Kondo; Univ. of Tokyo, Japan.* We propose a novel wavelength conversion device based on quasi phase matching in alternately bent waveguide with the laterally inverted semiconductor core structure. Numerical simulations reveal GaP/Alox bent rib waveguides are highly efficient.

JTuB22

An Ultra-Linear Modulator with Inherent SFDR Compensation Capability, *Andru J. Prescod*[1,2], *Benjamin B. Dingel*[3], *Nicholas Madamopoulos*[1]; [1]*City College of New York, USA,* [2]*Corning Inc., USA,* [3]*Nasfine Photonics Inc., USA.* We show a novel and inherent technique for maintaining high linearity in an ultra linear ring-resonator (RR)-based modulator. It compensates for SFDR degradation due to resonator waveguide losses and/or deviation of RR waveguide coupling coefficient.

JTuB23

New Reformulation of the Fourier Modal Method for Multilayered Metallic Strip Grating by Using the Space Adaptive Resolution, *Hatem Elamine*[1], *Brahim Guizal*[2], *Meherzi Oueslati*[3], *Tijani Gharbi*[1]; [1]*Inst. FEMTO-ST CNRS UMR n° 6174, France,* [2]*Equipe de Nanophotonique, Groupe d'Etude des Semiconducteurs UMR 5650, France,* [3]*Unité de Recherche Spectroscopie Raman, Tunisia.* The parametric formulation of the Combined Boundary conditions Method with spatial adaptive resolution is extended to multilayered structures of strip gratings using new method to solve the eigenvalue problem in all the layers.

JTuB24

Design Kits and Circuit Simulation in Integrated Optics, *Andrea Melloni*[1], *Antonio Canciamilla*[1], *Giuseppe Morea*[2], *Francesco Morichetti*[1], *Antonio Samarelli*[3], *Marc Sorel*[3]; [1]*Politecnico di Milano, Italy,* [2]*Politecnico di Bari, Italy,* [3]*Univ. of Glasgow, UK.* "Building block" and "circuit simulation" concepts are introduced and demonstrated in the optical domain similarly to electronic and microwave fields, allowing analysis, design and fast prototyping of complex integrated optical circuits.

JTuB25

Neural Network Analysis and Design of Directional Couplers, *V. F. Rodríguez-Esquerre*[1], *A. Dourado-Sisnando*[1], *Fabrício G. S. Silva*[2]; [1]*Federal Univ. of Bahia, UFBA, Brazil,* [2]*Federal Inst. of Bahia, IFBA, Brazil.* Directional couplers have been successfully and efficiently analyzed and designed by using artificial neural networks. The training data has been obtained by using analytical solutions and the finite element method.

JTuB26

Paper Withdrawn

JTuB27

Optical Codes for Packet Detection in the OpMiGua Switch Architecture, *Norvald Stol*[1], *Carla Raffaelli*[2], *Michele Savi*[2], *Gabriella Cincotti*[3]; [1]*Dept. of Telematics, Norwegian Univ. of Science and Technology, Norway,* [2]*D.E.I.S. , Univ. of Bologna, Italy,* [3]*Dept. of Applied Electronics, Univ. "Roma Tre", Italy.* Optical codes are applied to distinguish different types of information flows in optical networks. The OpMiGua architecture is investigated as a case study. Benefits of the approach are discussed with respect to previously proposed solutions.

JTuB28

New IQ-Splitting Device for Microwave/Millimeter-Wave Signals by Using Electro-Optic Modulation with Polarization Reversal, *Hiroshi Murata*, *Tomohisa Yokota, Yasuyuki Okamura; Osaka Univ., Japan.* A new optical device for IQ-splitting of micro-/millimeter-wave signals is proposed. Utilizing an electro-optic Mach-Zehnder modulator with periodically polarization-reversed structures and a waveguide X-junction, IQ-splitting operation is obtainable. The experimental demonstrations around 26GHz are reported.

JTuB29

Proposal for a XOR Logic Gate with Intensity and Phase Modulated Inputs, *Elham S. Nazemosadat*, *Perry P. Shum; Lightwave Technology Group, Network Technology Res. Ctr., Nanyang Technological Univ., Singapore.* An all-optical exclusive-OR logic gate which operates between OOK and BPSK signals is proposed and numerically studied. The working principle is based on cross phase modulation in a highly nonlinear fiber.

JTuB30

All-Optical Amplitude and Wavelength Modulation of a Standard Mid-Infrared Quantum Cascade Laser, *Gang Chen*[1,2], *Rainer Martini*[1], *Clyde G. Beath*[1,3], *Peter Grant*[3], *Richard Dudek*[3], *Hui C. Liu*[3]; [1]*Stevens Inst. of Technology, USA,* [2]*Chongqing Univ., China,* [3]*Inst. for Microstructural Sciences, Canada.* All-optical modulation of the emission power and wavelength are demonstrated up to 10.35 GHz and 1.6 GHz respectively in a standard mid-infrared quantum cascade laser by illuminating its front facet with femtosecond near-infrared pulse train.

JTuB31

Multiple Photonic Band Gaps in 1-D Fibonacci System, *Dan T. Nguyen*, *Robert A. Norwood, Nasser Peyghambarian; Univ. of Arizona, USA.* A new multilayer system based on a one-dimensional (1-D) Fibonacci sequence that can generate multiple photonic band gaps (MPBG) is presented. The structures are straightforward to make. Its potential for various applications is also discussed.

JTuB32

All-Optic Wavelength Conversion and Pulse Reshaping with Two FP Coupled Cavities, *Pablo Costanzo-Caso*[1,2], *Sergio Granieri*[1], ***Azad Siahmakoun***[1]; [1]*Dept. of Physics and Optical Engineering, Rose-Hulman Inst. of Technology, USA,* [2]*Univ. Nacional de la Plata, Argentina.* An all-optic wavelength converter and pulse reshaper is proposed and experimentally demonstrated. The device is based on two FBG-SOA-FBG coupled-resonators in Fabry-Perot geometry producing two wavelengths with rise/fall time of a few nanoseconds.

JTuB33

Modeling of WDM-Integrated Nodes and GMPLS Applicability in IP-Optical Networks, *Rie Hayashi*, *Kohei Shiomoto; NTT Network Service System Labs, Japan.* We show how to model a GPMLS node that implements WDM function in it and propose resource assignment methods necessary for optical path set up based on

GMPLS protocols for IP-optical networks.

JTuB34

Introducing TE Metrics to Account for Transponder and Grooming Resources in GMPLS Multi-Layer Networks, *Nicola Andriolli*[1]*, Filippo Cugini*[2]*, Paola Iovanna*[3]*, Giulio Bottari*[3]*,* ***Antonella Bogoni***[2]*, Luca Valcarenghi*[1]*, Piero Castoldi*[1]*;* [1]*Scuola Superiore Sant'Anna, Italy,* [2]*CNIT, Italy,* [3]*Ericsson, Italy.* Novel GMPLS TE Metric extensions are proposed to account for the availability of grooming and transponder resources. Advanced grooming policies exploiting these TE metrics are implemented yielding significant improvements of link usage and blocking probability.

JTuB35

Polarization Switchable Pulse Generation of Reduced Timing Jitter and Pulse Width from a Gain-Switched VCSEL with External Laser Beam Injection, ***Seoung Hun Lee****, Hae Won Jung, Kyong Hon Kim, Min Hee Lee; Inha Univ., Republic of Korea.* We report simultaneous reduction of timing jitter and pulse width of gain-switched pulses from 1.55 μm-wavelength single-mode VCSELs with an external laser injection at its main and side modes of parallel and perpendicular polarizations, respectively.

JTuB36

Maximizing Network Capacity Using the Reach Optimized Architecture for Multi-Rate Transport System (ROAMTS), ***Ashwin A. Gumaste****; Indian Inst. of Technology Bombay, India.* The ROAMTS architecture was proposed as a flexible-wavelength spacing solution for increasing the number and reach of wavelengths in metro networks. System design and optimization issues are studied.

JTuB37

Some Wavelength-Spacing Continuously Tunable Multi-Wavelength Fiber Lasers Based on Four-Wave-Mixing Effect, *Daru Chen*[1,2]*, Bing Sun*[2,3]*, Yizhen Wei*[3]*,* ***Shiming Gao***[2,3]*, Sailing He*[2,3]*;* [1]*Zhejiang Normal Univ., China,* [2]*Joint Res. Lab of Optics of Zhejiang Normal Univ. and Zhejiang Univ., China,* [3]*Zhejiang Univ., China.* Two wavelength-spacing continuously tunable multi-wavelength fiber lasers based on four-wave-mixing effect, one with a dispersion-shifted fiber and the Mach-Zehnder interferometer, the other with a highly nonlinear fiber and the two tunable lasers, are proposed.

JTuB38

Silicon-Based Fabry-perot Microcavity with Distributed Bragg Reflectors, *Jianwei Wang,* ***Daoxin Dai****, Sailing He; Ctr. for Optical and Electromagnetic Res., State Key Lab for Modern Optical Instrumentation, China.* A Fabry-Perot microcavity based on silicon nanowires is designed and fabricated. In order to obtain a high reflection, Bragg gratings are used as the F-P microcavity's reflectors. The numerical simulation and experimental results are presented.

JTuB39

Simultaneous Transmission of Unicast and Multicast Data in a WDM-PON by Switching ON/OFF RF Control Signal, ***Min Zhu***[1]*, Shilin Xiao*[1]*, Wei Guo*[1]*, Jie Shi*[1]*, Weisheng Hu*[1]*, Benoit Geller*[2]*;* [1]*State Key Lab of Advanced Optical Communication Systems and Networks, China,* [2]*UEI Lab, ENSTA Paris-Tech, France.* We propose and demonstrate a novel WDM-PON to simultaneously transmit unicast and multicast data with colorless ONUs. By simply switching on/off the radio frequency (RF) control signal, the flexible and dynamic multicast service is realized.

JTuB40

Single-Sideband Modulation of OFDM Signals Based on an Injection-Locked DFB Laser in 60-GHz RoF Systems, ***Cheng Zhang****, Jun Duan, Cheng Hong, Peng Guo, Weiwei Hu, Zhangyuan Chen; Peking Univ., China.* We experimentally demonstrate OFDM signal transmission over 60-GHz RoF systems using single-sideband modulation based on an injection-locked DFB laser. Both 3.2-Gb/s 64QAM and 4.3-Gb/s 16QAM OFDM signals transmission over 56-km SSMF are realized successfully.

JTuB41

A Novel Coherent Optical Single-Carrier Frequency-Division-Multiplexing (CO-SCFDM) Scheme for Optical Fiber Transmission Systems, ***Juhao Li****, Su Zhang, Fan Zhang, Zhangyuan Chen; Peking Univ., China.* We propose a novel coherent optical single-carrier frequency-division-multiplexing (CO-SCFDM) scheme, which has significantly lower PAPR while achieves high commonality in parameter design with CO-OFDM system. Moreover, orthogonal band multiplexing (OBM) is applicable for CO-SCFDM system.

JTuB42

Design and Fabrication of an Electrically Pumped 1-D Nanobeam Laser in GaAs, ***Uday K. Khankhoje****, Jingqing Huang, Axel Scherer; Caltech, USA.* The design of an electrically pumped nanolaser (formed in a nanobeam perforated by a chirped grating of air holes) is discussed in terms of the fabrication sequence and finite-difference time-domain simulations of the device geometry.

JTuB43

Electrically Processed OCDMA System Based on Spatial Coding and Subcarrier Multiplexing, ***Changjian Guo****, Cheng Luo, Sailing He; Zhejiang Univ., China.* A low-cost electrically processed OCDMA system based on spatial coding and subcarrier multiplexing is proposed. The simulation shows that at least 10 simultaneous users can be supported in a 16-code OCDMA system with 40-dB OSNR.

JTuB44

640 GHz Direct Optical Sampling of Microwave Signals, ***Francesco Fresi***[1]*, An Truong Nguyen*[1]*, Paolo Ghelfi*[2]*, Antonella Bogoni*[2]*, Luca Potì*[2]*;* [1]*Scuola Superiore Sant'Anna, Italy,* [2]*CNIT, Italy.* We present a technique for performing direct optical sampling at 640GSample/s on microwave signals. The sample stream is parallelized at lower frequency and digitally post-processed. SNR of 27dB and ENOB higher than 4 are achieved.

JTuB45

All-Optical NRZ-DPSK to RZ-OOK Format Conversion Using Optical Delay Line Interferometer and Semiconductor Optical Amplifier, ***Emma Lazzeri***[1]*, An Truong Nguyen*[1]*, Giovanni Serafino*[1]*, Nobuyuki Kataoka*[2]*, Naoya Wada*[2]*, Antonella Bogoni*[3]*, Luca Potì*[3]*;* [1]*Scuola Superiore Sant'Anna, Italy,* [2]*NICT, Japan,* [3]*Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Italy.* We describe an all-optical NRZ-DPSK to RZ-OOK converter employing an optical delay line interferometer and a semiconductor optical amplifier. System penalty at 10Gbit/s is experimentally demonstrated to be less than 1dB at BER of 10-9.

JTuB46

Applications of Large Optical 3-D MEMS Switches in Radio-over-Fiber in-Building Networks, ***Nicholas Madamopoulos***[1]*, Andru Prescod*[1,2]*;* [1]*City College of New York, USA,* [2]*Corning Inc., USA.* We describe the advantages of using large 3-D MEMS switches in in-building Radio-over-Fiber networks, where the large number of users can be interconnected through the switch, thus avoiding hardware intensive and expensive electro-optic conversions.

6:00 p.m.
Off-Site Dinner
Chateau Julien Wine Estate

• Wednesday, July 28•

7:30 a.m.–6:00 p.m., Registration Open, *Steinbeck Foyer*

8:30 a.m.–10:30 a.m.

IWA • Optical Modulators

Dan-Xia Xu; Natl. Res. Council Canada, Canada, Presider

IWA1 • 8:30 a.m. Invited

Recent Developments in Silicon Optical Modulators, ***Graham Reed***[1]*, F. Y. Gardes*[1]*, G. Z. Mashanovich*[1]*, Y., Hu*[1]*, D. Thomson*[1]*, G. Rasigade*[2]*, Delphine Marris-Morini*[2]*, L. Vivien*[2]*;* [1]*Univ. of Surrey, UK,* [2]*Inst. D'Electronique Fondamentale, Univ. Paris Sud, France.* One of the key enabling-components for silicon photonics is a high-performance modulator. An overview is given of the modulator research that has been pursued at the University of Surrey and the worldwide state-of the art.

8:30 a.m.–10:30 a.m.

IWB • Modeling and Simulation III: Photonic-Crystal and Waveguide Devices

Junji Yamauchi; Hosei Univ., Japan, Presider

IWB1 • 8:30 a.m.

Microring-Assisted Directional Couplers for Power Coupling Between Dissimilar Waveguides, ***David Perron***[1]*, Ping-Tong Ho*[2]*, Vien Van*[1]*;* [1]*Dept. of Electrical and Computer Engineering, Univ. of Alberta, Canada,* [2]*Dept. of Electronic Engineering, Tsinghua Univ., China.* A novel approach for attaining complete power transfer between dissimilar waveguides is proposed using microring-assisted coupling. Theoretical and FDTD analyses show 100% coupling is achievable with very short coupling length over the microring resonance bandwidth.

IWB2 • 8:45 a.m.

Mode Order Converter Using Tapered Multimode Interference Couplers, ***Amir Hosseini****, John Covey, Ray Chen; Univ. of Texas at Austin, USA.* Tapered MMI devices are proposed. It is demonstrated that the proposed single-stage MMI device's output power efficiency can be 55% higher than a conventional adiabatic taper by partially capturing the 2nd order mode power.

8:30 a.m.–10:30 a.m.

PWA • Signal Processing I

Ken-ichi Kitayama; Osaka Univ., Japan, Presider

PWA1 • 8:30 a.m. Invited

Ultra-Fast All Optical Signal Processing and Switching Based on PPLN Waveguides, ***Antonella Bogoni***[1,2]*, Xiaoxia Wu*[2]*, Jieng Wang*[2]*, Alan E. Willner*[2]*;* [1]*Natl. Lab of Photonic Networks, CNIT, Italy,* [2]*Univ. of Southern California, USA.* Ultra-fast optical signal processing based on PPLN waveguide is described. Logic operations, data exchange and regeneration functionalities are demonstrated for OOK and DPSK data signals up to 640 Gb/s.

8:30 a.m.–10:30 a.m.

PWB • Optical Switches, Wavelength Conversion

Hideaki Furukawa; NICT, Japan, Presider

PWB1 • 8:30 a.m.

Reconfigurable Optical Add/Drop Multiplexer Based on Bidirectional Wavelength Selective Switches, ***Philip N. Ji***[1]*, Yoshiaki Aono*[2]*, Ting Wang*[1]*;* [1]*NEC Labs America, USA,* [2]*NEC Corp., Japan.* We propose and experimentally demonstrate a reconfigurable optical add/drop multiplexer based on bidirectional wavelength selective switch. It delivers wavelength selection function at both the input and output ends, and reduces insertion loss, footprint and cost.

PWB2 • 8:45 a.m.

Coherent Receiver-Based Compensation of Phase Distortions Induced by Single-Pump HNLF-Based FWM Wavelength Converters, ***Thomas Richter***[1]*, Robert Elschner*[2]*, Lutz Molle*[1]*, Klaus Petermann*[2]*, Colja Schubert*[1]*;* [1]*Fraunhofer Heinrich-Hertz-Inst., Germany,* [2]*Technische Univ. Berlin, Germany.* We show an algorithm and its application in a coherent system which can be used to compensate signal distortions induced by pump-phase-modulation in single-pump wavelength converters based on four-wave mixing in highly

IWA2 • 9:00 a.m.
CMOS-Compatible Microring Modulators for Nanophotonic Interconnect, *Zhen Peng*, *David Fattal, Marco Fiorentino, Ray Beausoleil; Hewlett Packard Labs, USA.* We demonstrate a 6Gbps CMOS-compatible SOI microring modulators that uses carrier injection. Nanophotonic interconnect systems employing such devices can boost the performance of many-core computation in data centers.

IWA3 • 9:15 a.m.
Silicon Modulator Based on Coupled Microring Resonators, *Qianfan Xu*; *Rice Univ., USA.* We show a silicon electro-optic modulator design based on coupled microring resonators that relaxes the trade-off between optical bandwidth and power consumption in resonator-based modulators. It enables 40-Gbit/s modulation without a pre-emphasized driving signal.

IWA4 • 9:30 a.m.
Broadband Linear Silicon Mach-Zender Modulators, *Cheryl M. Sorace*, *Anatol Khilo, Franz X. Kaertner; MIT, USA.* We show that properly dimensioned push-pull Mach-Zehnder modulators using reverse biased silicon diodes exhibit superior linearity (>60dB) over conventional Lithium Niobate Mach-Zehnder modulators, making them

IWB3 • 9:00 a.m.
Polarization Crosstalk Generated in an Offset and a Y-Branch Rib Waveguide, *Junji Yamauchi,* ***Masashi Nakamura***, *Yuu Wakabayashi, Hisamatsu Nakano; Hosei Univ., Japan.* Generation of a cross polarization component is numerically demonstrated in an offset and a Y-branch rib waveguide. The asymmetry of the waveguide configuration results in the polarization crosstalk.

IWB4 • 9:15 a.m.
All-Optical Controlled-Transport of Nanoparticles on Wedge-Shaped Photonic Crystal Waveguides, *Pin-Tso Lin*, *Tsan-Wen Lu, Po-Tsung Lee; Dept. of Photonics, Inst. of Electro-Optical Engineering, Natl. Chiao Tung Univ., Taiwan.* A wedge-shaped photonic crystal waveguide is proposed to achieve controlled trapping and transport ability of nanoparticles all optically by varying the wavelength. The transport ability S is calculated to be 40.5 for tilted angle α=0.5°.

IWB5 • 9:30 a.m.
Three-Dimensional Vector Finite Element Analysis of Leakage Losses in One-Dimensional Photonic Crystal Coupled Resonator Optical Waveguides, *Yuki Kawaguchi*, *Kunimasa Saitoh, Masanori Koshiba; Hokkaido Univ., Japan.* We evaluated leakage losses of one-dimensional photonic-crystal coupled-resonator-optical waveguides (1-D

PWA2 • 9:00 a.m.
Low-Power Colorless All-Optical 2R Regeneration of 25 Gb/s NRZ Signals Using a Standard DFB Laser, *Koen Huybrechts[1], Christophe Peucheret[2], Jorge Seoane[2], Takuo Tanemura[3], Koji Takeda[3], Yoshiaki Nakano[3], Roel Baets[1],* ***Geert Morthier[1]***; *[1]Ghent Univ. - IMEC, Belgium, [2]Technical Univ. of Denmark, Denmark, [3]Univ. of Tokyo, Japan.* We demonstrate the first all-optical 2R regeneration of 25 Gbit/s NRZ data based on hysteresis in a DFB laser. The scheme results in BER improvement, exhibits low power consumption and is effective after fiber transmission.

PWA3 • 9:15 a.m.
Investigation of All-Optical Division Processing Using a SOA-MZI-Based XOR Gate for All-Optical FEC with Cyclic Code, *Yohei Aikawa*, *Satoshi Shimizu, Hiroyuki Uenohara; Tokyo Inst. of Technology, Japan.* We investigated an optical divider circuit using a SOA-MZI-based XOR gate for all-optical FEC scheme with cyclic code. We achieved the all-optical division processing under the optimized condition obtained with simulation for the first time.

PWA4 • 9:30 a.m. Invited
Waveguide Array Devices for Modulation and Routing, *Chris Doerr*; *Bell Labs, Alcatel-Lucent, USA.* This talk discusses photonic integrated circuits that utilize parallel "processing" of waveguide arrays, such as arrayed waveguide gratings. Parallel arrays exhibit scalability and smoothing of imperfections. We apply this to coherent-system

nonlinear fibre.

PWB3 • 9:00 a.m. Invited
Scaling Optical Switches to 100 Tb/s Capacity, *Shifu Yuan*, *Chris Lee; Calient Networks Inc., USA.* We review the current status of 3-D MEMS optical switching technology and discuss scaling optical switches to 100 Tb/s capacity with up to 1000x1000 ports supporting 100Gbit/s channel rate.

PWB4 • 9:30 a.m.
Parametric Wavelength Exchange for Phase-Shifted Signal, *Gao Ying[1], Jiaojiao Fu[1],* ***Shiming Gao[1]***, *Chester Shu[2], Sailing He[1]; [1]Ctr. for Optical and Electromagnetic Res., Zhejiang Univ., China, [2]Dept. of Electronic Engineering, Chinese Univ. of Hong Kong, China.* We propose and experimentally demonstrate all optical wavelength exchange between two DPSK signals using pumps

attractive for analog electronic to photonic conversion systems.

IWA5 • 9:45 a.m.
Alignment-Free Fabrication of a Hybrid Electro-Optic Polymer Modulator Platform, *Ismail E. Araci*[1], *Robert A. Norwood[1], J. D. Luo[2], Alex K. Y. Jen[2], N. Peyghambarian[1]; [1]College of Optical Sciences, Univ. of Arizona, USA, [2]Dept. of Materials Science and Engineering, Univ. of Washington, USA.* A hybrid platform for electro-optic (EO) polymer modulators was realized on glass substrates with a simplified fabrication technique. The coplanar configuration device has 4.5 dB insertion loss with 7.5 μm electrode spacing.

IWA6 • 10:00 a.m.
Reversible Switching of an Optical Gate Using Phase-Change Material and Si Waveguide, *Yuichiro Ikuma*[1], *Yuya Shoji[2], Masashi Kuwahara[2], Xiaomin Wang[2], Kenji Kintaka[2], Hitoshi Kawashima[2], Daiki Tanaka[1], Hiroyuki Tsuda[1]; [1]Keio Univ., Japan, [2]AIST, Japan.* Optical gate switch that uses $Ge_2Sb_2Te_5$ phase-change material was fabricated and the reversible switching has been achieved for the first time. The switch is only 5-μm long and laser pulse irradiation was used for switching.

PC-CROW). We show design methods of low-loss 1-D PC-CROW and leakage losses of proposed structure are one order of magnitude lower than normal 1-D PC-CROW.

IWB6 • 9:45 a.m.
Efficient Numerical Method for Analyzing Photonic Crystal Slab Waveguides Based on Dirichlet-to-Neumann Maps, *Lijun Yuan*, *Ya Yan Lu; City Univ. of Hong Kong, Hong Kong.* An efficient numerical method based on Dirichlet-to-Neumann maps was developed for computing waveguide modes in photonic crystal slabs. The discretization of a 3-D volume is avoided.

IWB7 • 10:00 a.m.
3-D FEM Simulations of High-Q Resonances in Photonic Crystal Microcavities, *Sven Burger[1,2], Lin Zschiedrich[1],* ***Frank Schmidt*[1,2]**; *[1]JCMwave, Germany, [2]Zuse Inst. Berlin, Germany.* Optical resonances in 1-D photonic crystal microcavities are investigated numerically using 3-D finite-element solvers. The results are compared to experimental results from the literature and validated by comparison to theoretical findings from the literature.

modulators and receivers.

PWA5 • 10:00 a.m.
All-Optical Routing and Switching in Two-Dimensional Waveguide Arrays, *Robert Keil*[1], *Alexander Szameit[2], Felix Dreisow[1], Matthias Heinrich[1], Stefan Nolte[1], Andreas Tünnermann[1,3]; [1]Inst. of Applied Physics, Friedrich-Schiller-Univ. Jena, Germany, [2]Physics Dept. and Solid State Inst., Technion-Israel Inst. of Technology, Israel, [3]Fraunhofer Inst. for Applied Optics and Precision Engineering, Germany.* We experimentally demonstrate all-optical routing and switching of light pulses in array-junctions of evanescently coupled waveguides in fused silica. These junctions can be used as constituting elements of non-planar photonic circuits.

with synchronized phase shifts. With the proposed scheme, two DPSK signals at 10 Gb/s are successfully swapped experimentally.

PWB5 • 9:45 a.m.
Novel All-Optical on-off-Keyed to Alternate-Mark-Inversion Converter, *James Dailey*, *Rod Webb, Bob Manning; Tyndall Natl. Inst., Univ. College Cork, Ireland.* We numerically investigate a novel 40 Gbps OOK to AMI all-optical modulation format converter employing an SOA-based Mach-Zehnder interferometer. We demonstrate operation with a 2^7-1 PRBS and explain the phase modulation's relationship with patterning.

PWB6 • 10:00 a.m. Invited
Monolithic SOA Switch Fabric, *Ian White*, *Richard V. Penty, Adrian Wonfor; Univ. of Cambridge, UK.* This paper will review recent advances in semiconductor optical amplifier based switches. It will describe a 16x16 optical router with more than 1000 integrated components and indicate potential routes for advancement of this work.

IWA7 • 10:15 a.m.
Broad Tuning of Whispering-Gallery Modes in Microdisks, ***Jeffrey M. Shainline****, Lyuba Kuznetsova, Zhijun Liu, Gustavo Fernandes, Jimmy Xu; Brown Univ., USA.* Silicon microdisks with dynamically-tunable resonances are achieved with narrow, in-plane silicon electrical contacts in a single lithographic step. A 14nm wavelength shift is demonstrated with 1.6mW power consumption in devices with quality factors exceeding 20,000.

IWB8 • 10:15 a.m.
Staircase Approximation of Oblique Boundaries to Compute the Band Structures of Photonic Crystals, ***Stefan F. Helfert****; Fern Univ., Germany.* The computational window of photonic crystals is modeled by a staircase approximation to compute band structures with methods based on finite differences. Particularly, the treatment of discretization points outside the computational window is described.

PWA6 • 10:15 a.m.
Optical Logic Gates Using Interconnected Photodiodes and Electro-Absorption Modulators, ***Erik J. Skogen***[1]*, Allen Vawter*[1]*, Anna Tauke-Pedretti*[1]*, Mark Overberg*[1]*, Greg Peake*[1]*, Charles Alford*[2]*, David Torres*[3]*, Florante Cajas*[3]*, Charles T. Sullivan*[1]*;* [1]*Sandia Natl. Labs, USA,* [2]*Sandia Staffing Alliance, LLC, USA,* [3]*LMATA Government Services, LLC, USA.* We demonstrate an optical gate architecture with optical isolation between input and output using interconnected PD-EAMs to perform AND and NOT functions. Waveforms for 10 Gbps AND and 40 Gbps NOT gates are shown.

Coffee Break/Exhibits Open, 10:30 a.m.–11:00 a.m., *Cypress Foyer*

11:00 a.m.–12:30 p.m.

IWC • All-Optical Signal Processing

Graham Reed; Univ. of Surrey, UK, Presider

IWC1 • 11:00 a.m. Invited
All-Optical Signal Processing with Silicon-Organic Hybrid Slot Waveguides, ***Juerg Leuthold***[1]*, C. Koos*[1]*, W. Freude*[1]*, T. Vallaitis*[1]*, L. Alloatti*[1]*, D. Korn*[1]*, P. Dumon*[2]*, W. Bogaerts*[2]*, R. Baets*[2]*, I. Biaggio*[3]*, F. Diederich*[4]*;* [1]*Univ. of Karlsruhe, Germany,* [2]*Ghent Univ.-IMEC, Belgium,* [3]*Lehigh Univ., USA,* [4]*ETH Zürich, Switzerland.* The silicon-organic hybrid (SOH) platform is reviewed. The SOH approach is a promis-ing CMOS compatible photonic platform enabling ultrafast nonlinear signal processing in compact silicon photonic devices.

11:00 a.m.–12:30 p.m.

IWD • Modeling and Simulation IV: Optoelectronics

Vien Van; Univ. of Alberta, Canada, Presider

IWD1 • 11:00 a.m. Invited
Photon Management in Thin Film Solar Cells, ***Falk Lederer****, Carsten Rockstuhl, Stephan Fahr; Friedrich-Schiller-Univ. Jena, Germany.* We analyze the absorption enhancement in tandem solar cells where the interplay of two mechanisms is exploited, the scattering at textured surfaces, which increases the path of light, and the reflection at nanostructured intermediate layers.

11:00 a.m.–12:30 p.m.

PWC • Terabit/s, OFDM

Idelfonso Tafur Monroy; Technische Univ. Denmark, Denmark, Presider

PWC1 • 11:00 a.m. Invited
All-Optical FTT Signal Processing of a 10.8 Tb/s Single Channel OFDM Signal, ***Juerg Leuthold***[1]*, M. Winter*[1]*, W. Freude*[1]*, C, Koos*[1]*, D. Hillerkuss*[1]*, T. Schellinger*[1]*, R. Schmogrow*[1]*, T. Vallaitis*[1]*, R. Bonk*[1]*, A. Marculescu*[1]*, J. Li*[1]*, M. Dreschmann*[1]*, J. Meyer*[1]*, M. Huebner*[1]*, J. Becker*[1]*, S. Ben Ezra*[2]*, N. Narkiss*[2]*, B. Nebendahl*[3]*, F. Parmigiani*[4]*, P. Petropoulos*[4]*, B. Resan*[5]*, A. Oehler*[5]*, K. Weingarten*[5]*, T. Ellermeyer*[6]*, J. Lutz*[6]*, M. Möller*[6]*;* [1]*Karlsruhe Inst. of Technology, Germany,* [2]*Finisar Corp., Israel,* [3]*Agilent Technologies, Germany,* [4]*Univ. of Southampton, UK,* [5]*Time-Bandwidth Products, Switzerland,*

11:00 a.m.–12:30 p.m.

PWD • Signal Processing II

Antonella Bogoni; CNIT, Italy, Presider

PWD1 • 11:00 a.m.
Effective Sample Parallelization in a Single Nonlinear Device for High Sampling Rate Photonic Assisted ADC, *Lingmei Ma*[1]*,* ***Paolo Ghelfi***[2]*, Minyu Yao*[1]*, Fabrizio Berizzi*[3,4]*, Antonella Bogoni*[2]*;* [1]*Dept. of Electronic Engineering, Tsinghua Univ., China,* [2]*Natl. Lab on Photonic Networks, CNIT, Italy,* [3]*RaSS Ctr. - CNIT, Italy,* [4]*Dept. of Information Engineering, Univ. of Pisa, Italy.* An effective parallelization scheme in a single nonlinear device for high-sampling-rate photonic-assisted ADC is presented. 10-fold parallelization of 9.95GS/s signal is experimentally demonstrated with

IWC2 • 11:30 a.m.
Broadband Wavelength Conversion by Nondegenerate Four-Wave Mixing in a Silicon-on-Insulator Waveguide, ***Shiming Gao***[1,2]*, Zhiqiang Li*[1]*, En-Kuang Tien*[2]*, Qiang Liu*[1]*, Sailing He*[1]*, Ozdal Boyraz*[2]*;* [1]*Zhejiang Univ., China,* [2]*Univ. of California at Irvine, USA.* A bandwidth enhancement method is presented for silicon-on-insulator waveguide-based wavelength conversion using nondegenerate four-wave mixing. The conversion bandwidth is broadened by 28% in a 300 × 500 nm² waveguide as compared with the degenerate case.

IWD2 • 11:30 a.m.
Design and Optimization of Ultra Low Voltage, Wide Bandwidth Substrate Removed Electro-Optic Modulators, ***Selim Dogru****, JaeHyuk Shin, Nadir Dagli; Univ. of California at Santa Barbara, USA.* Design and optimization of wide bandwidth ultra low voltage substrate removed electro-optic modulators is described. 30 GHz bandwidth, 50 Ω impedance with V_π of 0.2 V should be possible.

[6]*Micram Microelectronic GmbH, Germany.* OFDM data with line rates at 10.8 Tbit/s is generated and decoded with a real-time alloptical FFT receiver.

PWC2 • 11:30 a.m.
Terabit/Second Modulation Format Independent Optical Transmitter and Receiver Using Optical Arbitrary Waveform Generation and Measurement, ***David J. Geisler****, Nicolas K. Fontaine, Ryan P. Scott, Jonathan P. Heritage, S. J. B. Yoo; Univ. of California at Davis, USA.* We investigate optical transmission systems using optical arbitrary waveform generation and measurement supporting any modulation format and scalable to >Tb/s. Experiments include 1.2 Tb/s packet generation and 3 b/s/Hz spectral efficiency and dispersion pre-compensated transmission.

capability for 6-bits ENOB. Potentials for larger parallelization is also discussed.

PWD2 • 11:15 a.m.
Super-Long Cavity, Monolithically Integrated 1-GHz Hybrid Mode-Locked InP Laser for All-Optical Sampling, ***Stanley Cheung***[1]*, Jong-Hwa Baek*[1]*, Francisco M. Soares*[1]*, Ryan P. Scott*[1]*, Xiaoping Zhou*[1]*, Nicolas K. Fontaine*[1]*, Michael Shearn*[2]*, Axel Scherer*[2]*, Douglas M. Baney*[3]*, S. J. Ben Yoo*[1]*;* [1]*Univ. of California at Davis, USA,* [2]*Caltech, USA,* [3]*Agilent Technologies, USA.* A 1-GHz hybrid mode-locked monolithic semiconductor laser on an InP platform is demonstrated. Monolithic integration of the 4.1 cm laser with active quantum well and passive waveguide is achieved with 1-D photonic crystal mirrors.

PWD3 • 11:30 a.m. Invited
Fourier-Transform, Integrated-Optic Spatial Heterodyne Spectrometers on Planar Lightwave Circuits, ***Katsunari Okamoto****; AiDi Corp., Japan.* Operational principle of an integrated-optic spectrometer based on Fourier-transform spectroscopy is described. Measurement results of the source spectrum with 20-GHz resolution using silica-based planar waveguide spectrometer will be presented.

Cypress I & II

IWC3 • 11:45 a.m. Invited

Chalcogenide Glass Chip Based Nonlinear Signal Processing, *Mark D. Pelusi*[1], *F. Luan[1], S. J. Madden[2], D.-y. Choi[2], D.a.p. Bulla[2], B. Luther-Davies[2], B. J. Eggleton[1]; [1]CUDOS, Univ. of Sydney, Australia, [2]CUDOS, Australian Natl. Univ., Australia.* We review the latest advances in dispersion-shifted, highly nonlinear planar rib waveguides fabricated in As_2S_3 glass for enabling broadband wavelength conversion and phase conjugation of high-speed, phase shift keyed signals via CW pumped four-wave mixing.

IWC4 • 12:15 p.m.

Slow Light in Coupled Resonator Large Cross-Section Rib Waveguides, *Jeremy J. Goeckeritz, **Steve Blair**; Univ. of Utah, USA.* We experimentally investigate the optical properties of a slow-light

Big Sur

IWD3 • 11:45 a.m.

Investigation of Gain-Bandwidth Limitations in Separate Absorption, Charge and Multiplication InAlAs/InGaAs Avalanche Photodiodes Using Frozen Field Monte Carlo Simulations, *Hektor T. Meier*[1], *Denis Dolgos[1], Markus Blaser[2], Bernd Witzigmann[3]; [1]ETH Zurich, Switzerland, [2]Enablence, Switzerland, [3]Univ. of Kassel, Germany.* Separate absorption, charge and multiplication (SACM) avalanche photodiodes (APDs) are investigated using a frozen field Monte Carlo (MC) approach. Gain-bandwidth limitations are analyzed by investigation of carrier arrival times at various positions within the device.

IWD4 • 12:00 p.m.

Adaptive Reduced Basis Method for Optical Scattering Problems, *Jan Pomplun, **Frank Schmidt**, Sven Burger, Lin Zschiedrich; Zuse Inst. Berlin, Germany.* We present an adaptive, error controlled reduced basis method for solving parameterized optical scattering problems. We present a 3-D optimization application from optical proximity correction (OPC) with extremely short online computation times.

IWD5 • 12:15 p.m.

All Optical Switching Based on Nonlinear Quasi Periodic Photonic Crystals, *Mohammad Hosain Teimourpour*; *Kermanshah Univ. of Technology, Islamic Republic of Iran.* A novel all optical switch

Cypress III

PWC3 • 11:45 a.m.

Negative Power Penalty of Optical OFDM Signal Transmission over Directly Modulated DFB Laser-Based IMDD Systems Incorporating Negative Dispersion Fibres, *Jianming Tang*, *Xing Zheng, Xianqing Jin, Roger Giddings, Jinlong Wei, Emilio Hugues-Salas, Yanhua Hong; School of Electronic Engineering, Bangor Univ., UK.* Simulated negative power penalties of optical OFDM transmissions over directly modulated DFB-based IMDD MetroCor SMFs show excellent agreements with real-time experimental measurements. Such penalties originating from reduced subcarrier-subcarrier intermixing impairments are controllable and cyclic prefix-independent.

PWC4 • 12:00 p.m. Invited

Terabit Optical Ethernet, *Daniel Blumenthal*; *Univ. of California at Santa Barbara, USA.* Abstract not available.

Cypress IV

PWD4 • 12:00 p.m.

Insertion Loss-Free 1×4 InGaAsP/InP Multimode Interference Waveguide Switch Integrated with Optical Amplifier, *Tetsuro Kubo*[1], *Shinji Tomofuji[1], Shinji Matsuo[2], Takaaki Kakitsuka[2], Ken-ichi Kitayama[1]; [1]Osaka Univ., Japan, [2]NTT Photonics Labs, Japan.* We prepare and experimentally demonstrate the compensation of the insertion loss of 1×4 InGaAsP/InP multimode interference (MMI) waveguide switch integrated with a semiconductor optical amplifier. The loss compensation of more than 12 dB is obtained.

PWD5 • 12:15 p.m.

Monolithic All-Optical Set-Reset Flip-Flop Operating at 10 Gb/s, *Andrea Trita*[1], *G. Mezosi[2], M. J. Latorre Vidal[1], M. Zanola[1], M. Sorel[2], I. Cristiani[1], P. Ghelfi[3], A. Bogoni[3], G. Giuliani[1]; [1]Univ. of Pavia, Italy,* waveguide realized on a silicon chip. We measure the group index, bandwidth and propagation loss.

based on Kerr bistability in odd sequence of Thue-Morse quasi periodic photonic crystal is investigated. Finite element analysis is used to investigate bistable switching with low threshold (6.12 W/cm^2).

[2]Univ. of Glasgow, UK, [3]CNIT, Italy. A monolithic semiconductor ring laser is operated as an all-optical Flip-Flop triggered by 4ps optical pulses. Bit-Error-Rate measurements of Set-Reset switchings under the injection of a Pseudo-Random-Bit-Sequence at 5 and 10 Gb/s have been performed.

12:30 p.m.–2:00 p.m., Lunch (on your own)

2:00 p.m.–4:00 p.m.

IWE • Photonic Nanowires and Crystals

Joyce Poon; Univ. of Toronto, Canada, Presider

IWE1 • 2:00 p.m. **Invited**
Nanowire Lasers and Nanophotonic Sources, *Silvija Gradecak*; *MIT, USA.* Application of semiconductor nanowire heterostructures as wavelength-tunable nanoscale lasers and light emitting diodes will be discussed. Cathodoluminescence in TEM directly correlates structural and optical properties of nanowire heterostructures with high spatial resolution for future device optimization.

2:00 p.m.–4:00 p.m.

IWF • Monolithic and Hybrid Photonic Integration in Silicon

Nadir Dagli; Univ. of California at Santa Barbara, USA, Presider

IWF1 • 2:00 p.m. **Invited**
Integration of Optical Receivers for On-Chip Interconnects, *Solomon Assefa*; *IBM T.J. Watson Res. Ctr., USA.* Compact germanium waveguide photodetector with 10fF capacitance, 40Gbps bandwidth and 0.4A/W responsivity was monolithically integrated into front-end CMOS process utilizing a rapid-melt-growth technique. In the avalanche regime, gain-bandwidth product above 350GHz was achieved at ~3V.

2:00 p.m.–4:00 p.m.

PWE • Nanophotonics, Lasers, Flip-Flops

Bryan S. Robinson; MIT Lincoln Lab, USA, Presider

PWE1 • 2:00 p.m. **Invited**
Extremely-Low-Power Nanophotonic Devices Based on Photonic Crystals, *Kengo Nozaki*[1], *A. Shinya[1], T. Tanabe[1], S. Matsuo[2], T. Sato[2], T. Kakitsuka[2], E. Kuramochi[1], H. Taniyama[1], M. Notomi[1]; [1]NTT Basic Res. Labs, Japan, [2]NTT Photonics Labs, Japan.* Photonic crystal nanocavities are expected to greatly reduce the size and energy consumption of a wide variety of optical devices. We have successfully demonstrated this feature in all-optical switches, bistable memories, and other optical functionalities.

2:00 p.m.–4:00 p.m.

PWF • RF/Optical, PON, WAN Testbed

Loukas Paraschis; Cisco Systems, USA, Presider

PWF1 • 2:00 p.m.
65km Transmission of Dispersion-Compensation-Free, Extended-Reach OCDMA-PON System with Passive Remote Node Using Single Multi-Port Encoder/Decoder, *Nobuyuki Kataoka*[1], *Satoshi Yoshima[2], Yusuke Tanaka[3], Junichi Nakagawa[2], Naoya Wada[1], Ken-ichi Kitayama[3]; [1]NICT, Japan, [2]Mitsubishi Electric Corp., Japan, [3]Osaka Univ., Japan.* In an extended-reach OCDMA-PON system with passive remote node, 10-Gbps, 4-user, OCDMA transmission over 65-km standard SMF using a single multi-port encoder/decoder and 3R receiver for 10G-EPON systems without inline dispersion compensation is successfully demonstrated.

PWF2 • 2:15 p.m.
System Performance oOf 2x2 Coupler-Based All-Optical OFDM System, *Seong-Jin Lim*, *June-Koo Kevin Rhee; KAIST, Republic of Korea.* Fiber optic Fourier transform devices for all-

IWE2 • 2:30 p.m.

Enhanced Room-Temperature Light-Emission from Tensile-Strained Germanium Nanocrystals, *Latha Nataraj[1], Fan Xu[1],* ***Sylvain G. Cloutier**[1,2]; [1]Univ. of Delaware, USA, [2]Delaware Biotechnology Inst., USA.* We report on the high room-temperature luminescence from Germanium nanocrystals synthesized by mechanical grinding. Transients and optical spectroscopy measurements are consistent with HRTEM and electron diffraction, suggesting high tensile strains favoring direct band-to-band transitions.

IWE3 • 2:45 p.m.

Hybrid III-V Photonic Crystal Waveguide Laser on Silicon Wire, *Yacine Halioua[1,2], Alexandre Bazin[1], Timothy Karle[1], Paul Monnier[1], Isabelle Sagnes[1], Gunther Roelkens[2], Rama Raj[1],* ***Fabrice Raineri**[1,3]; [1]CNRS - LPN, France, [2]Ghent Univ., Belgium, [3]Univ. Paris Diderot, France.* We report laser emission from InP-based wire cavities bonded to silicon on insulator wafers. Both, Cavities bonded to unpatterned wafers and bonded to wafers with singlemode waveguides are studied.

IWF2 • 2:30 p.m. Invited

Heterogeneous InP on SOI Integration for the Realization of All-Optical Logic Devices, ***Geert Morthier**[1], Liu Liu[1], Rajesh Kumar[1], Pauline Mechet[1], Koen Huybrechts[1], Gunther Roelkens[1,2], Thijs Spuesens[1], Tsjibbe De Vries[2], Erik-Jan Geluk[2], Philippe Regreny[3], Roel Baets[1], Dries Van Thourhout[1]; [1]IMEC- Univ. of Ghent, Belgium, [2]Technische Univ. Eindhoven, Netherlands, [3]Univ. de Lyon, France.* InP-based microdisk lasers, heterogeneously integrated onto SOI waveguides, can be used as generic non-linear devices for realizing all-optical logic. We will discuss the performance of individual microdisk lasers, and the implementation of more complex circuits.

PWE2 • 2:30 p.m.

Fast All-Optical Memory and Switching with Mode-Locked Quantum Dot Lasers, *Mingming Feng[1], Steven Cundiff[2], Richard P. Mirin[1],* ***Kevin L. Silverman**[1]; [1]NIST, USA, [2]JILA, NIST, Univ. of Colorado, USA.* We investigate the wavelength switching properties of a bistable two-section quantum-dot diode laser. The switching time is about 150 ps, which is approximately two round trips times of the laser.

PWE3 • 2:45 p.m.

Electro-Optic Modulation with a Single Quantum Dot Strongly Coupled to a Nanocavity, ***Arka Majumdar**[1], Andrei Faraon[1], Nicolas Manquest[1], Hyochul Kim[2], Pierre Petroff[1], Jelena Vuckovic[1]; [1]Stanford Univ., USA, [2]Univ. of California at Santa Barbara, USA.* The resonance of a quantum-dot strongly coupled to a photonic-crystal cavity is electrically controlled. This effect is employed to demonstrate an electro-optic modulator operating at 1fJ/bit control energy and speed of 150MHz.

optical OFDM systems show critical crosstalk penalties against phase errors in the device. We report active phase control can effectively mitigate crosstalk significantly even under existent of loss errors**.**

PWF3 • 2:30 p.m. Invited

Next Mobile Network Based on Optical Switching, ***Masami Yabusaki**, Hendrik Berndt, Joerg Widmer; Docomo Communications Labs Europe GmbH, Germany.* We propose to introduce optical-switching technologies to the next mobile network to handle the huge volume of future mobile traffic. This requires research on key technologies such as optical mobility management and inter-base station MIMO.

Cypress I & II

IWE4 • 3:00 p.m.
Photoluminescence from Silicon Dioxide Photonic Crystal Cavities with Embedded Silicon Nanocrystals, *Yiyang Gong*[1], *Satoshi Ishikawa[2], Szu-Lin Cheng[1], Yoshio Nishi[1], Jelena Vuckovic[1]; [1]Stanford Univ., USA, [2]Process Res. Ctr., Corporate Manufacturing Engineering Ctr., Toshiba Corp., Japan.* One dimensional nanobeam photonic crystal cavities are fabricated in silicon dioxide with silicon nanocrystals. Photoluminescence from 600 nm to 800 nm is coupled to the cavities with experimental quality factors of over 9,000.

IWE5 • 3:15 p.m.
3-D Woodpile Photonic Crystal Fabrication Using a One Step Scaffold Inversion Method, *Leo T. Varghese*, *Li Fan, Yi Xuan, Lin Zhao, Minghao Qi; Purdue Univ., USA.* 3-D photonic crystals can be fabricated in one step through HSQ scaffolds patterned by e-beam lithography and inversed by thin film deposition. A defect-free Si woodpile is demonstrated with transmission dip of 70% near IR.

IWE6 • 3:30 p.m.
Antireflection and Enhanced Absorption in Tapered Silicon Photonic Crystals, *Yung-Jr. Hung*[1], *San-Liang Lee[1], Brian J. Thibeault[2], Larry A. Coldren[2]; [1]Dept. of Electronic Engineering, Natl. Taiwan Univ. of Science and Technology, Taiwan, [2]Dept. of Electrical and Computer Engineering, Univ. of California at Santa Barbara, USA.* Tapered silicon photonic crystals provide a broad and wide-angle

Big Sur

IWF3 • 3:00 p.m.
Integrated Multi-Wavelength Silicon Germanium High Speed Receivers, *Ying-hao Kuo*[1], *Martin Kwakernaak[1], Xiaochen Sun[1,2], John Pescatore[2], Mark Gilmer[2], John-Rolf Oakley[2,3], Zhenli Ji[3], Anguel Nikolov[3]; [1]PhotonIC Corp., USA, [2]Advanced Integrated Photonics Inc., USA, [3]APIC Corp., USA.* A multi-wavelength receiver was fabricated on SOI using a monolithically integrated arrayed waveguide grating (AWG) and 32 germanium waveguide photodetectors. The CMOS compatible high-speed detectors are capable for OC-192 or 10Gb/s data rate.

IWF4 • 3:15 p.m.
Waveguide-Integrated Photodiode in Deposited Silicon, *Kyle Preston*, *Mian Zhang, Michal Lipson; Cornell Univ., USA.* We demonstrate photodiodes in deposited polycrystalline silicon at 1550nm with 0.15 A/W responsivity, 40 nA dark current, and GHz response time. We propose an interconnect scheme with modulators and photodetectors in the same deposited material.

IWF5 • 3:30 p.m.
Integrated Hybrid Silicon Triplexer, *Hsu-Hao Chang*[1], *Ying-hao Kuo[1], Richard Jones[2], Assia Barkai[3], John Bowers[1]; [1]Univ. of California at Santa Barbara, USA, [2]Intel Corp., USA, [3]Intel Corp., Israel.* We demonstrate a triplexer with an integrated wavelength splitter, two photodetectors and a transmit laser. The measured 3dB bandwidth of the integrated laser and photodetectors are 2GHz and

Cypress III

PWE4 • 3:00 p.m. Invited
Fast and Energy Efficient Optical Switches and Modulators Based on Photonic Crystals, *Jelena Vučković*, *Bryan Ellis, Arka Majumdar, Gary Shambat, Andrei Faraon, Dirk Englund; Edward L. Ginzton Lab, Stanford Univ., USA.* Nanophotonic devices have been employed to demonstrate efficient all-optical and electro-optical switching at the control energies even below 1fJ, and speeds that could exceed 10GHz.

PWE5 • 3:30 p.m.
Analytical Investigation of an All-Optical T-Type Flip-Flop Using an SOA-MZI with Push-Pull Configuration for DPSK Encoding, *Satoshi Shimizu*, *Hiroyuki Uenohara; Tokyo Inst. of Technology, Japan.* We propose an all-optical T-type Flip-Flop for DPSK encoding consisting of an SOA-MZI with push-pull configuration and a feedback mirror. Numerical simulation

Cypress IV

PWF4 • 3:00 p.m.
Format Multiplexing from ASK and DPSK to QPSK in an Assistant Light Controlled SOA, *Ying Gao[1], Jiaojiao Fu[1], **Shiming Gao**[1], Chester Shu[2], Sailing He[1]; [1]Ctr. for Optical and Electromagnetic Res., Zhejiang Univ., China, [2]Dept. of Electronic Engineering, Chinese Univ. of Hong Kong, China.* We propose and demonstrate an all-optical format-multiplexing scheme for combining DPSK and ASK into QPSK format in an assistant light controlled SOA. A 20 Gb/s QPSK signal have been successfully obtained with error-free demodulated results.

PWF5 • 3:15 p.m.
A Proposal for a Tunable Light Storage Method Based on Quasi-Light-Storage and Frequency-to-Time-Conversion, *Kambiz Jamshidi*, *Christian Alexander Bunge, Thomas Schneider; Deutsche Telecom Hochschule für Telekommunikation Leipzig, Germany.* We propose a quasi-light-storage method which is based on frequency-to-time conversion and capable of being integrated with a delay-bitrate product of 50 bits. The delay can be tuned in fine and coarse range easily.

PWF6 • 3:30 p.m. Invited
Experiments of IP Optical Multi-Layer Network in Japan National Testbed, *Kohei Shiomoto*[1], *Akeo Masuda[1], Akinori Isogai[1], Yoshihiro Nakajima[2], Testuo Kawano[2], Mitsuru Maruyama[2], Eiji Ohtsuki[3], Kazumasa Kobayashi[3], Shinji Shimojo[3]; [1]NTT Network Service Systems Labs, Japan, [2]NTT Network Innovation Labs, Japan, [3]NICT, Japan.* IP Optical Multi-layer Network (MLN) integrates the traffic engineering

antireflective window and strong optical resonances for enhanced absorption for TE- and TM-polarized light, respectively, showing the potential for improving the performance of photovoltaic devices.

IWE7 • 3:45 p.m.

Photonic Crystal Waveguide Structures Based on Epitaxial Barium Titanate Thin Films, ***Zhifu Liu***[1], *Jianheng Li*[1], *Pao-Tai Lin*[1], *Bruce W. Wessels*[1], *Alexandra Joshi-Imre*[2], *Leonidas E. Ocola*[2]; [1]*Northwestern Univ., USA,* [2]*Argonne Natl. Lab, USA.* Two-dimensional photonic crystal waveguide structures were fabricated from $BaTiO_3$ thin film using focused ion beam method. At a wavelength of 1.55 μm, drive voltage has a factor of 6.6 improvement compared to conventional waveguide structure.

16GHz, respectively.

IWF6 • 3:45 p.m.

High Sensitivity Defect-Enhanced Silicon Ring-Resonator Photodetectors at Telecom Wavelengths, ***Dylan F. Logan***[1], *Philippe Velha*[1], *Marc Sorel*[1], *Richard De La Rue*[1], *Andrew Knights*[2], *Paul Jessop*[2]; [1]*Univ. of Glasgow, UK,* [2]*McMaster Univ., Canada.* We report the fabrication and characterization of a 29 mA/W sensitivity integrated silicon microring photodetector at 1550 nm. It is formed of a lateral p-i-n junction with defects incorporation via high energy ion implantation.

reveals its possibility of stable operation in 10Gbps.

PWE6 • 3:45 p.m.

Transfer Function and Toggling Speed Analysis of an Optical Flip-Flop Based on Coupled SOA-MZIs, ***Dimitrios Fitsios***[1], *Konstantinos Vyrsokinos*[2], *Nikos Pleros*[1]; [1]*Aristotle Univ. of Thessaloniki, Greece,* [2]*Informatics and Telematics Inst., Ctr. for Res. and Technology Hellas, Greece.* We derive an analytical expression for the frequency-domain transfer function of an optical flip-flop relying on two coupled SOA-MZIs, demonstrating qualitative and quantitative toggling speed performance analysis for different coupling lengths between the two MZIs.

control across IP and optical layers. We developed a technology to provide stable and on-demand transmission of gigabit-class wideband video over the IP Optical MLN. We succeeded in verifying our concept through the actual deployment of uncompressed HDTV transmission in JGN2plus, a nation-wide R&D testbed network in Japan.

4:00 p.m.–4:30 p.m., Coffee Break/Exhibits Open, *Cypress Foyer*

4:30 p.m.–6:30 p.m.

IWG • Nonlinear Nanophotonics

Romain Quidant; ICFO, Presider

IWG1 • 4:30 p.m. **Invited**
Optical Parametric Oscillation on a Chip, *Alexander Gaeta*; *Cornell Univ., USA.* Abstract not available.

IWG2 • 5:00 p.m.
Nonlinear Frequency Conversion in GaP Photonic Crystal Nanocavities, *Kelley Rivoire*[1], *Ziliang Lin[1], Fariba Hatami[2], W. Ted Masselink[2], Jelena Vuckovic[1]; [1]Stanford Univ., USA, [2]Humboldt Univ., Germany.* Using photonic crystal nanocavities fabricated in the semiconductor gallium phosphide, we demonstrate second harmonic generation with

4:30 p.m.–6:30 p.m.

IWH • Modeling and Simulation V: Waveguides

Ya Yan Lu; City Univ. of Hong Kong, Hong Kong, Presider

IWH1 • 4:30 p.m.
Ultra-Compact Optical Coupler and Splitter Using High-Contrast Grating Hollow-Core Waveguide, *Bala Pesala*[1], *Vadim Karagodsky[2], Connie Chang-Hasnain[2]; [1]Central Electronics Engineering Res. Inst., India, [2]Univ. of California at Berkeley, USA.* Large size reduction of photonic components by a factor of 10 is predicted using hollow-core waveguides based on high-contrast grating. Simulation results show extremely compact coupler and splitter with a length of 26 μm and 3.6 μm respectively.

IWH2 • 4:45 p.m.
A Short Polarization Converter Using an L-Figured Si Wire Waveguide, *Yuu Wakabayashi*, *Masashi Nakamura, Junji Yamauchi, Hisamatsu Nakano; Hosei Univ., Japan.* A simple Si wire polarization converter is proposed and numerically analyzed. An extinction ratio of more than 20 dB is obtained over a wide wavelength range of 1.3 μm to 1.6 μm.

IWH3 • 5:00 p.m.
Numerical Study of a Waveguide Polarizer Using a Loaded Metal Film, *Junji Yamauchi,* ***Tomohiro Nakano****, Hisamatsu Nakano; Hosei Univ., Japan.* An embedded waveguide is modified to a polarizer, in which either TE or TM polarized wave is transmitted. The thickness and the refractive index of a buffer layer are key parameters to cut undesirable

4:30 p.m.–6:30 p.m.

PWG • Closing Session

nanowatts of input continuous wave powers (at 1550 nm). We also show sum frequency generation using two cavity modes.

IWG3 • 5:15 p.m.
Nonlinearity Enhancement with Low-Dispersion Slow-Light in Chalcogenide Glass Photonic Crystal Waveguide, *Keijiro Suzuki*[1,2], *Yohei Hamachi[1,2], Toshihiko Baba[1,2]; [1]Yokohama Natl. Univ., Japan, [2]JST-CREST, Japan.* We demonstrate several-pi phase shift through self-phase modulation in a 400- µm -long chalcogenide-glass photonic-crystal waveguide. The nonlinearity is enhanced by low-dispersion slow-light mode to 160 times higher than in Si wire waveguide.

IWG4 • 5:30 p.m.
Compact MZ- Interferometer Based on Self-Collimation of Light in a Silicon Photonic Crystal, *Huub Salemink*; *Delft Univ. Technology, Netherlands.* We demonstrate a compact silicon photonic crystal Mach-Zehnder interferometer operating in the self-collimation regime.The 2-D and 3-D simulation results, silicon membrane nanofabrication, near-field propagation and MZ output are discussed.

IWG5 • 5:45 p.m.
Low Power and Compact Reconfigurable Silicon Multiplexing Devices, *Po Dong*[1], *Wei Qian[1], Hong Liang[1], Roshanak Shafiiha[1], Ning-Ning Feng[1], Dazeng Feng[1], Xuezhe Zheng[2], Ashok V. Krishnamoorthy[2], Mehdi Asghari[1]; [1]Kotura Inc., USA, [2]Oracle America,*

polarization.

IWH4 • 5:15 p.m.
Ultrabroadband Low Dispersion Silicon-on-Nitride Waveguide in Mid-Infrared Region, *Yang Yue*[1], *Lin Zhang[1], Raymond Beausoleil[2], Alan Willner[1]; [1]Univ. of Southern California, USA, [2]HP Labs, USA.* The designed silicon-on-nitride waveguide illustrates an ultrabroadband (~4200 nm) low chromatic dispersion (±0.05 ps/(nm·m)) in mid-infrared wavelength region. This provides a good nonlinear medium for broadband signal processing.

IWH5 • 5:30 p.m.
Higher-Order Dispersion of Optical Waveguides, *J. A. Mores-Jr.*[1,2], *G. N. Malheiros-Silveira[1], H. E. Hernández-Figueroa[1], H. L. Fragnito[2]; [1]UNICAMP, State Univ. of Campinas, Brazil, [2]Inst. de Física "Gleb Wataghin", UNICAMP, Brazil.* We present an efficient Code that allows analysis of higher-order dispersion parameters (HODP) of Optical Waveguides. Synthesis is possible to Photonic Crystal Fibers (PCF). The results show that our Code can model accurately such parameters.

IWH6 • 5:45 p.m.
Highly-Nonlinear Horizontal Slot Waveguideswith Low and Flat Dispersion, *Masa-aki Komatsu*, *Kunimasa Saitoh, Masanori Koshiba; Hokkaido Univ., Japan.* We present an optimum design of highly-nonlinear horizontal slot waveguides with

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Inc., USA. We present thermally reconfigurable multiplexing devices based on silicon microring resonators with a low tuning power of 21 mW per free spectral range and a negligible thermal crosstalk for rings separated by 15 μm.

IWG6 • 6:00 p.m.
High Reflectivity Dielectric Gratings With Large Focusing Power, *David A. Fattal*, *Jingjing Li, Marco Fiorentino, Zhen Peng, Raymond G. Beausoleil; HP Labs, USA.* We introduce a novel optical element, a dielectric resonance grating with a non-periodic pattern, able to reflect nearly 100% of incident light while shaping the reflected light phase front in an arbitrary way.

IWG7 • 6:15 p.m.
Integrated Photonic Magic-T (with Twice the Magic), *Miloš A. Popović*[1], *Anatol N. Khilo*[2]; [1]*Univ. of Colorado at Boulder, USA,* [2]*MIT, USA.* We propose a photonic 4-port that doubly guarantees 50:50 signal splitting from either input port: by symmetry, analogously to the microwave "magic T", and by adiabaticity. Applications include coherent receivers, dual-output modulators and polarization diversity.

6:30 p.m.–7:30 p.m.

IWI • IPR Postdeadline Session

flat dispersion characteristics. Numerical simulations show that 6000 $W^{-1}m^{-1}$ nonlinear coefficient and flat dispersion on a 260-nm bandwidth can be achieved.

IWH7 • 6:00 p.m.
Characterization of Nanoscale Silicon Photonic Devices, *David Leung,* ***B.M.A. Rahman****, M.A. Ashraf, H. Tanvir, N. Kejalakshmy, A. Agrawal, R. Kabir, K.T.V. Grattan; City Univ. London, UK.* The full-vectorial H and E-field profiles along with the Poynting vector are shown for the nanoscale silicon waveguides. Uses for sensing and polarization conversion are also discussed for the design of compact silicon photonic devices.

IWH8 • 6:15 p.m.
Improved Analysis of Rectangular Dielectric Waveguides Based on a Legendre Pseudospectral Penalty Scheme, *Shun-Fan Chiang*[1], *Bang-Yan Lin*[1], *Chun-Hao Teng*[2], ***Hung-chun Chang***[1]; [1]*Natl. Taiwan Univ., Taiwan,* [2]*Natl. Chiao Tung Univ., Taiwan.* A Legendre pseudospectral method with penalty scheme is established in frequency domain for high-accuracy waveguide mode analysis. For a square dielectric waveguide, the calculated modal index is seen to converge to the order of 10^{-11}.

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Key to Authors and Presiders

(**Bold** denotes Presider or Presenting Author)

Integrated Photonics Research, Silicon and Nano Photonics (IPR)/ Photonics in Switching (PS)

Update Sheet

Location Updates:

The conference Get Together Party on Sunday night will be located on the Lower Terrace. Further information is located in your registration packet.
The Welcome Reception will now be in the Cypress Foyer.

Withdrawals:

JTuB5

Presentation Time Update:

PWC4, Terabit Optical Ethernet, *Daniel Blumenthal;* *Univ. of California at Santa Barbara, USA* will be presented from 11:00 a.m.–11:30 a.m.in session **PWC, Terabit/s, OFDM.**
PWC1, All-Optical FTT Signal Processing of a 10.8 Tb/s Single Channel OFDM Signal*, **Juerg Leuthold**[1], M. Winter[1], W. Freude[1], C, Koos[1], D. Hillerkuss[1], T. Schellinger[1], R. Schmogrow[1], T. Vallaitis[1], R. Bonk[1], A. Marculescu[1], J. Li[1], M. Dreschmann[1], J. Meyer[1], M. Huebner[1], J. Becker[1], S. Ben Ezra[2], N. Narkiss[2], B. Nebendahl[3], F. Parmigiani[4], P. Petropoulos[4], B. Resan[5], A. Oehler[5], K. Weingarten[5], T. Ellermeyer[6], J. Lutz[6], M. Möller[6]; [1]Karlsruhe Inst. of Technology, Germany, [2]Finisar Corp., Israel, [3]Agilent Technologies, Germany, [4]Univ. of Southampton, United Kingdom, [5]Time-Bandwidth Products, Switzerland, [6]Micram Microelectronic GmbH, Germany* will be presented from 12:00 p.m.–12:30 p.m. in session in session **PWC, Terabit/s, OFDM.**

Presenter Update:

ITuA4 will be presented by ***Juejun Hu;*** *MIT, USA*
IWG1 will be presented by ***Mark Foster,*** *Johns Hopkins Univ., USA*
IWH5 will be presented by ***H. E. Hernández-Figueroa,*** *Inst. de Física "Gleb Wataghin", UNICAMP, Brazil*
JTuB1 will be presented by ***Kunimasa Saitoh,*** *Hokkaido Univ., Japan*
PDPWG2 will be presented by ***Antonella Bogoni;*** *Univ. of Southern California, USA*

Presider Update:

PMC will be presided over by ***Takuo Tanemura;*** *Univ. of Tokyo, Japan*
PTuD will be presided over by ***Pulak K. Chowdhury;*** *Univ. of California at Davis, USA*
PWC will be presided over by ***Shifu Yuan;*** *Calient Networks, USA*

Author Block Update:

The author block for **JTuB41** should read: ***Juhao Li,*** *Su Zhang, Fan Zhang, Zhangyuan Chen, Chunxu Zhao; Peking Univ., China.*
The author block for PWA1 should read: ***Antonella Bogoni**[1,2], Xiaoxia Wu[2], Jian Wang[2], Alan E. Willner[2]; [1]Natl. Lab of Photonic Networks, CNIT, Italy, [2]Univ. of Southern California, USA.*

• Wednesday, July 28, 2010 •

Photonics in Switching
Postdeadline Paper Abstracts

PWG • Closing Session

Cypress III & IV
4:30 p.m.–5:30 p.m.
John Bowers; Univ. of California at Santa Barbara, USA, Presider

PDPWG1 • 4:30 p.m.
Routing, Wavelength Assignment, and Spectrum Allocation in Transparent Flexible Optical WDM (FWDM) Networks, *Ankitkumar N. Patel[1,2], **Philip N. Ji**[1], Jason P. Jue[2], Ting Wang[1]; [1]NEC Labs America, USA, [2]Univ. of Texas at Dallas, USA.* We propose the flexible optical WDM network architecture, and introduce the routing, wavelength assignment, and spectrum allocation problem in transparent FWDM networks. Spectrum and cost efficiency are improved compared to fixed grid networks.

PDPWG2 • 4:45 p.m.
50-Gbaud/s Optical Addition and Dual-Directional Subtraction of Quaternary Base Numbers using Nonlinearities and 100-Gbit/s (D)QPSK Signals, ***Jian Wang**, Scott Nuccio, Jeng-Yuan Yang, Hao Huang, Xiaoxia Wu, Antonella Bogoni, Alan Willner; Univ. of Southern California, USA.* We report an optical approach to addition/subtraction of quaternary numbers using nonlinearities and (D)QPSK signals. 50-Gbaud/s quaternary addition(A+B) and dual-directional subtraction(A-B/B-A) are demonstrated with 100-Gbit/s (D)QPSK. Power penalties <4 (addition) and 3dB (subtraction) are obtained.

PDPWG3 • 5:00 p.m.
Silicon-chip-based Optical Performance Monitoring Of Thz Bandwidth Phase And Intensity Modulated Signals, *Bill Corcoran[1], Trung D. Vo[1], **Mark D. Pelusi**[1], Christelle Monat[1], Adam Densmore[2], Rubin Ma[2], Dan-Xia Xu[2], Siegfried Janz[2], David J. Moss[1], Benjamin J. Eggleton[1]; [1]CUDOS, IPOS, School of Physics, Univ. of Sydney, Australia, [2]Inst. for Microstructural Sciences, NRC-CNRC, Canada.* We present a silicon-chip-based optical performance monitor, using an all-optical RF spectral analysis technique, capable of real-time performance monitoring both phase and intensity encoded signals. The device operates unimpeded by the effects of photo-generated free-carriers.

Integrated Photonics Research, Silicon and Nano Photonics (IPR)
Postdeadline Paper Abstracts

IWI • IPR Postdeadline Session

Cypress I & II
6:30 p.m.–7:30 p.m.
Andrea Melloni; Politecnico di Milano, Italy, Presider
Liming Zhang; Bell Labs, Lucent Technologies, USA, Presider

PDIWI1 • 6:30 p.m.
Superconducting Transition-Edge Sensors for Waveguide Coupled Single Photon Detection, ***Anna E. Fox**, Adriana E. Lita, Brice Calkins, Kevin L. Silverman, Richard P. Mirin, Sae Woo Nam; NIST, USA.*
We present the design and important preliminary superconducting properties of an evanescently coupled number-resolving single photon detector operating near 1550 nm that is in development for integration into a silicon-on-insulator waveguide based optical system.

PDIWI2 • 6:42 p.m.
As-Grown InGaAs Nanolasers for Integrated Silicon Photonics, ***Roger Chen**, Thai-Truong D. Tran, Kar Wei Ng, Wai Son Ko, Linus C. Chuang, Forrest G. Sedgwick, Connie Chang-Hasnain; Univ. of California at Berkeley, USA.* We report on-chip InGaAs nanopillar lasers directly grown on silicon using a low-temperature, CMOS-compatible MOCVD process. A novel whispering gallery and Fabry-Perot hybrid cavity mode provides optical feedback for laser oscillation in as-grown subwavelength nanopillars.

PDIWI3 • 6:54 p.m.
Electroluminescence of Erbium Doped Silicon Nitride Films, ***Selcuk Yerci**, Rui Li, Luca Dal Negro; Boston Univ., USA.* Electroluminescence at 980nm and 1535nm from erbium-doped silicon nitride films was reported and the Er effective excitation cross section was measured under electrical pumping. Erbium electroluminescence is observed at voltages as low as 5V.

PDIWI4 • 7:06 p.m.

Room Temperature Nano-Square Plasmon Laser, ***Renmin Ma****, Rupert F. Oulton, Volker J. Sorger, Guy Bartal, Xiang Zhang; Univ. of California at Berkeley, USA.* We report plasmon lasers with strong cavity feedback and optical confinement to 1/20th wavelength. Strong feedback arises from total internal reflection of plasmons, while confinement enhances the spontaneous emission rate by up to 18 times.

PDIWI5 • 7:18 p.m.

Demonstration of a High Speed 4-Channel Integrated Silicon Photonics WDM Link with Hybrid Silicon Lasers, ***Andrew Alduino***[1]*, Ling Liao*[1]*, Richard Jones*[1]*, Michael Morse*[1]*, Brian Kim*[1]*, Wei-Zen Lo*[1]*, Juthika Basak*[1]*, Brian Koch*[1]*, Hai-Feng Liu*[1]*, Haisheng Rong*[1]*, Matthew Sysak*[1]*, Christine Krause*[1]*, Rushdy Saba*[2]*, Dror Lazar*[2]*, Lior Horwitz*[2]*, Roi Bar*[2]*, Stas Litski*[2]*, Ansheng Liu*[1]*, Kevin Sullivan*[1]*, Olufemi Dosunmu*[1]*, Neil Na*[1]*, Tao Yin*[1]*, Frederick Haubensack*[1]*, I-wei Hsieh*[1]*, John Heck*[1]*, Robert Beatty*[1]*, Hyundai Park*[1]*, Jock Bovington*[1]*, Simon Lee*[1]*, Hat Nguyen*[1]*, Hinmeng Au*[1]*, Katie Nguyen*[1]*, Priya Merani*[1]*, Mahtab Hakami*[1]*, Mario Paniccia*[1]*;* [1]*Intel Corp., USA,* [2]*Intel Corp., Israel.* The demonstration of a 4λx10Gbps Silicon Photonics CWDM link integrating all optical components, electronics and packaging technologies required for system integration is reported. Further demonstration of the link operating at 50Gbps, 4λx12.5Gbps, is also shown.

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Key to Authors and Presiders

(**Bold** denotes Presider or Presenting Author)