

Colored Optical Packet Switching and Related Technologies

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University Roma Tre, Italy

CNIT, Italy

ISCOM, Italy

Univ. Duisburg-Essen, Germany

it, Portugal

Budapest Univ. of Technology and Economics, Hungary

.....and many past collaborators

Acknowledgment

A part of this work has been done in collaboration with University Roma Tre, Osaka University, Yokogawa Electric, NTT Electronics, Fujitsu, Anritsu, and Amonics

I would like to thank H. Furukawa, N. Kataoka, H. Harai, Y. Awaji, X. Wang, S. Shinada, H. Ohtsuki, T. Miyazaki, Y. Tomiyama, T. Hanyu, N. Takezawa, T. Hashimoto, H. Sumimoto, and T. Makino of NICT for their collaboration in experiments

I would like to extend my thank G. Cincotti of University Roma Tre and K. Kitayama of Osaka University for their valuable discussion and collaboration in all-optical label processing



Outline

- 1. Background**
- 2. Concept & Key technologies for IP over WDM-colored OPS**
- 3. 80G bps/port WDM-colored OPS prototype & 3D-HDTV Video Streaming demonstration**
- 4. 160G bps/port WDM-colored OPS prototype & field demonstration**

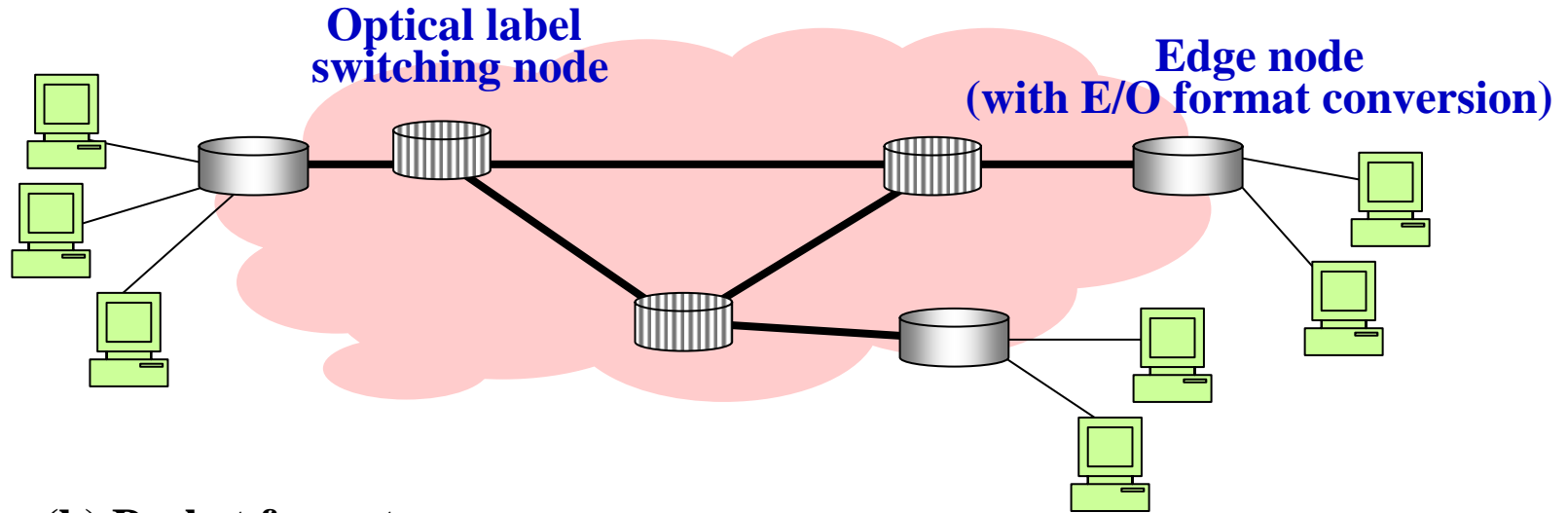
Outline

1. Background

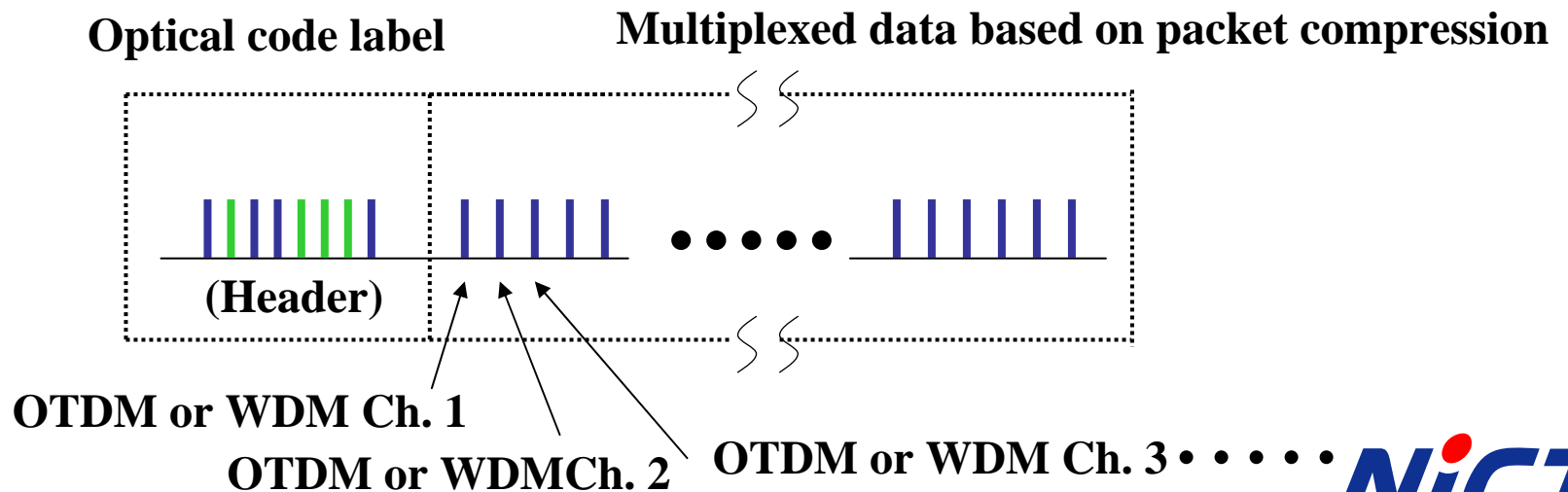
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Network architecture and packet format

(a) Network architecture

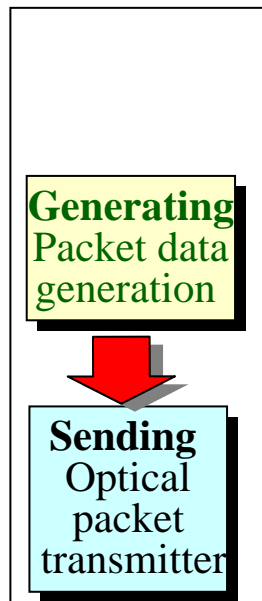


(b) Packet format

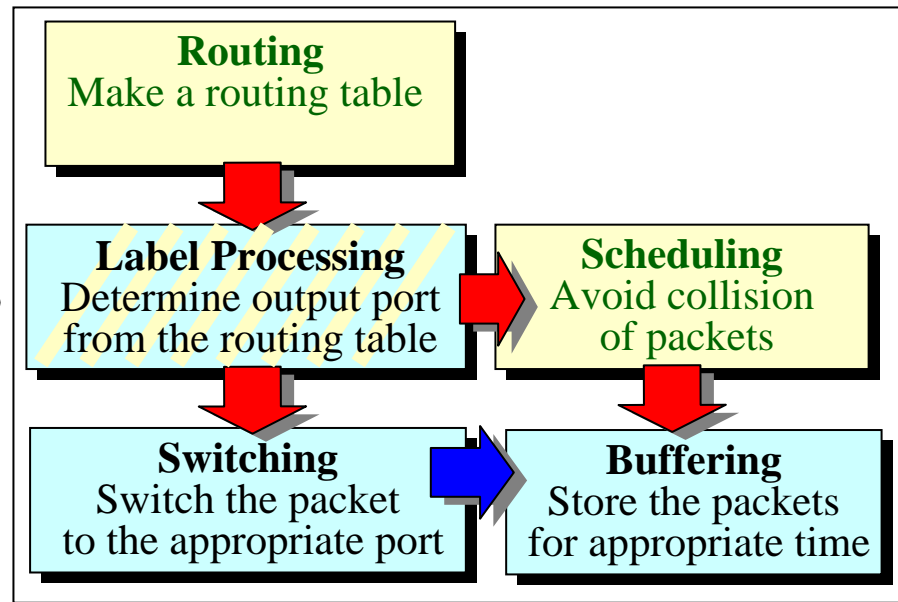


Functions of OPS prototype

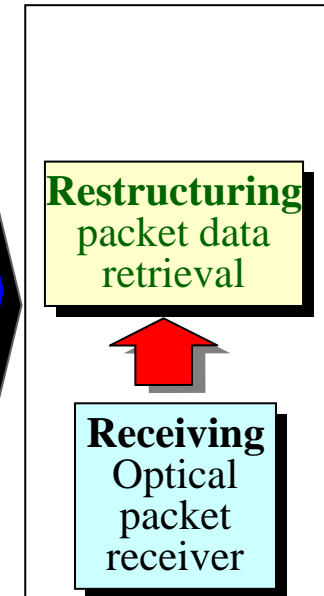
Ingress node



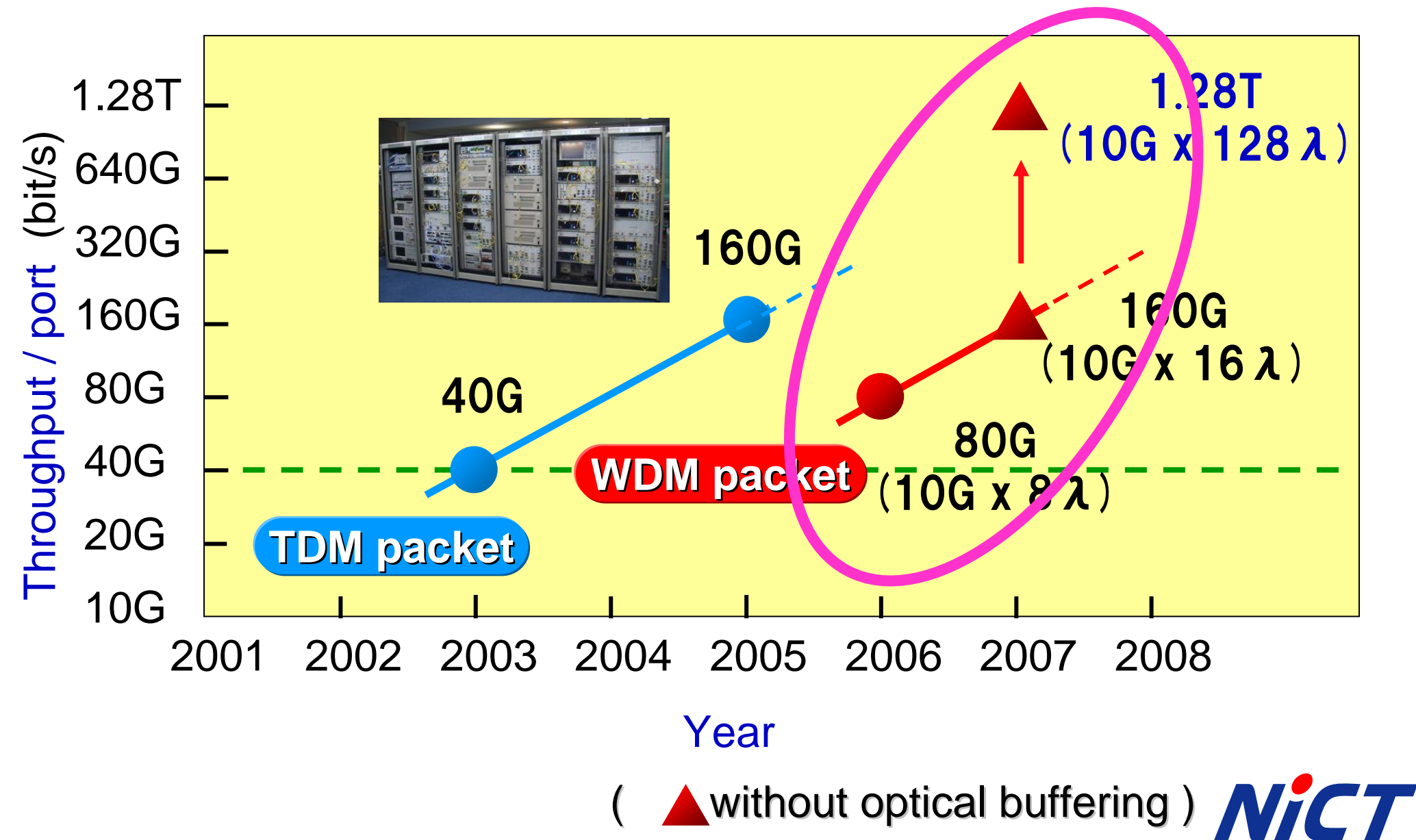
OPS node



Egress node



OPS Prototype Development by NICT



Performance of 160 Gbit/s

Phone: 64k

ADSL: 50M

FTTH: 100M

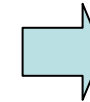
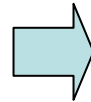
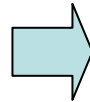
OPS: 160G



(x 800)

(x 2)

(x 1600)



8000
character/s
||

6.25 million
character/s
||

12.50 million
character/s
||

20 billion
character/s
||

2 page/s of A4

1500 page/s of A4

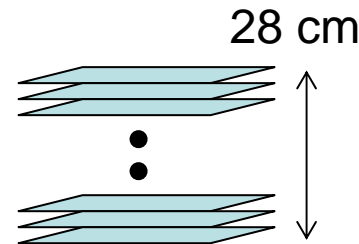
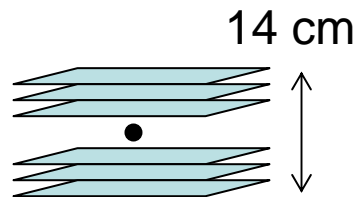
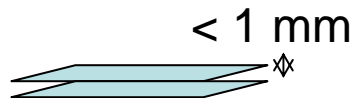
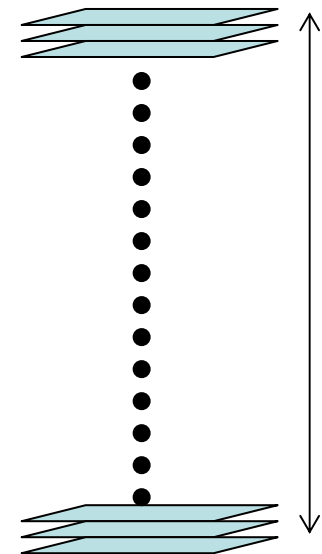
3000 page/s of A4

4.8 million page/s of A4

Let's stack papers.....



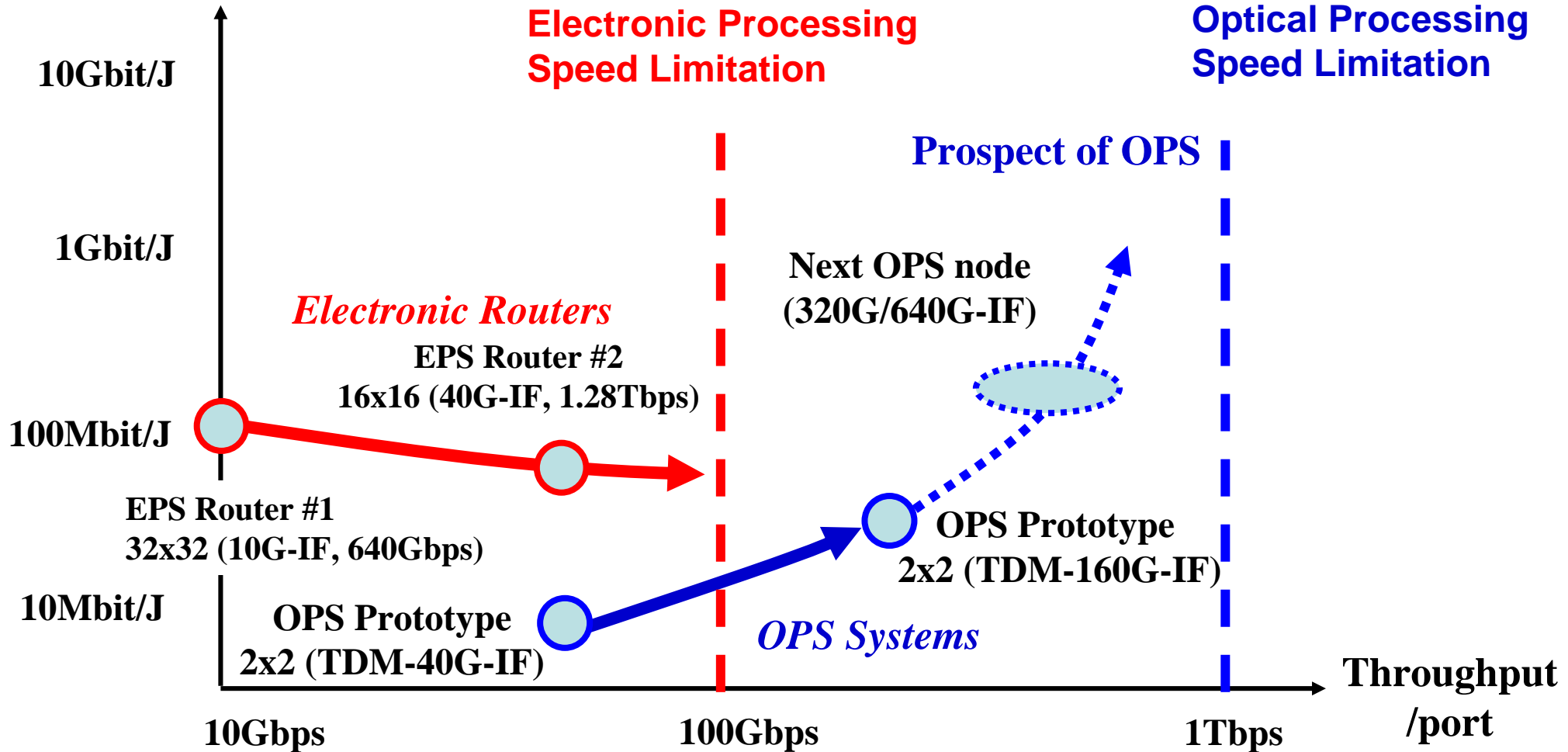
440 m



(1 character = 8 bit)

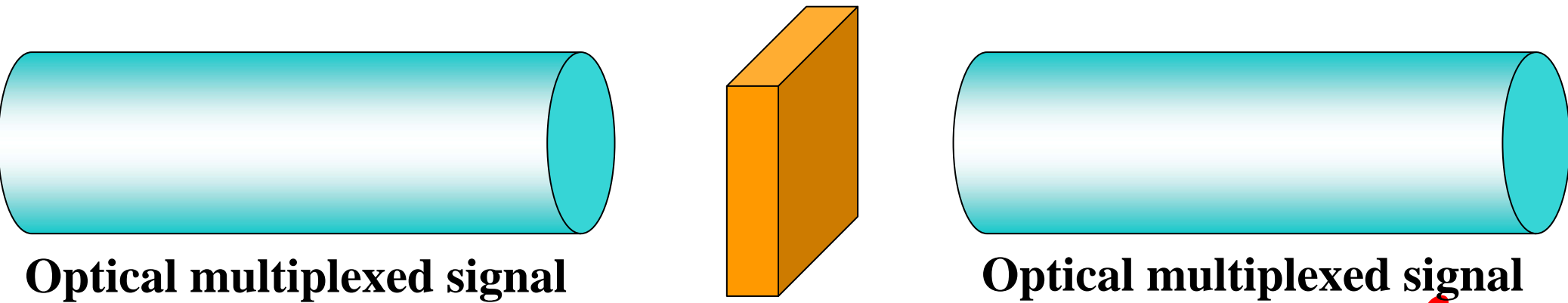
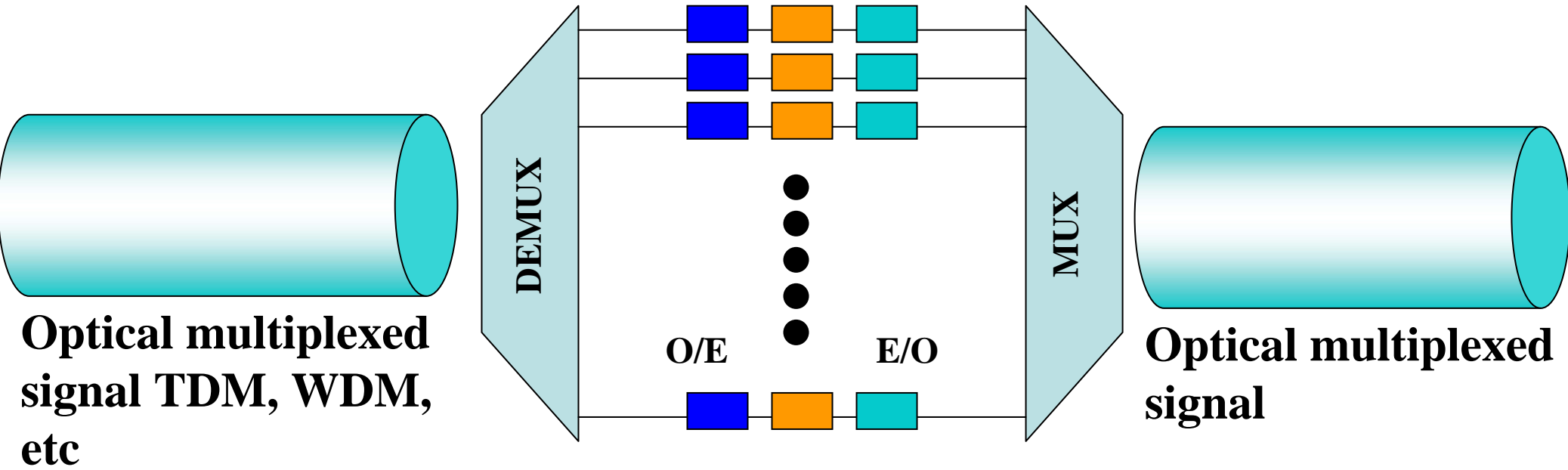
Possibility of high speed node with low power

Performance : bit/J



EPS: Electronic Packet Switch
OPS: Optical Packet Switch

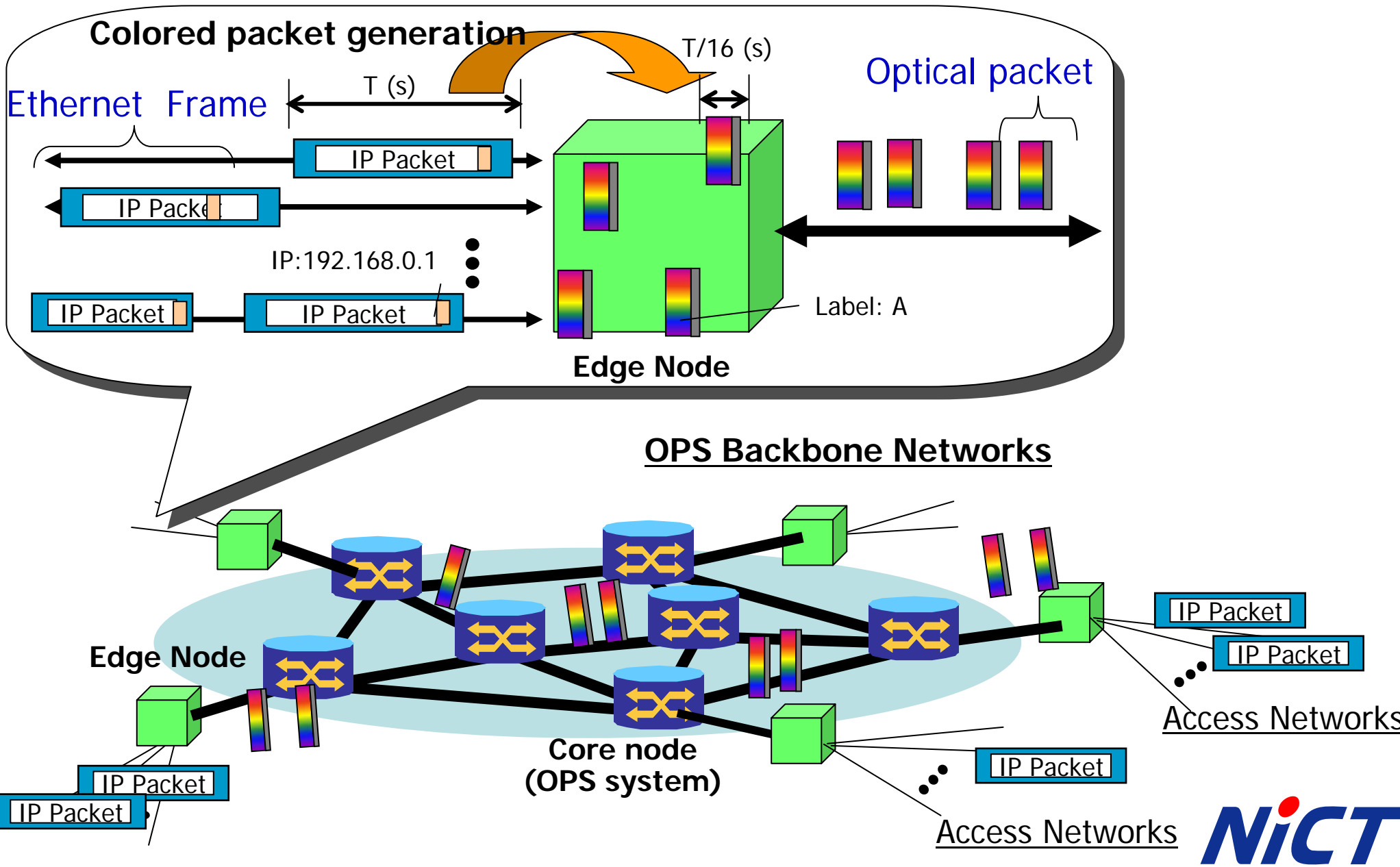
Wideband switching (Electrical vs. Optical)



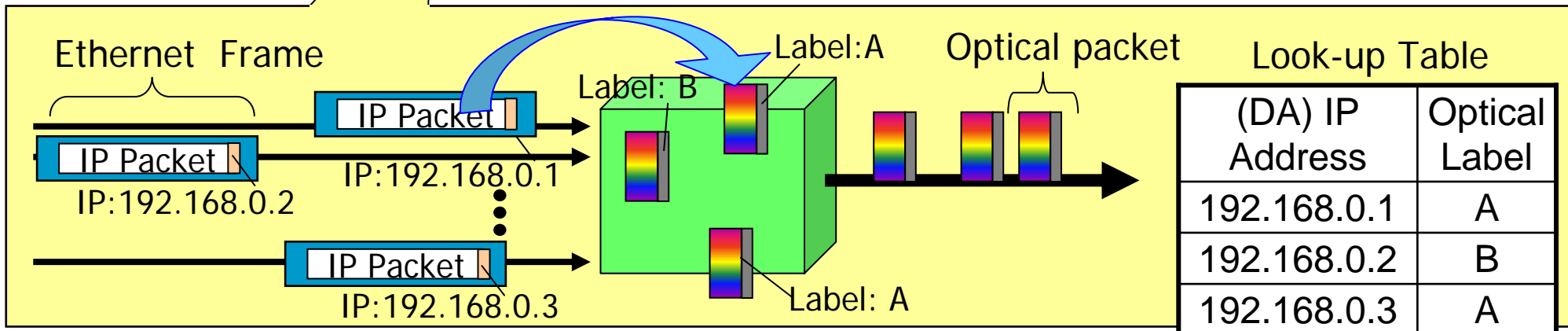
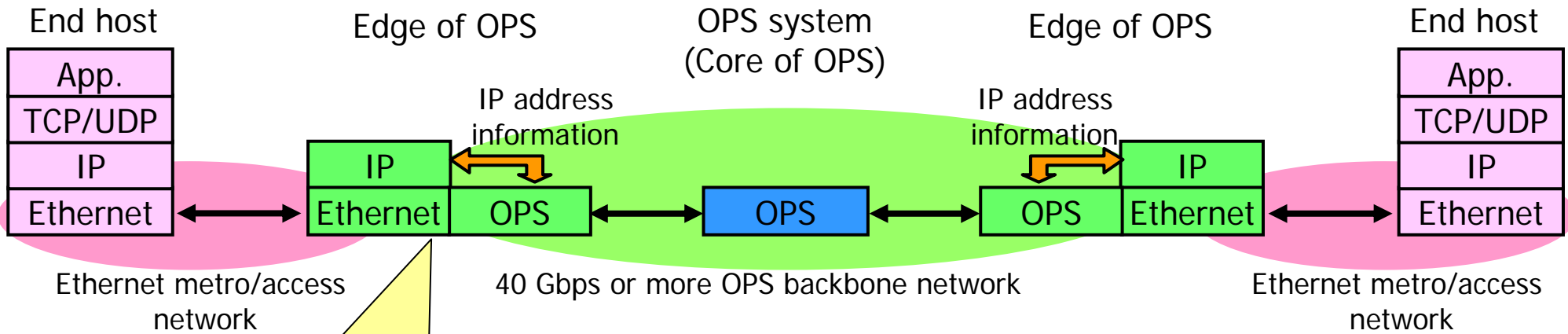
Outline

1. Background
2. **Concept & Key technologies for IP over WDM-colored OPS**
3. **80G bps/port WDM-colored OPS prototype & 3D-HDTV Video Streaming demonstration**
4. **160G bps/port WDM-colored OPS prototype & field demonstration**

IP over WDM-colored OPS network

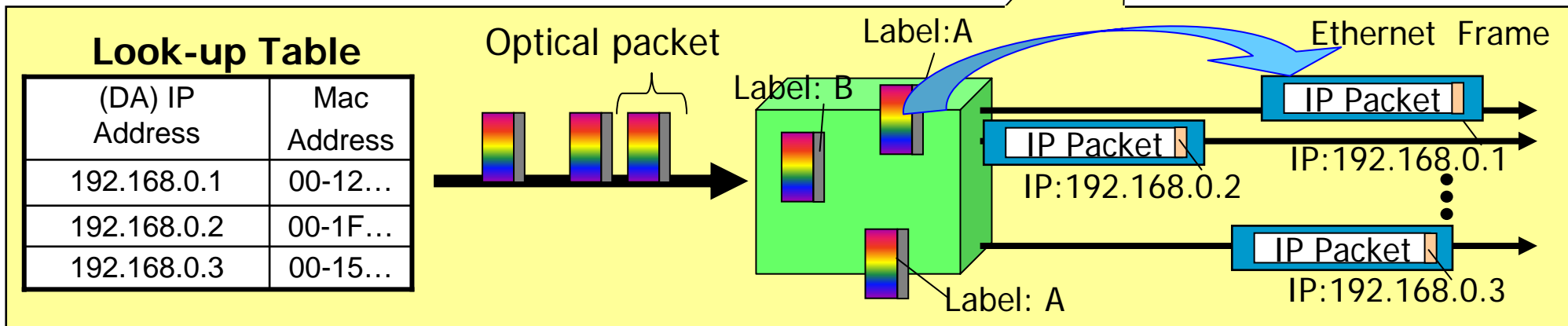
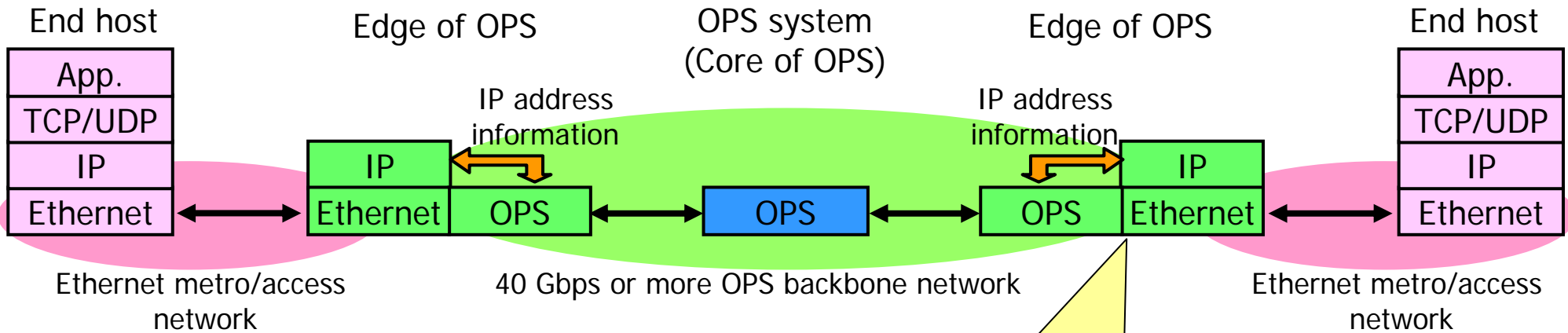


Concept of IP over WDM-colored OPS network



The 80GOP packet and the IP packet are one-to-one corresponding.

Concept of IP over WDM-colored OPS network



We develop novel interfacing technologies to **connect between 10Gb Ethernet and 80Gbps OPS networks**, and demonstrate the **IP over WDM-colored OPS network**.

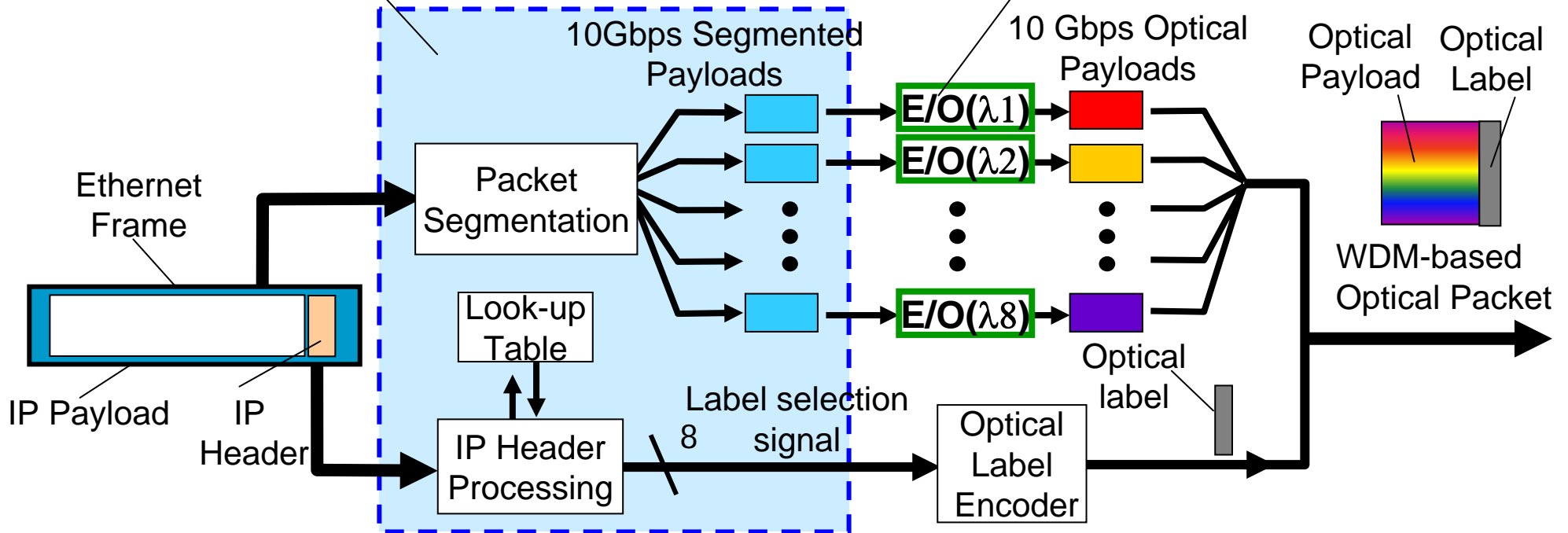
10GbE-OP converter and Packet Tx.



10GbE-OP converter



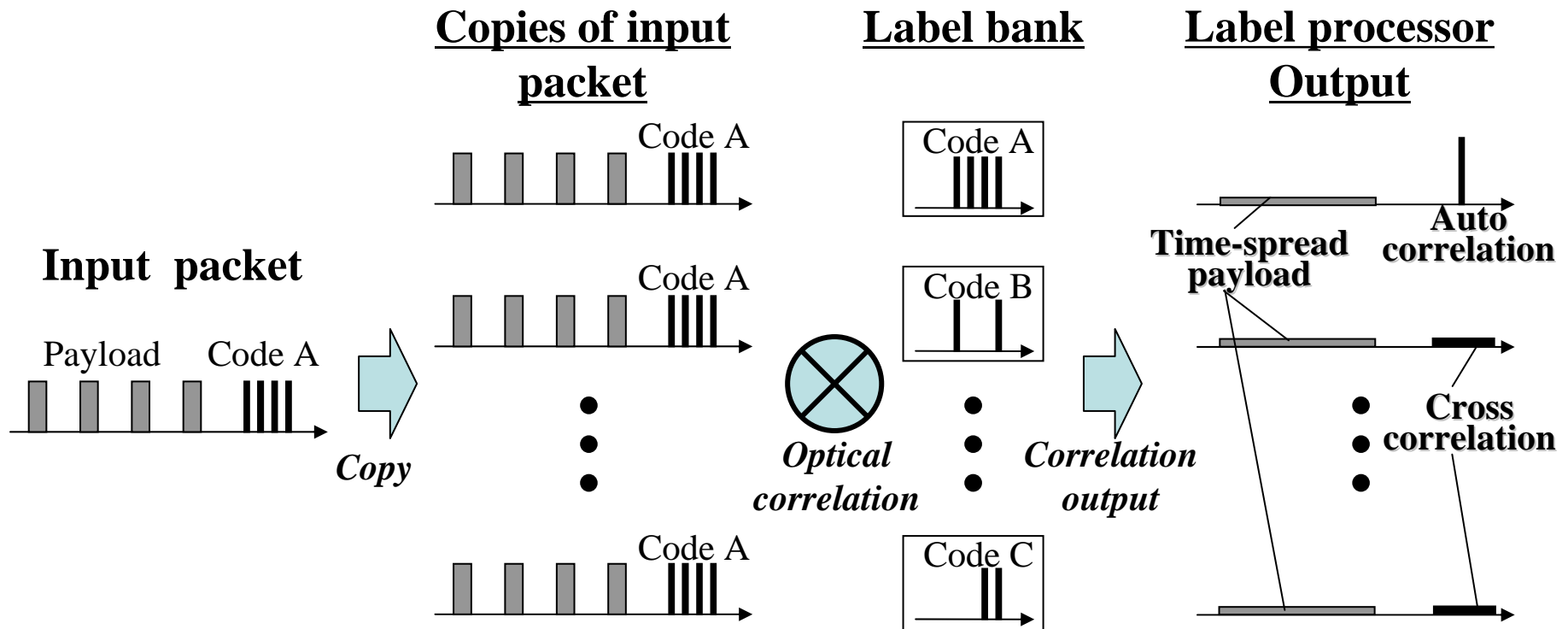
Burst mode
packet Tx. array



- Tx.: Electro-absorption modulators (EAM) with distributed feedback (DFB) lasers



All-optical label processing based on optical correlation

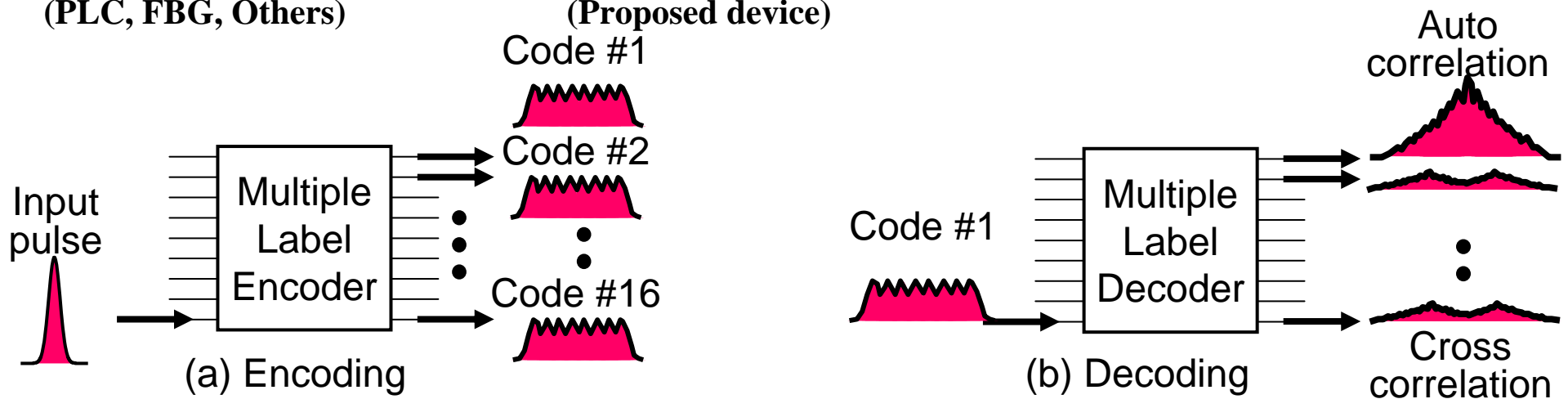
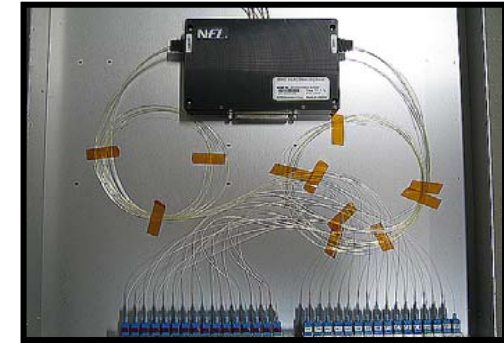
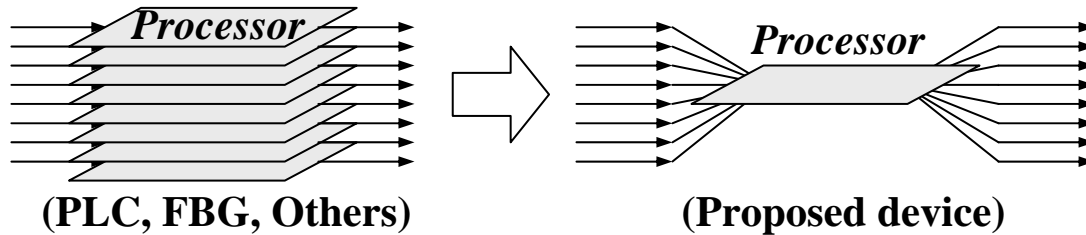


Multiple optical label processing

- We first introduce 200 Gchip/s multiple optical code (OC) encoder/decoder with an arrayed waveguide configuration.
- It can generate and recognize simultaneously sixteen different 16-chip optical phase shift keying codes with low latency.
- The processing rate is 13 Gpacket/s.

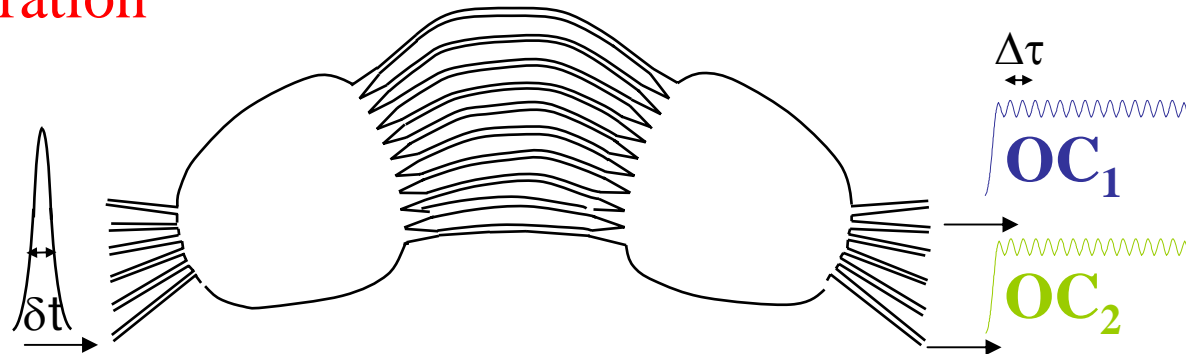
Stack of processing devices

A "multiple" processing device

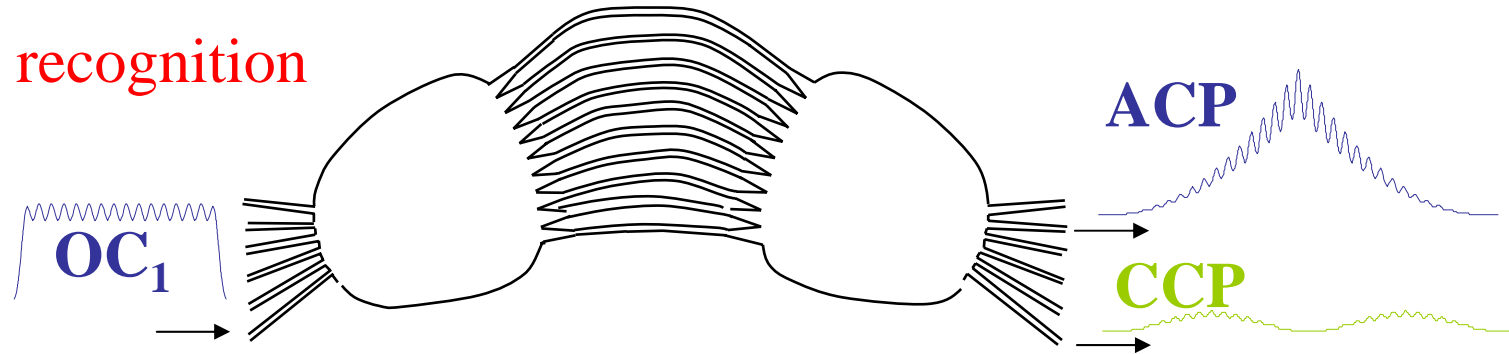


Multiple encoder/decoder in a AWG like configuration

Code generation

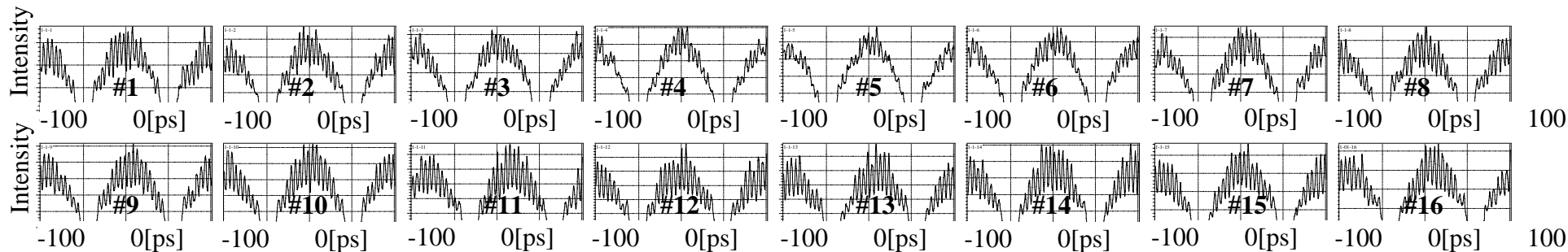


Code recognition

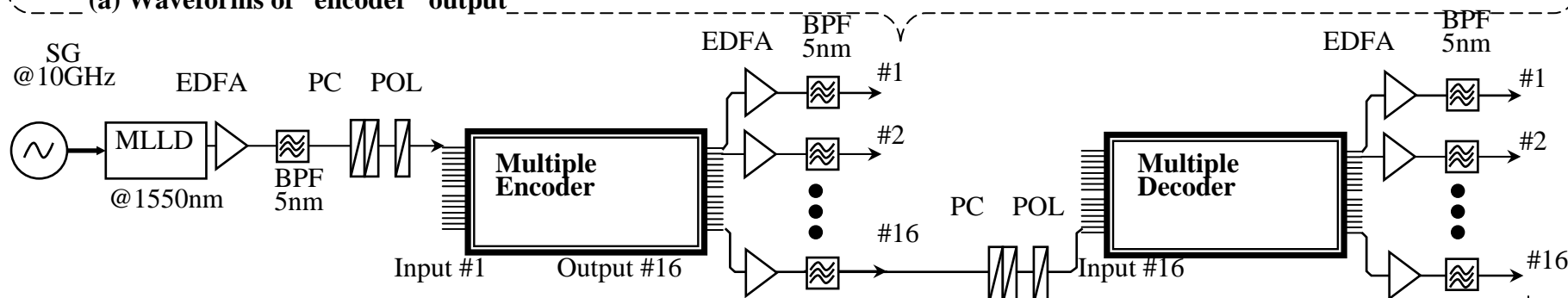


See G. Cincotti, et al., IEEE/OSA J. Lightwave Technol., vol.24, no.1, pp.103-112, 2006.

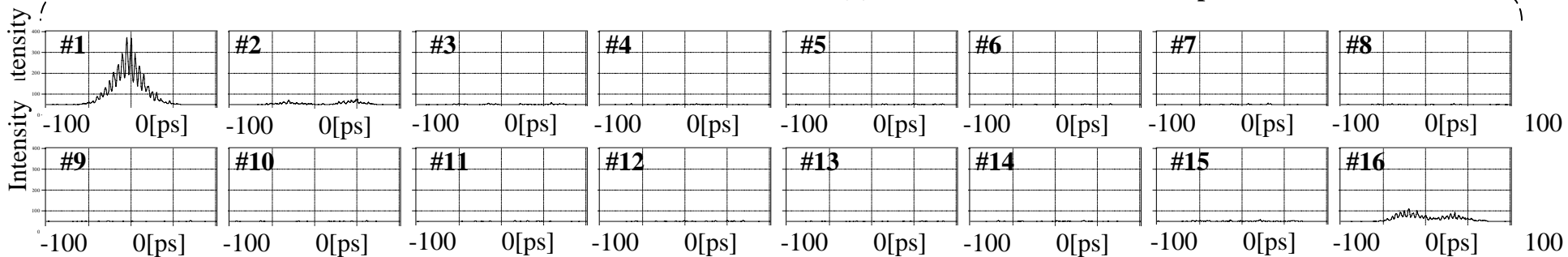
Multiple-optical label recognition



(a) Waveforms of "encoder" output



(b) Waveforms of "decoder" output



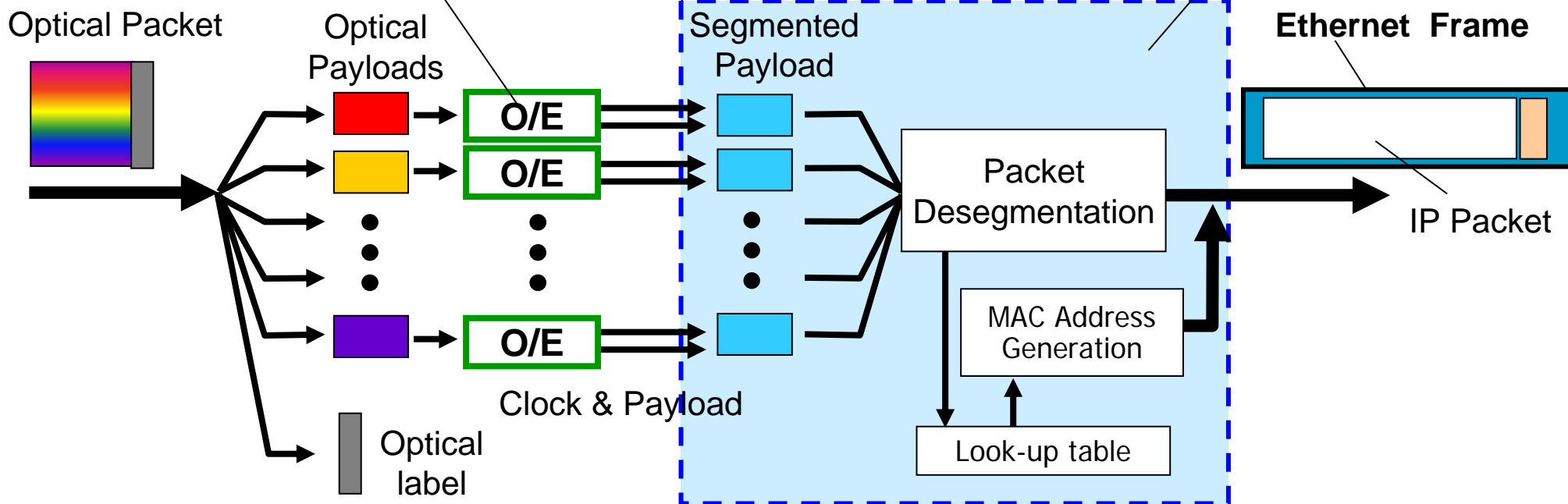
Packet Rx. and OP-10GbE converter



Burst mode
packet Rx. array

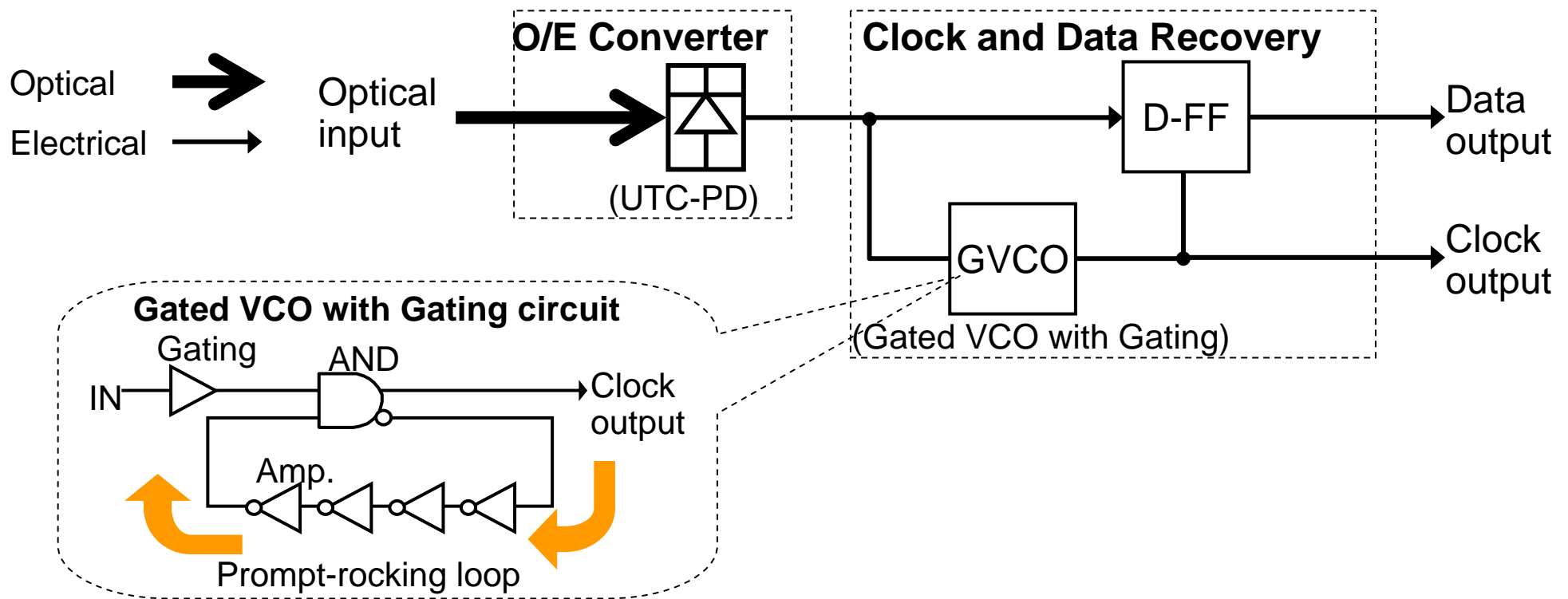


OP-IP converter



- The receiver consists of high-speed uni-traveling-carrier PD and a low jitter gated voltage controlled oscillator with digital ring PLL.

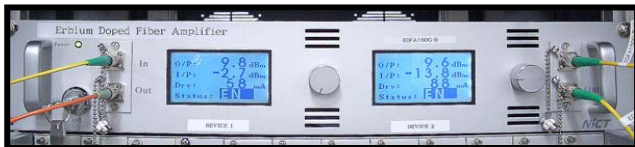
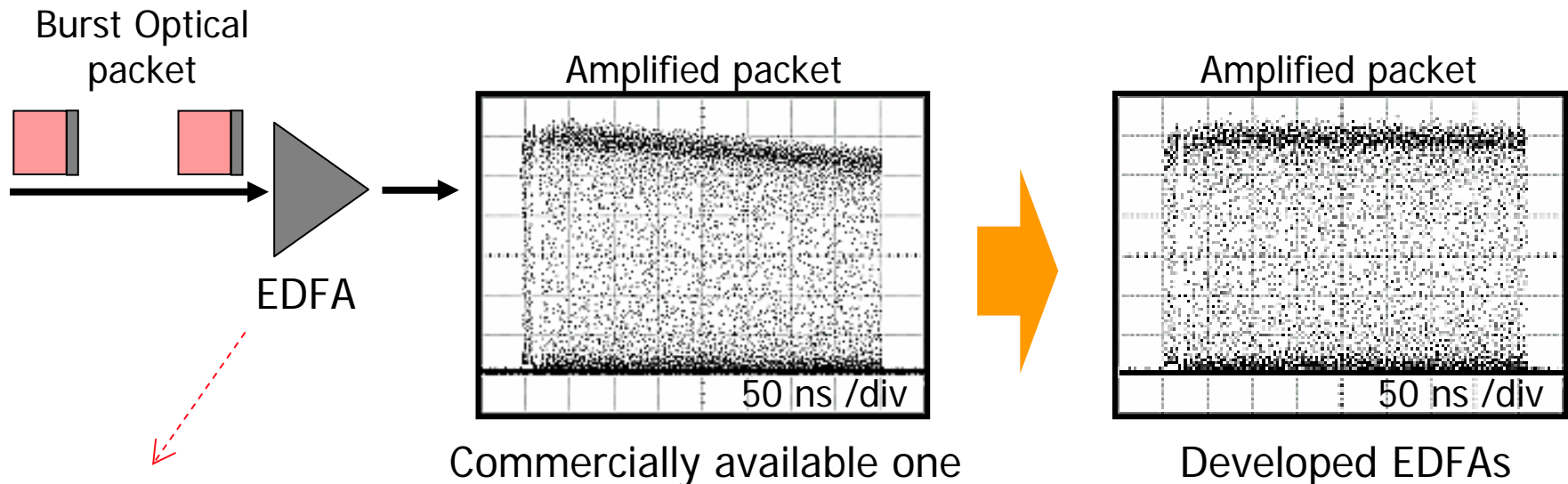
Burst-mode Packet Receiver



- The receiver mainly consists of specially tuned **high-speed UTC** (uni-traveling-carrier) **PD** and a **low jitter gated VCO** (voltage controlled oscillator) with **digital ring PLL** (phase lock loop).
- The gating circuit and the PLL enable very fast **synchronization time** (< 1 ns) of the output clock phase with the input data phase.

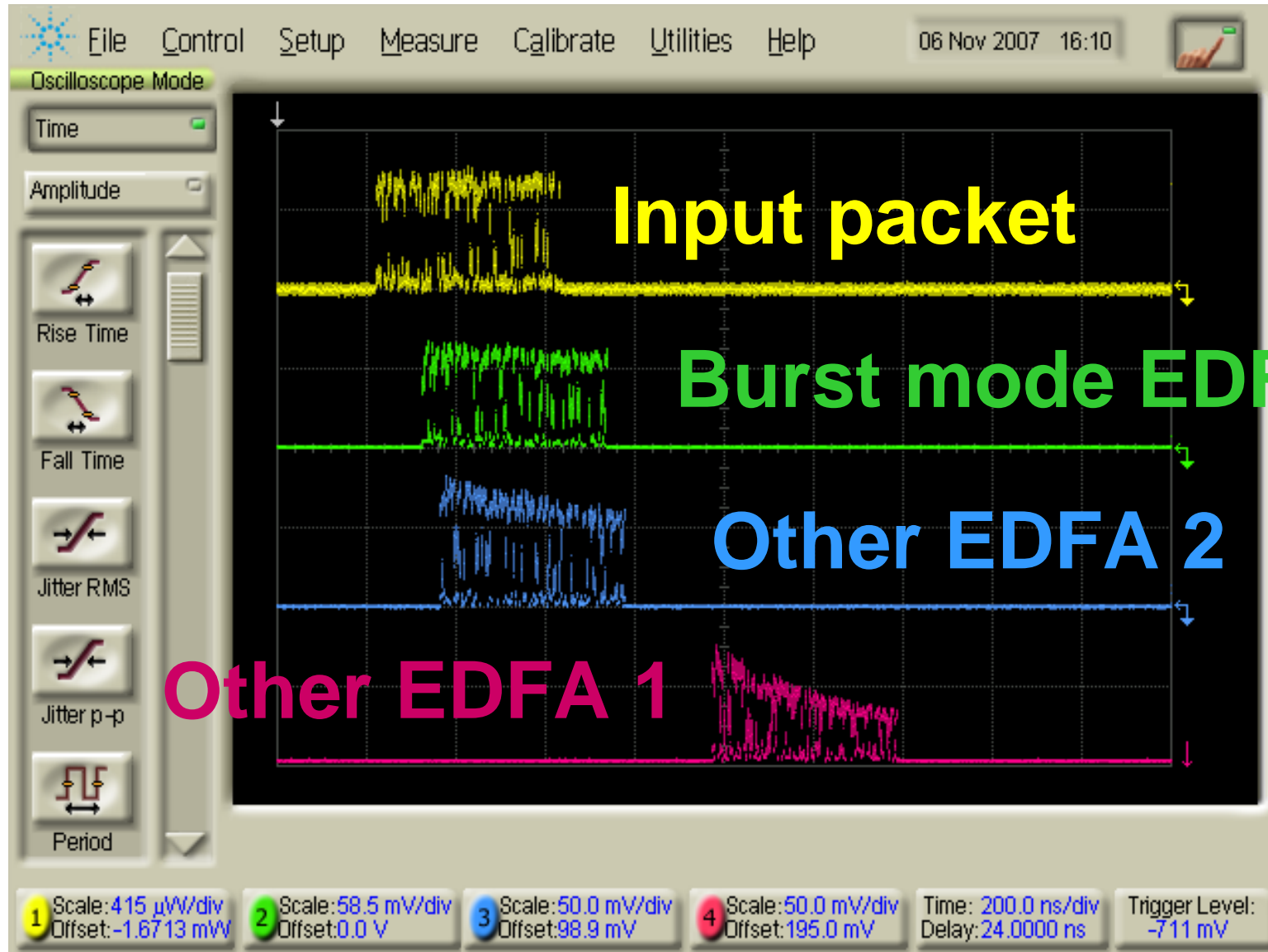
Burst mode EDFA

- A transient response of EDFA distorts the waveform of short-term optical packet.
- Many EDFAs are used in systems and networks. The cumulative transient response effect is very big.
- We developed a new EDFA which adopted EDF with enhanced active erbium area and successfully suppressed the transient response.
- Y. Awaji, et al., CLEO 2007, JTuA133, 2007 and OFC2008, JWA73.



Burst mode EDFA

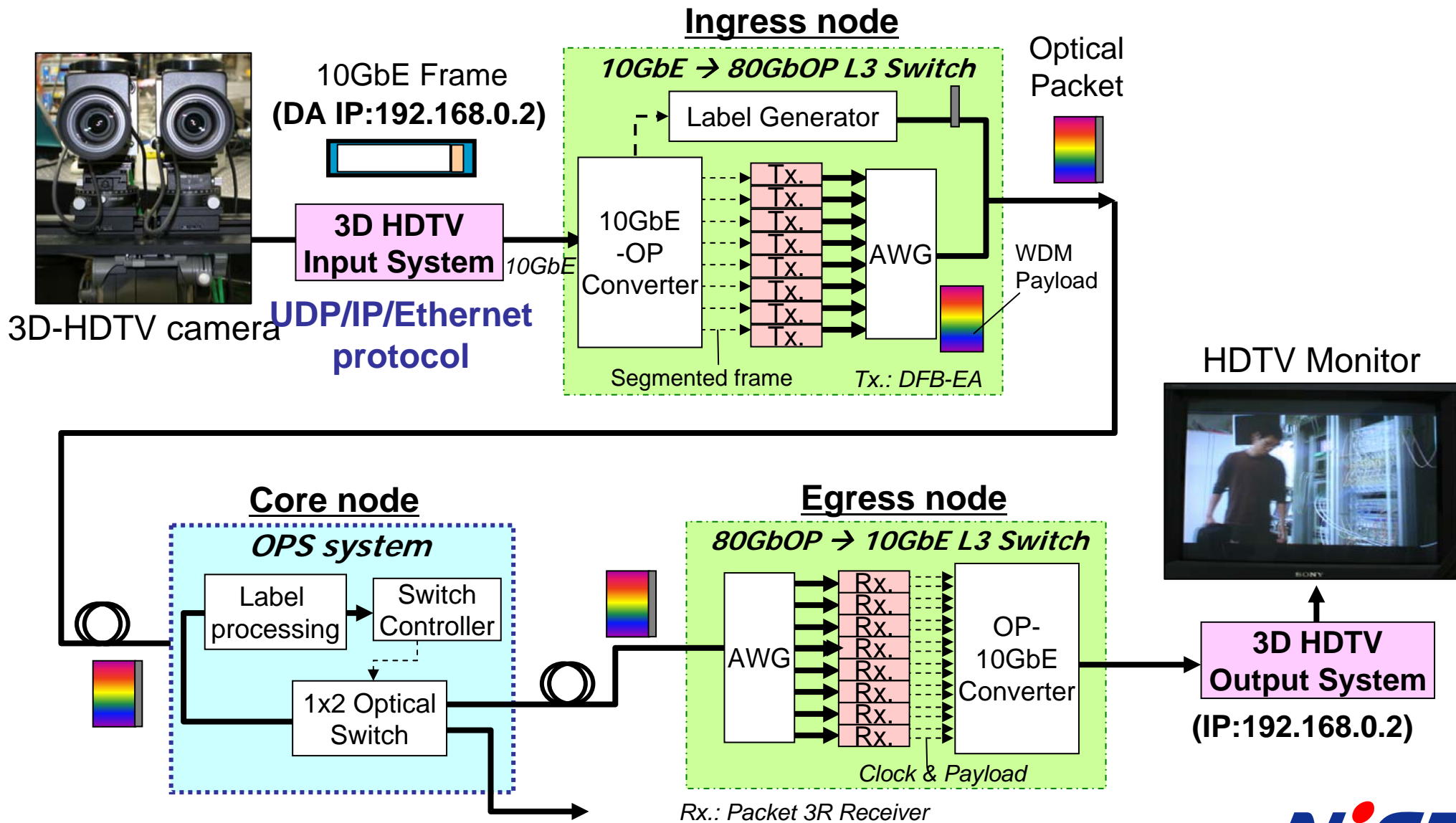
Live demonstration @ NICT Booth #4025



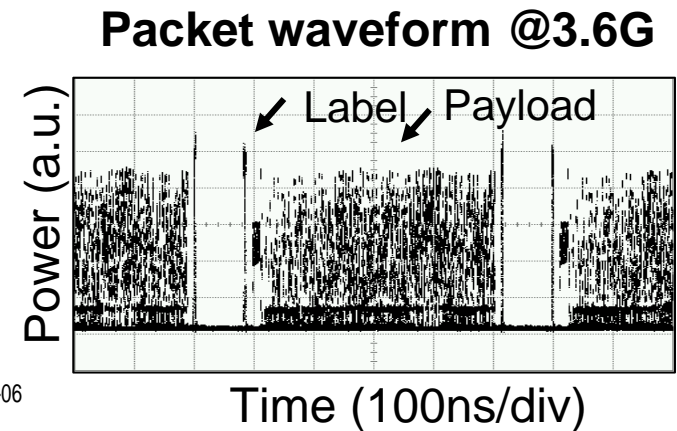
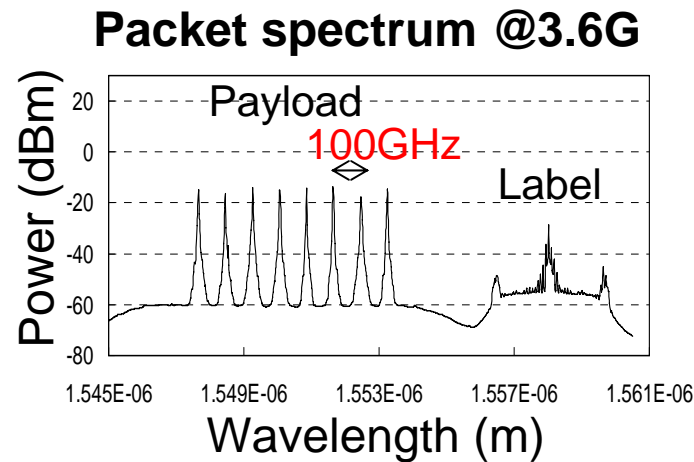
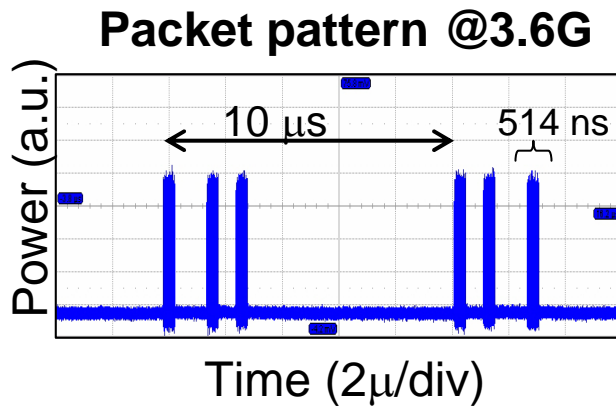
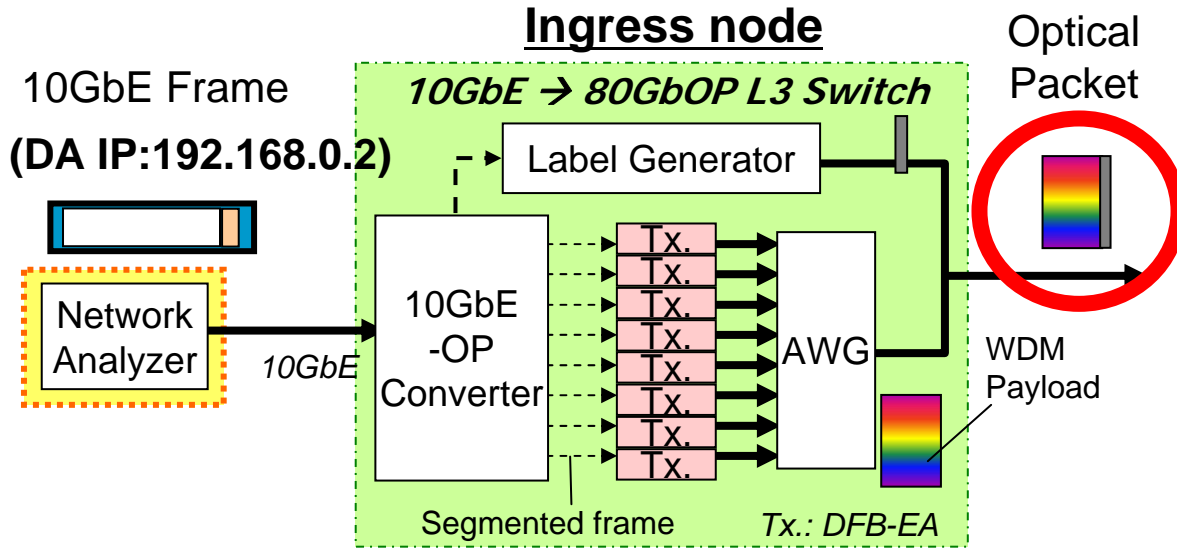
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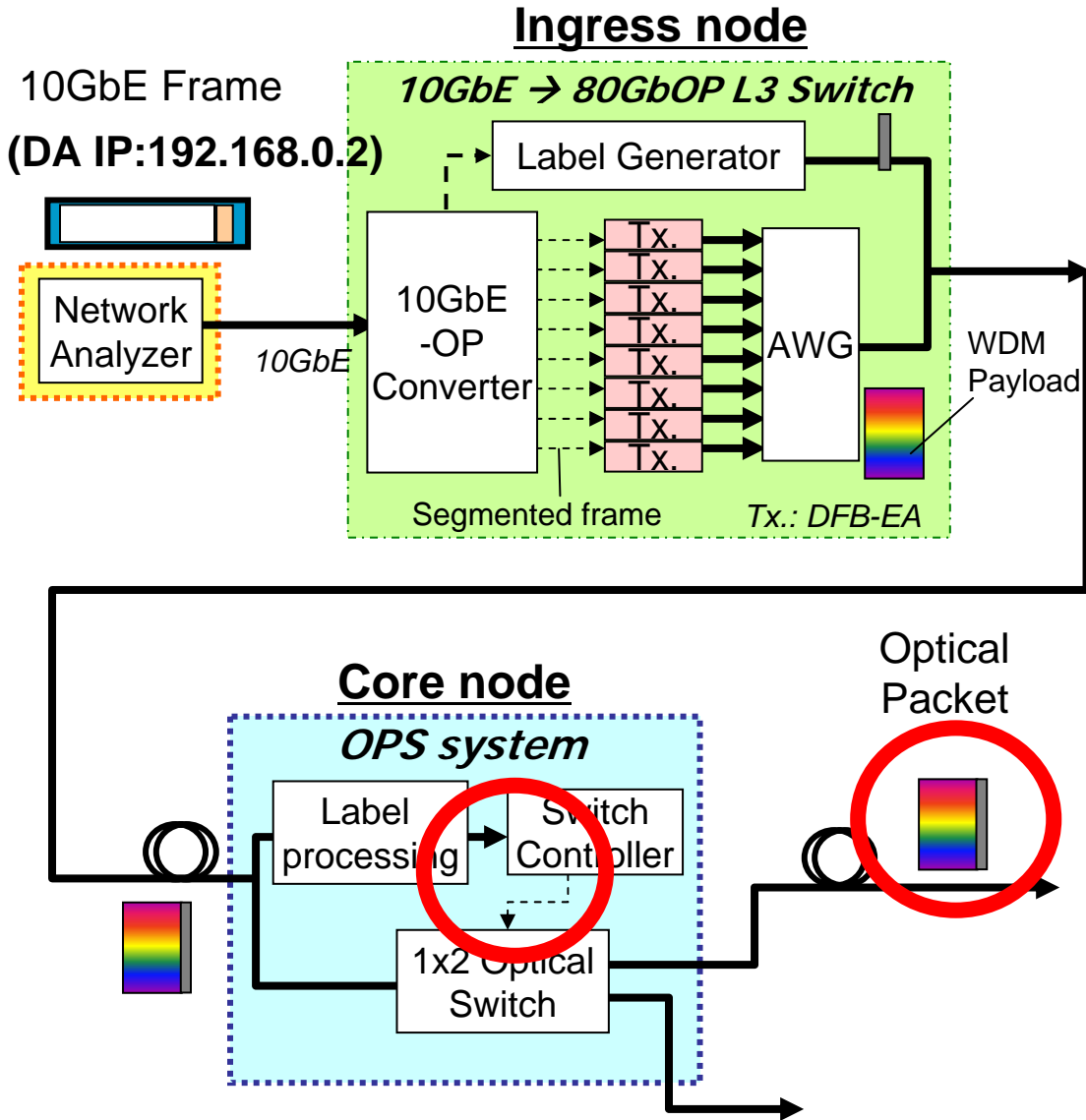
3D-HDTV Video Streaming over WDM-Colored OPS



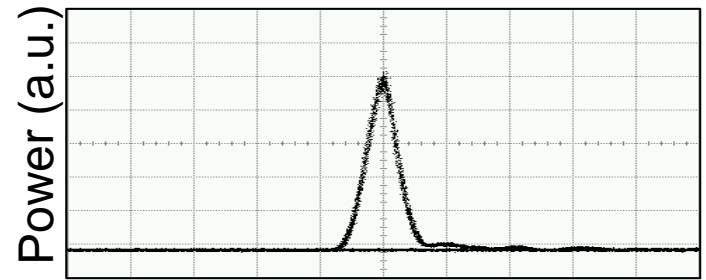
Experimental Results 1



Experimental Results 2

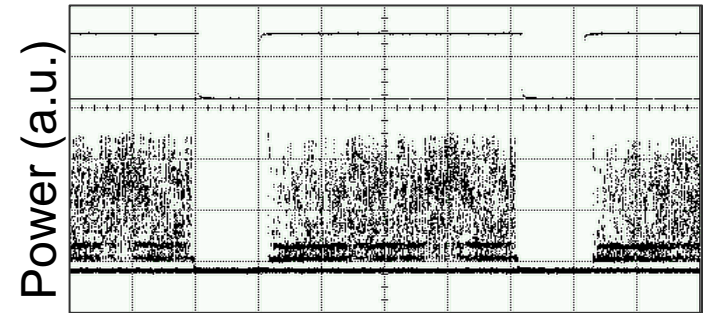


Auto-correlation signal from optical label processing



Time (100ps/div)

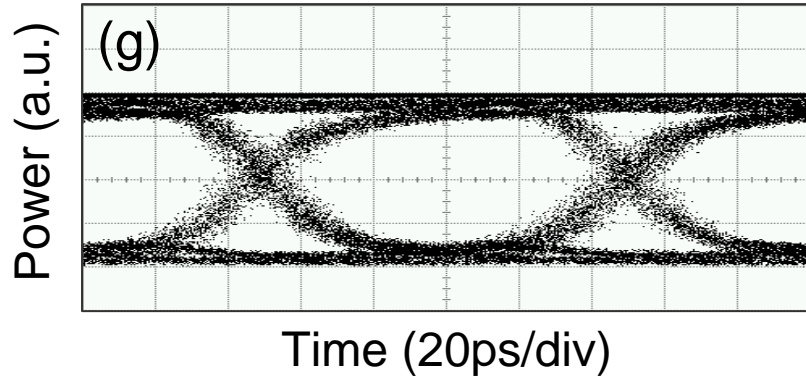
Gate signal and switched packets



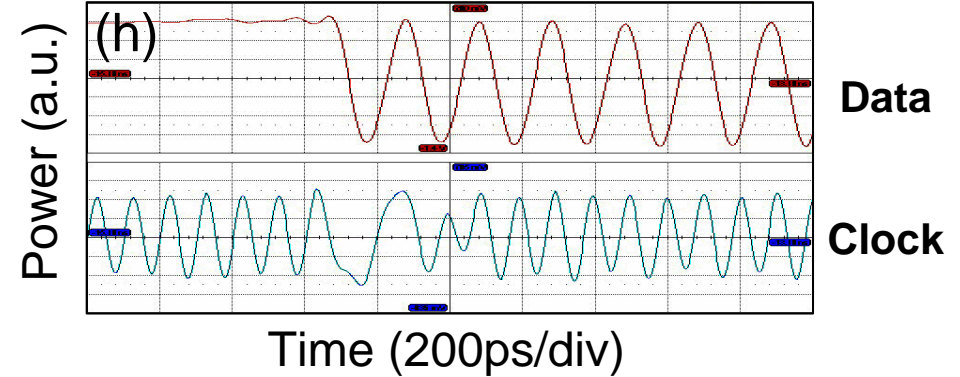
Time (100ns/div)

Experimental Results 3

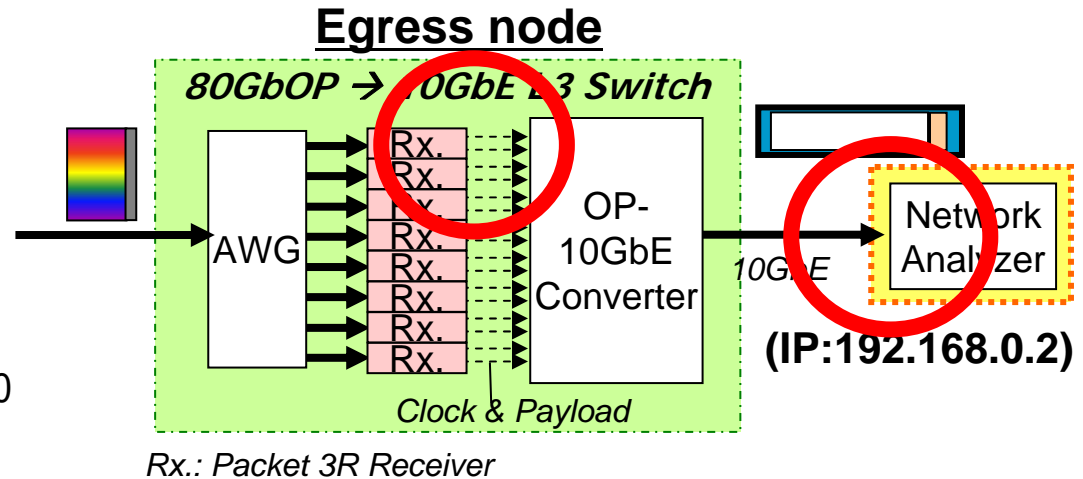
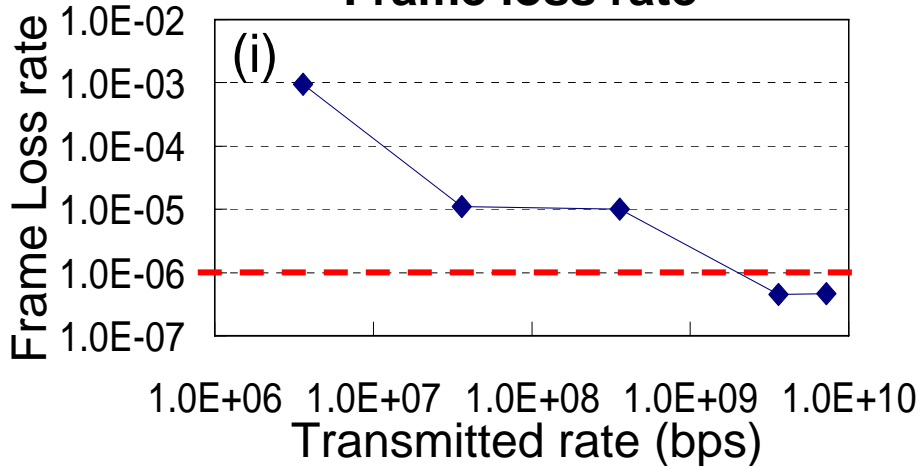
Eye of Recovered payload by Packet Rx.



Recovered clock by Packet Rx.



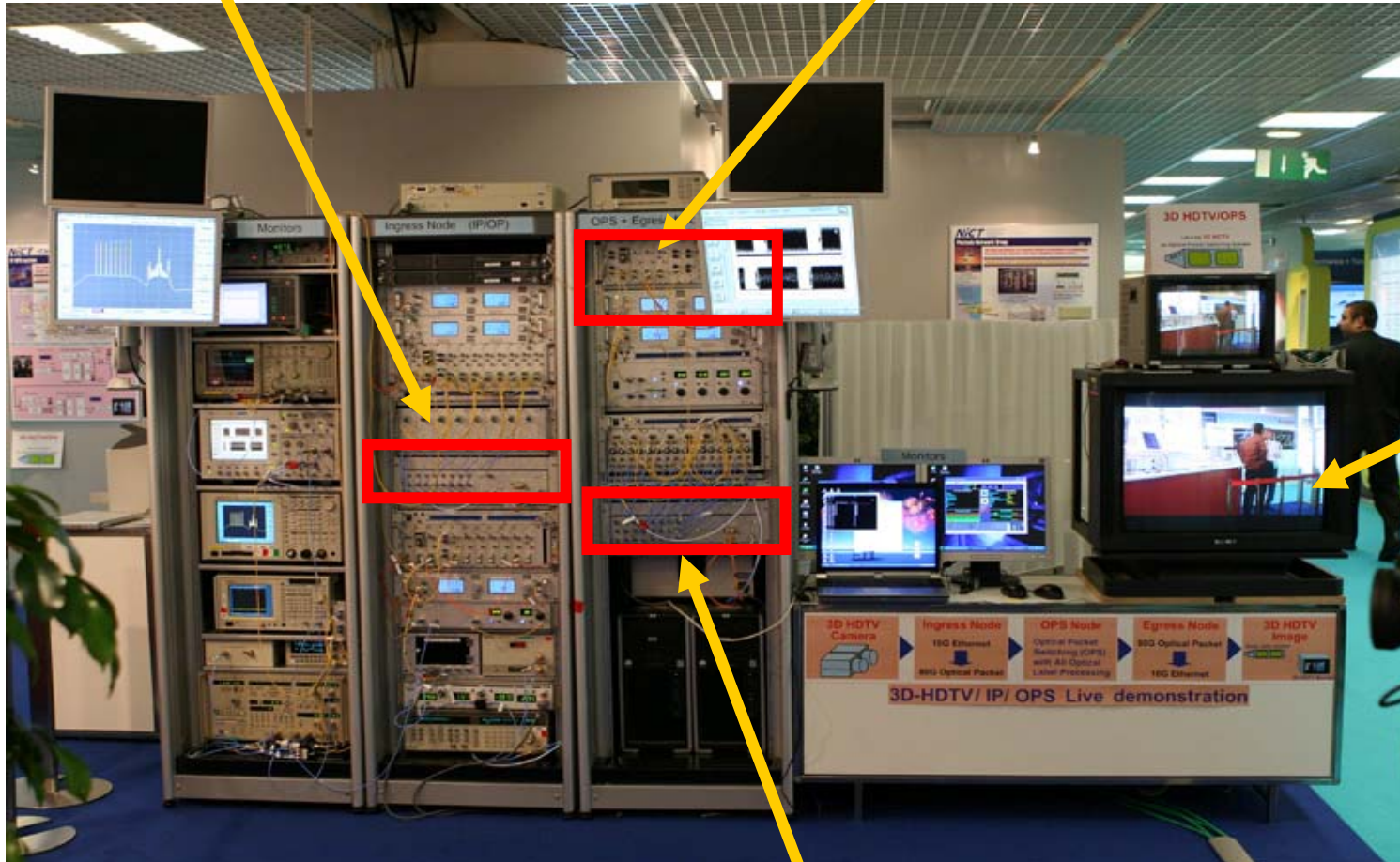
Frame loss rate



Exhibition @ECOC, Cannes, 2006

10GbE → 80GbOP converter

OPS system



HDTV Monitor

80GbOP → 10GbE converter

Outline

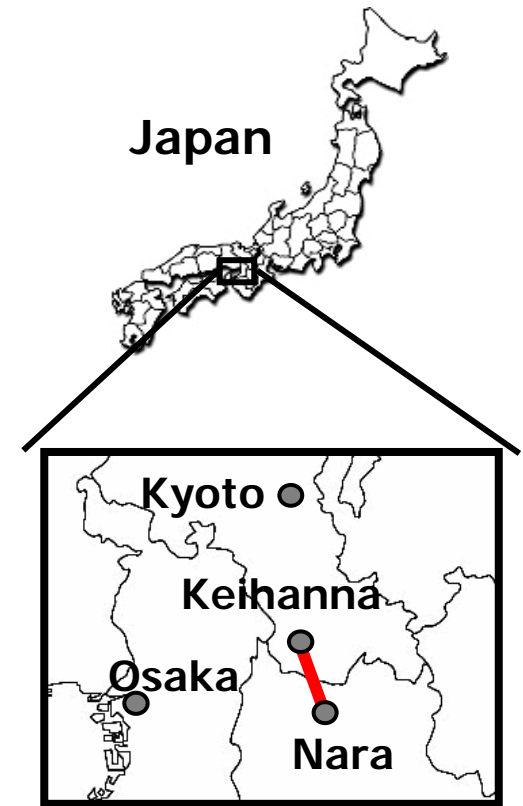
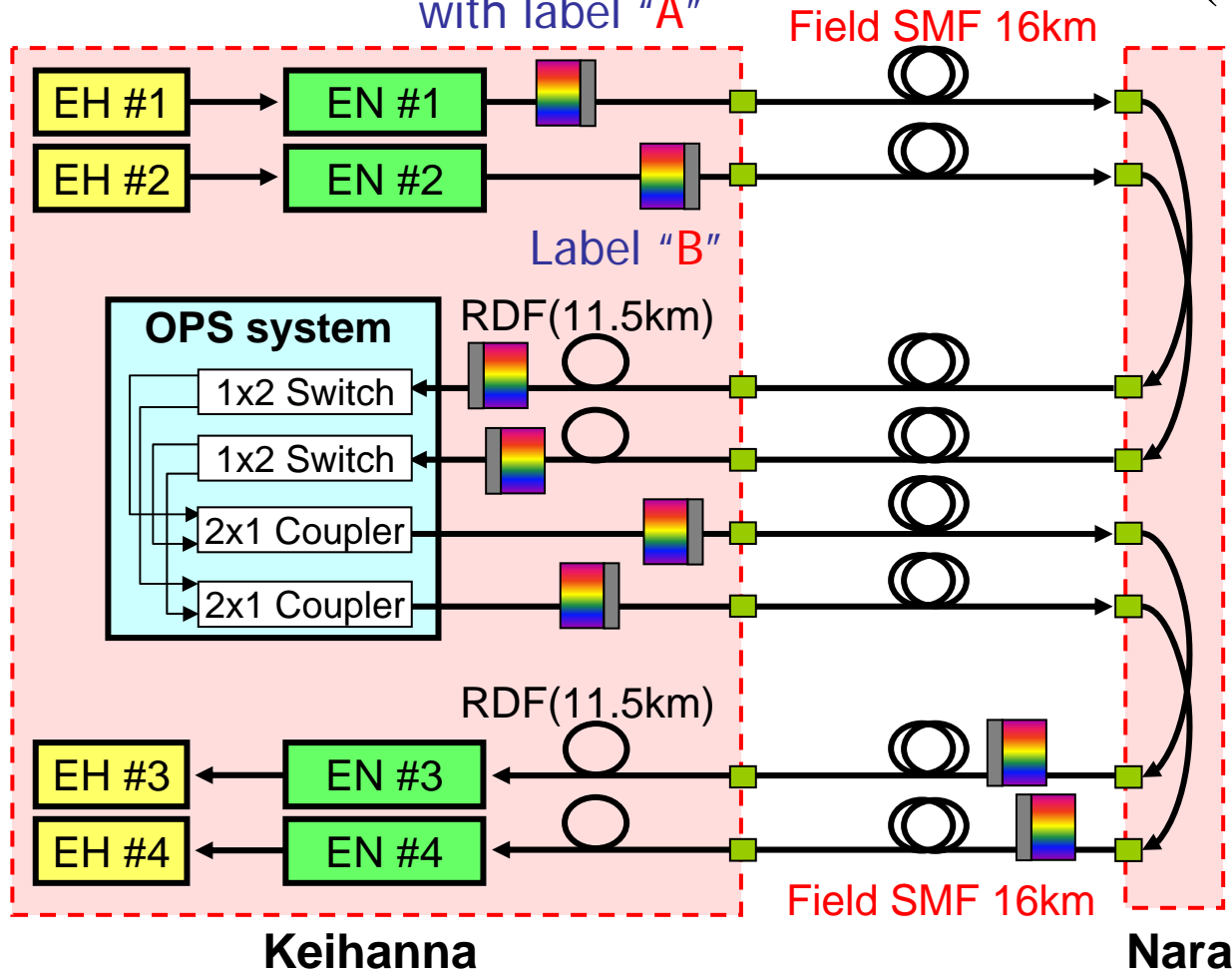
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Field-trial of 160 Gbps OPS network

OFC2007 PDP-04

160Gbps WDM
Optical Packet
with label "A"

JGN2 testbed network
(<http://www.jgn.nict.go.jp>)



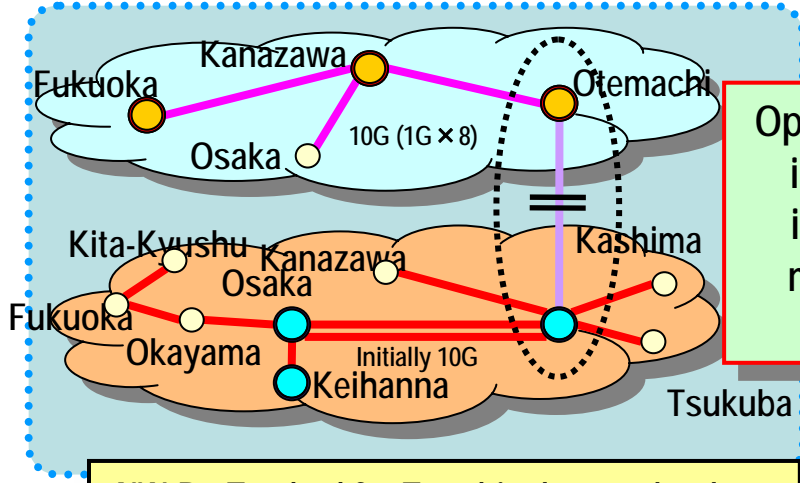


JGN-II R&D Network Core Structure

JGNII

NW-A : Testbed for network operation technology

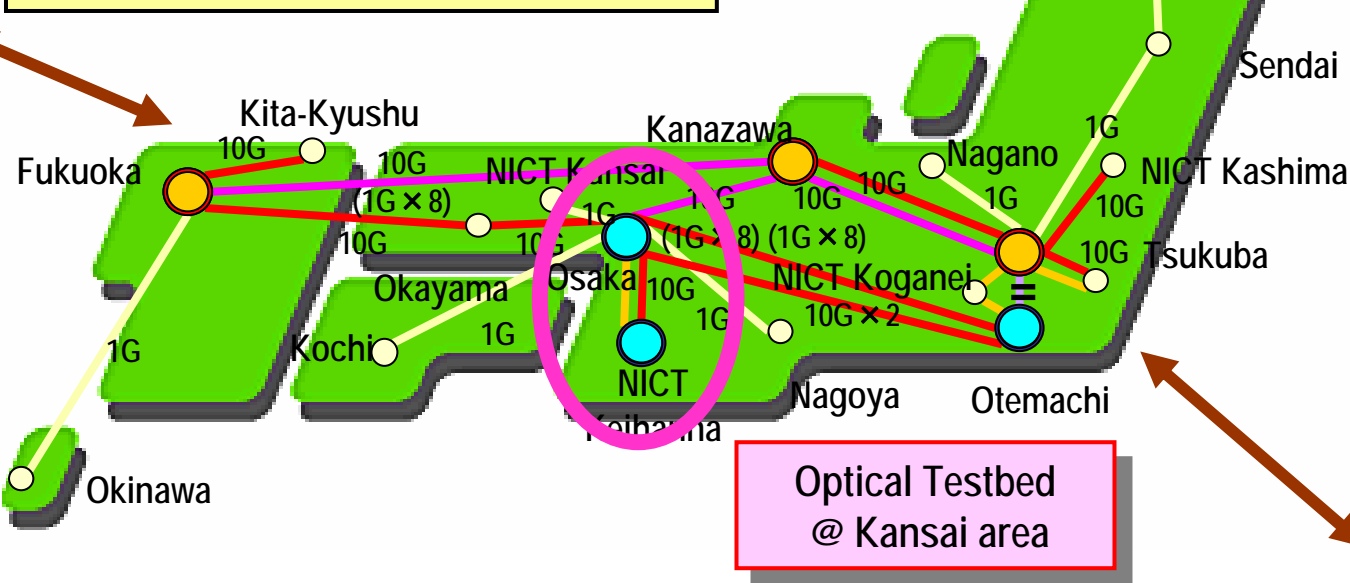
- # OXC based 10 Gbit/s backbone
- # Nation-wide 63 access points
- # Optical testbed (DF) segments available



Optical networks inter-domain interworking management (GMPLS)

NW-B : Testbed for Tera-bit class technology

To Korea

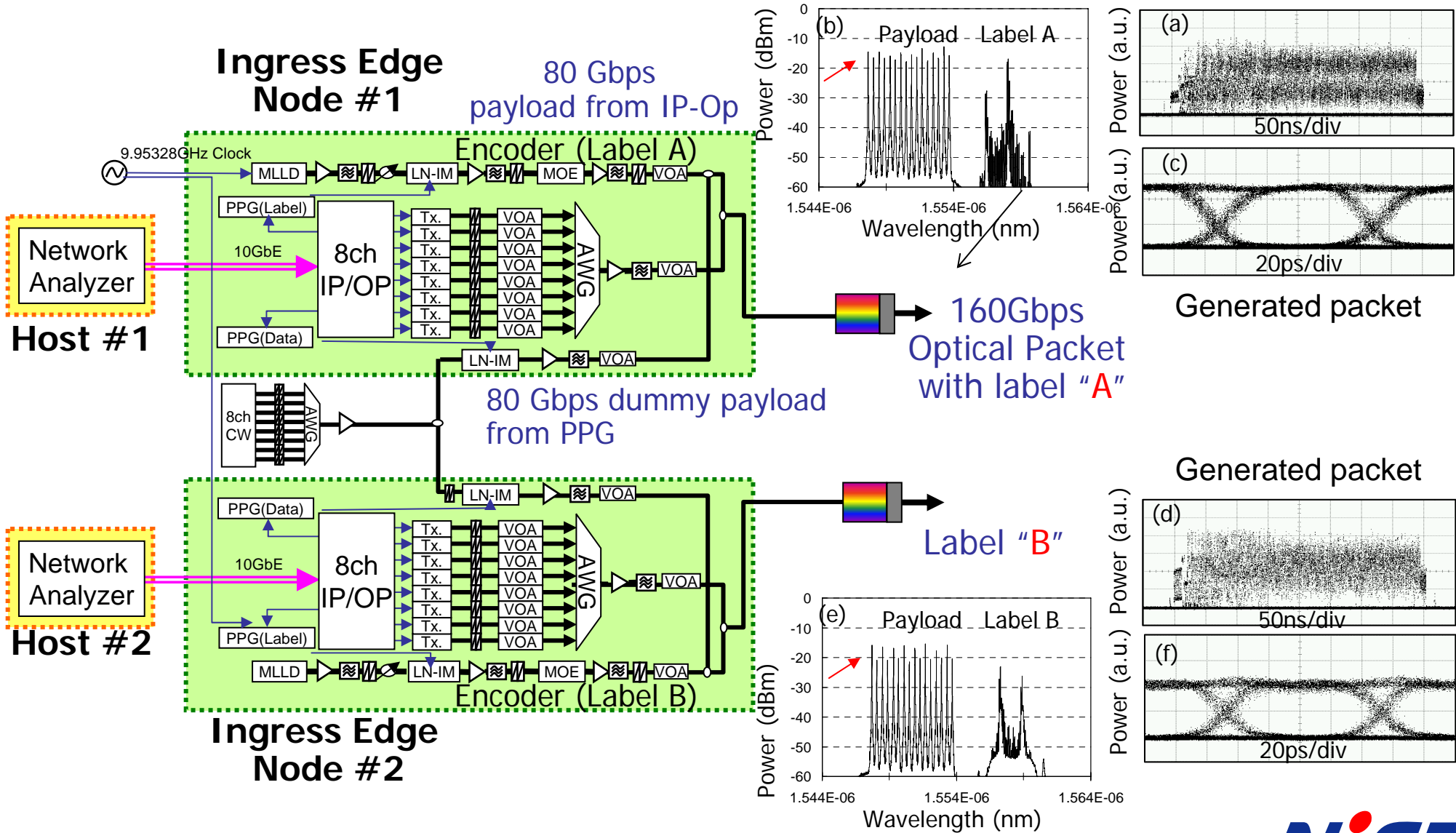


Optical Testbed @ Kansai area

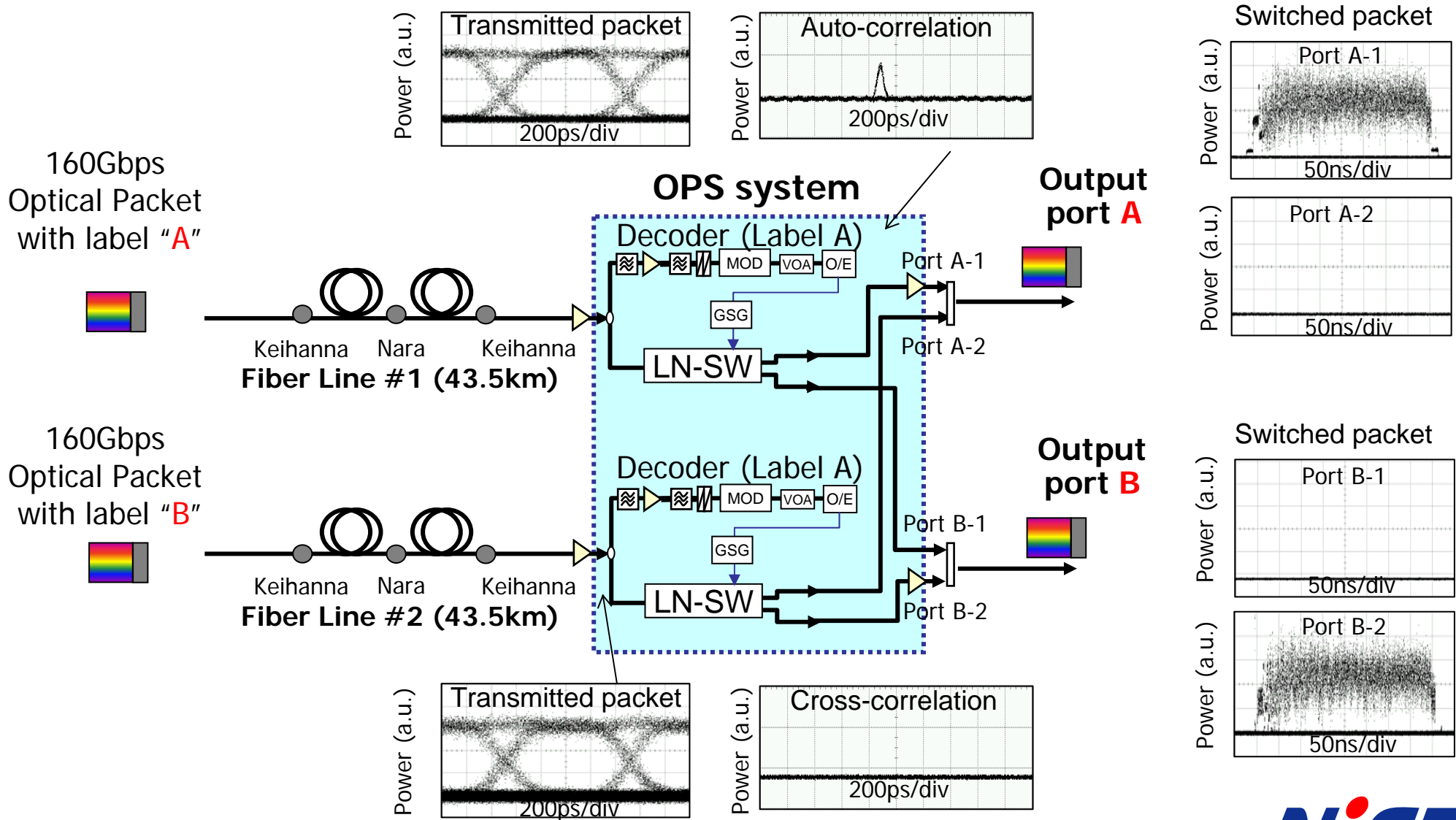
To USA



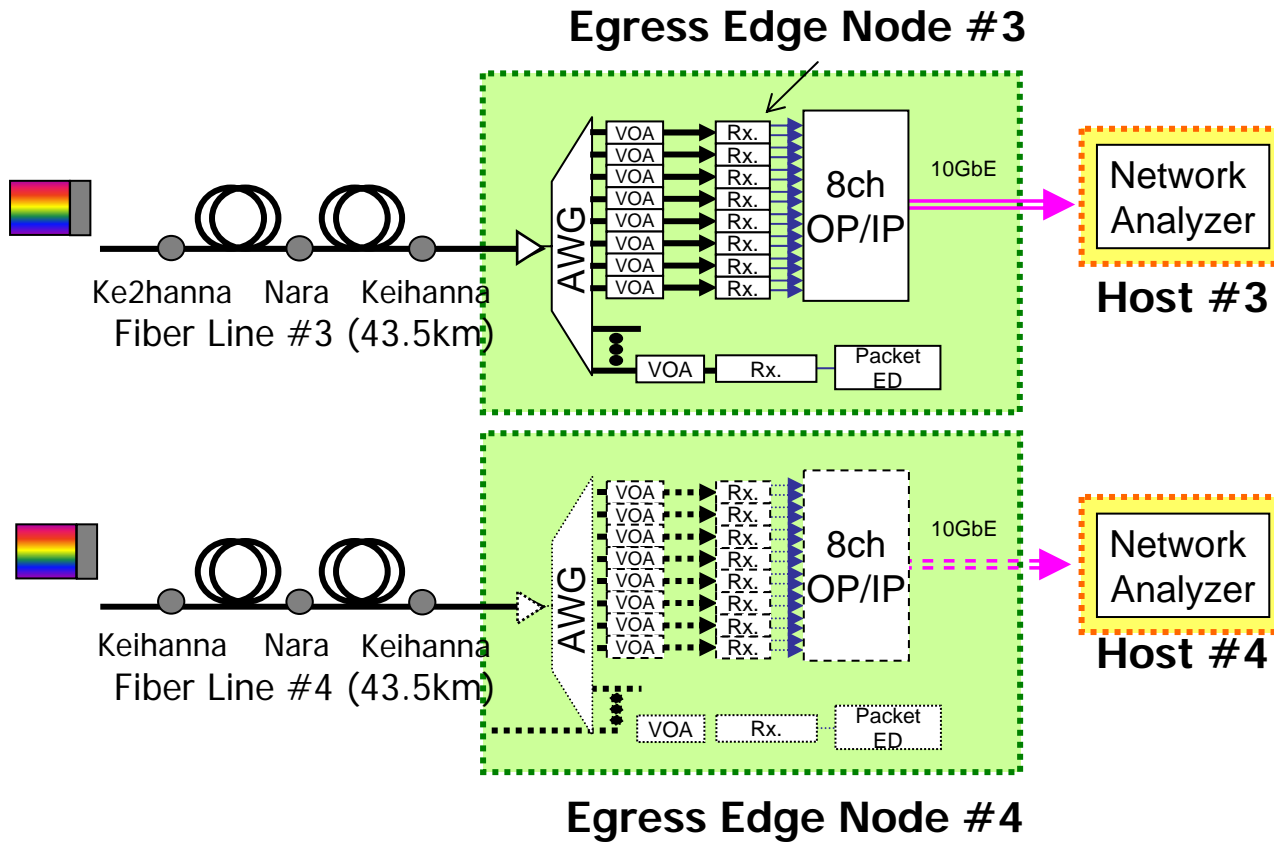
Setup and Results 1



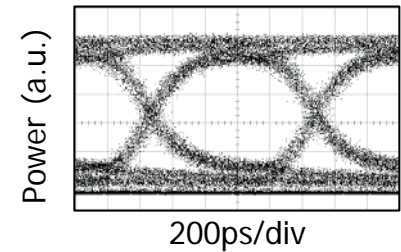
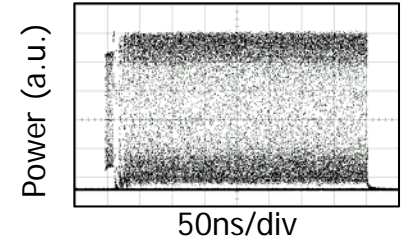
Setup and Results 2



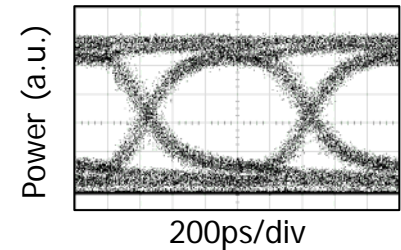
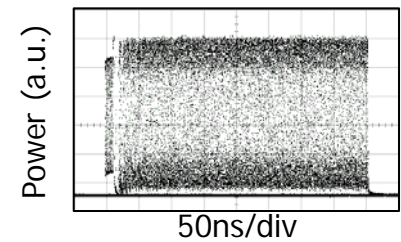
Setup and Results 3



Received packet at Rx.



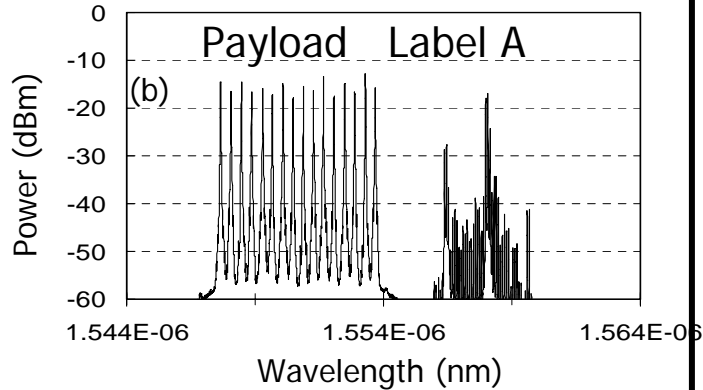
Received packet at Rx.



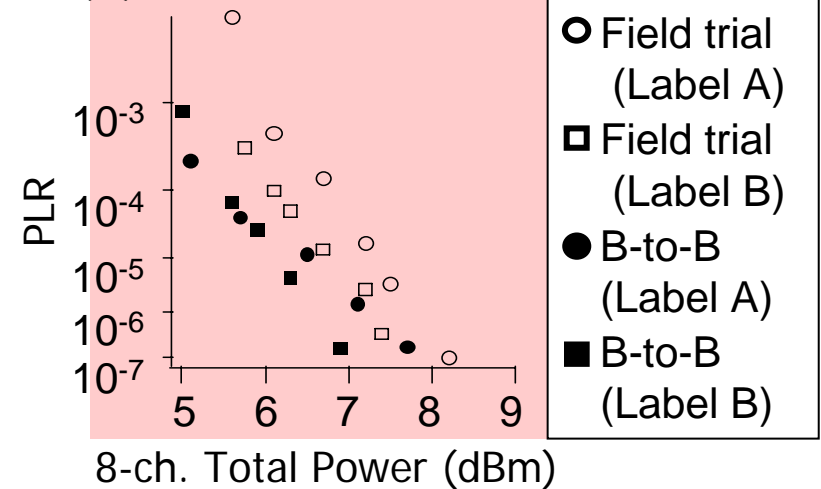
Packet-loss-rate / Bit-error-rate

160 (16λx10)
Gbps WDM
Optical Packet

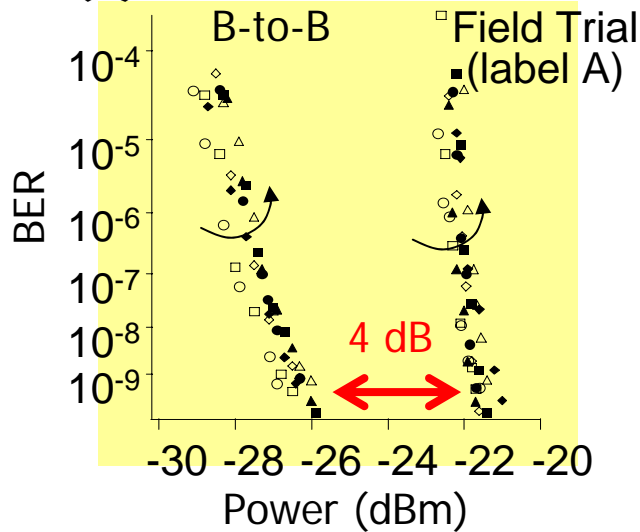
(80 Gbps payload
including IP)
(80 Gbps dummy
payload)



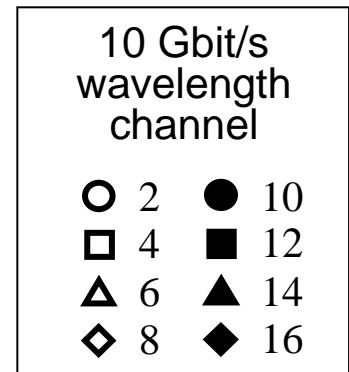
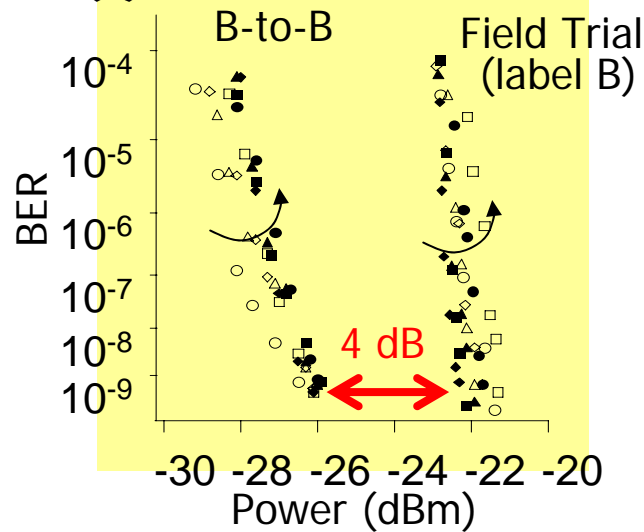
(a) PLR @ EN #3,#4



(b) BER @ EN #3



(c) BER @ EN #4



Summary

160 Gbps/port WDM-colored OPS network with

- > all-optical multiple label processor,**
- > arrayed burst mode Tx./Rx.,**
- > 10GbE/optical packet converter, and**
- > a novel transient response suppressed EDFA,**
- > error free (PLR $<10^{-6}$ and BER $<10^{-9}$) operation with over 87km transmission by field installed fiber**

has been successfully demonstrated.