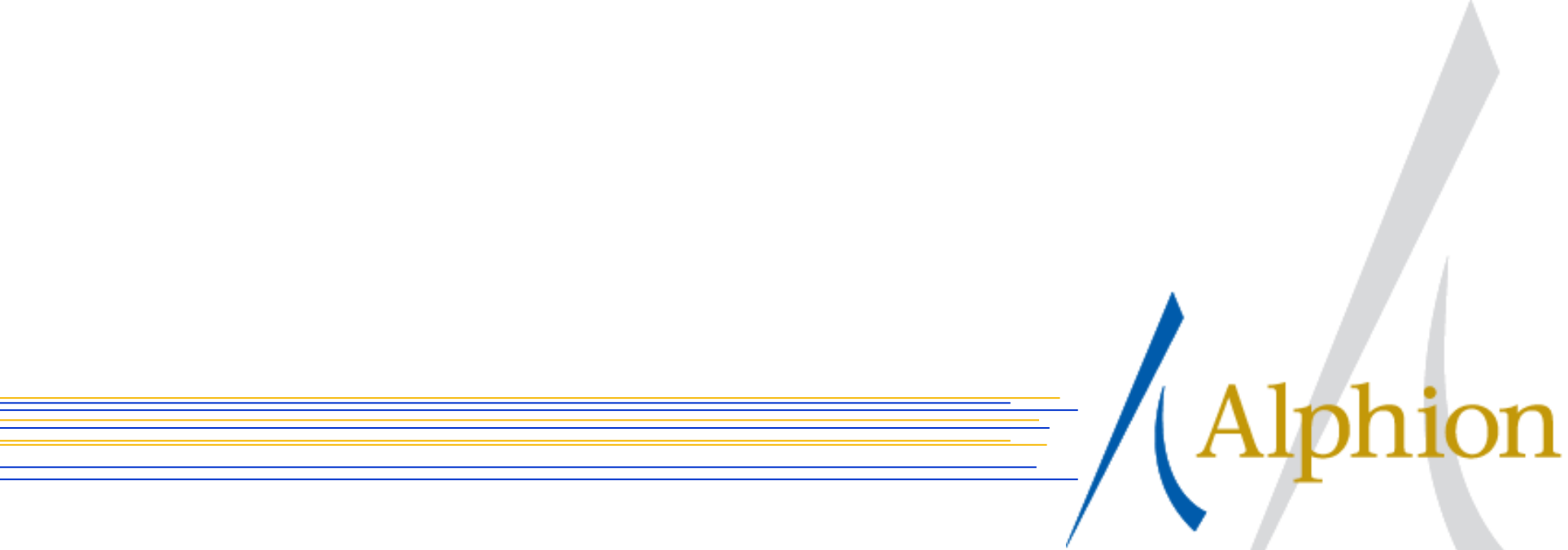
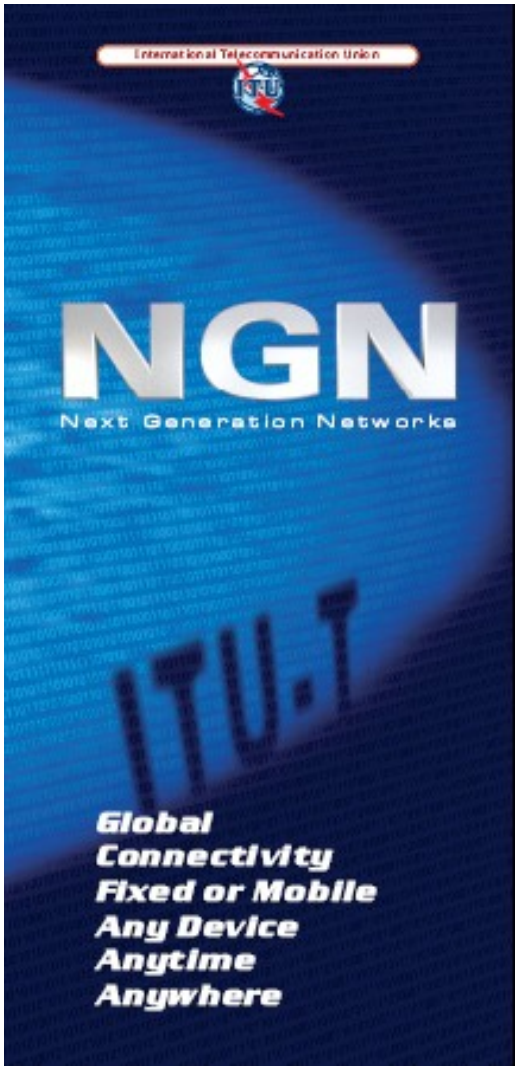


Photonics in Broadband Access and the Next Generation Network

Leo Spiekman

The Next Generation Network

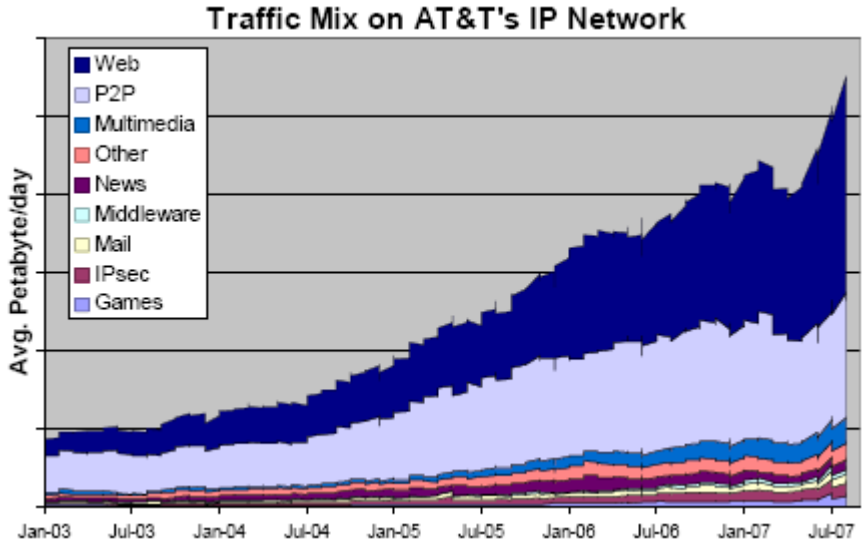
- Architectural evolution in core and access
- One network for all information and services
- Everything transmitted as packets



Internet Traffic Growth

Near-exponential increase in bandwidth use

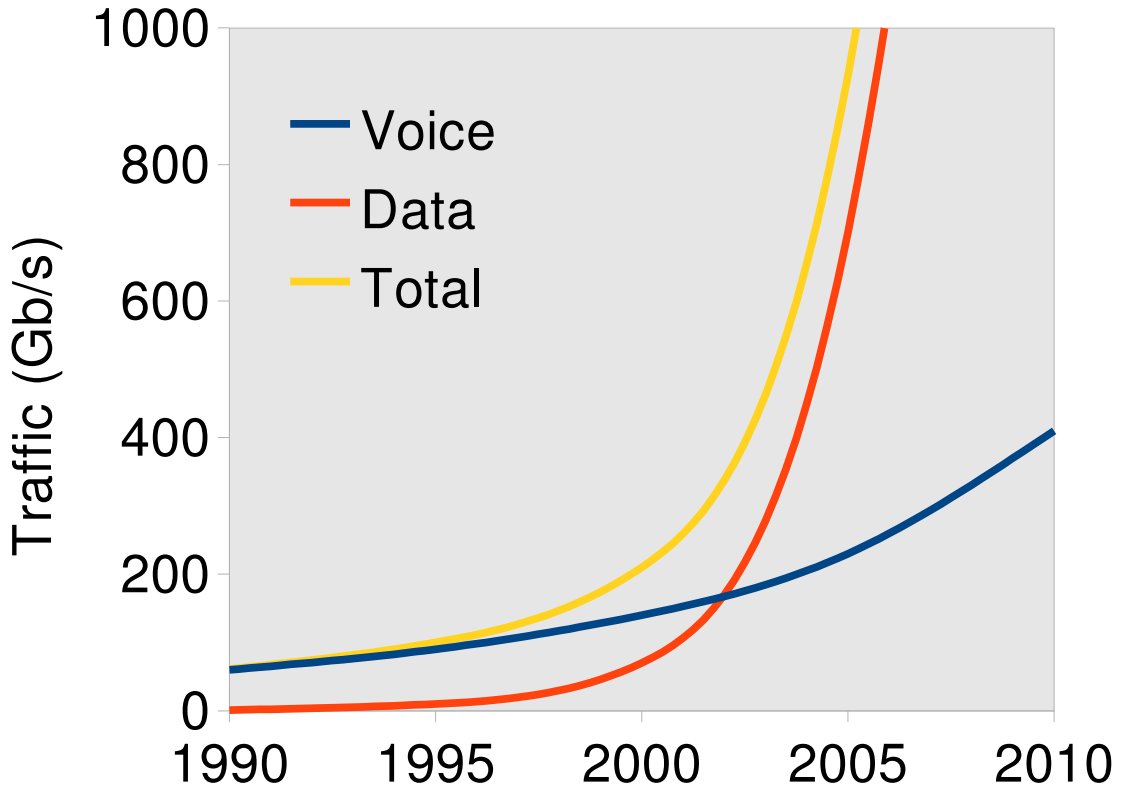
- Organic growth – increase in customer base
- Shift in content, away from static pages, toward multimedia embedded content and streaming video
- Larger bandwidth demand of content providers and other high end users



(P. Magill, AT&T Labs, LEOS Annual Mtg. 2007)

Traffic Type Is Changing

Packets (data) have overtaken circuits (voice)

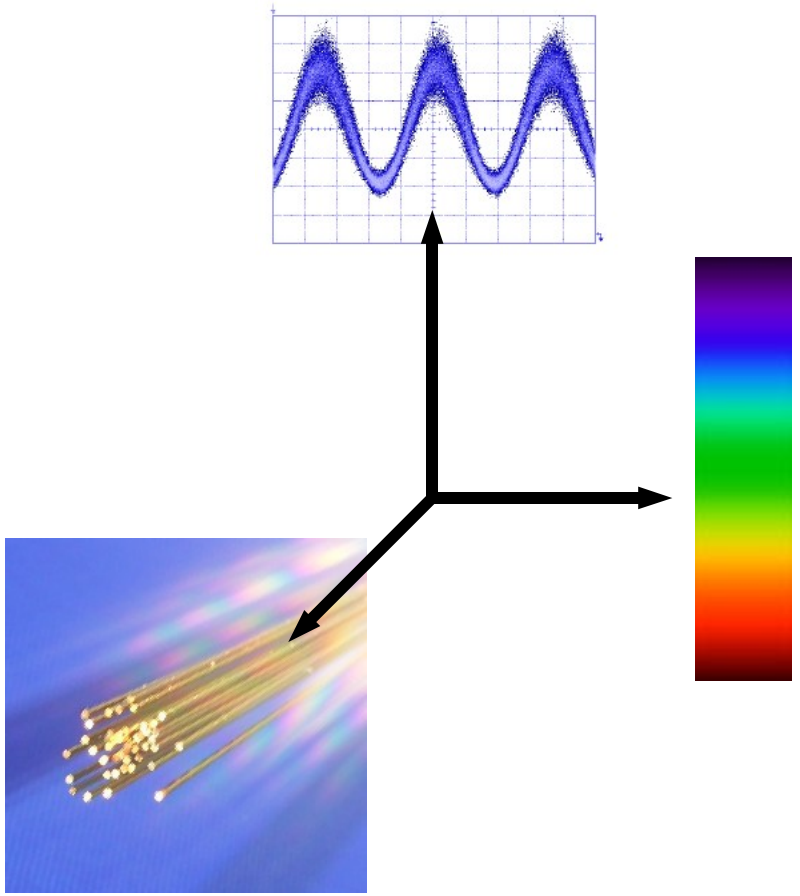


(R. Tkach, Alcatel-Lucent, OFC 2008)

Economies of Unified Management

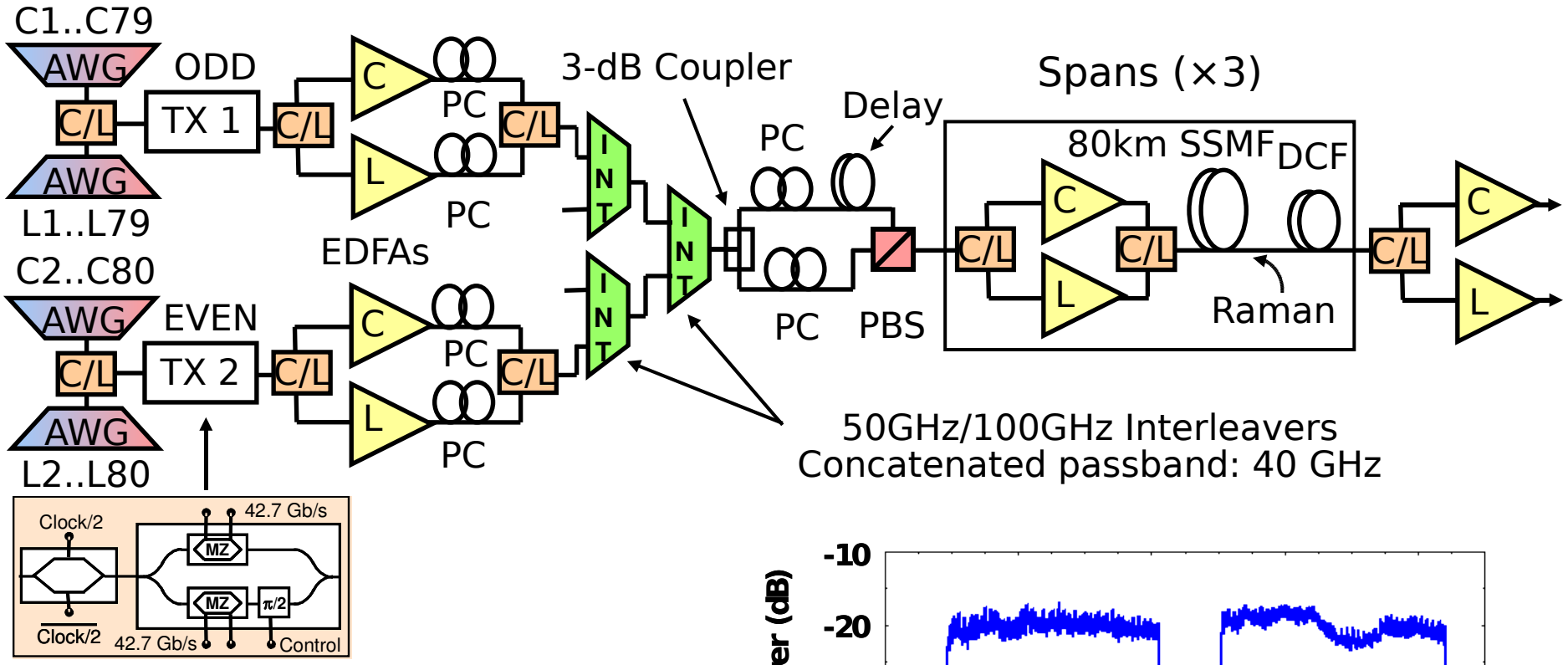
Three Ways to Increase Capacity

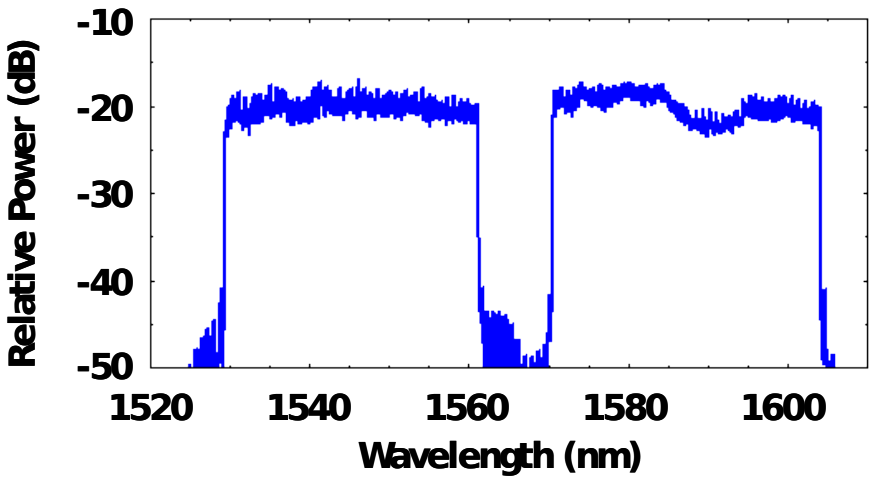
- Increase bitrates
- More wavelengths
- More fibers



New technologies are introduced
if and when they become cost-effective

25.6 Tb/s Transmission



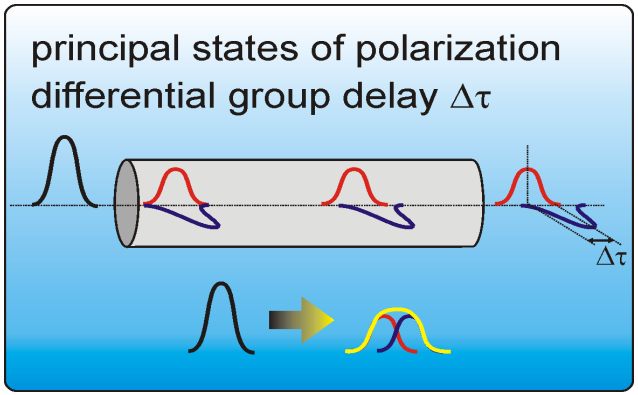


(A. Gnauck, Alcatel-Lucent, OFC 2007)

- 160 Channels
- Two Polarizations
- 2 x 42.7 Gb/s RZ-DQPSK

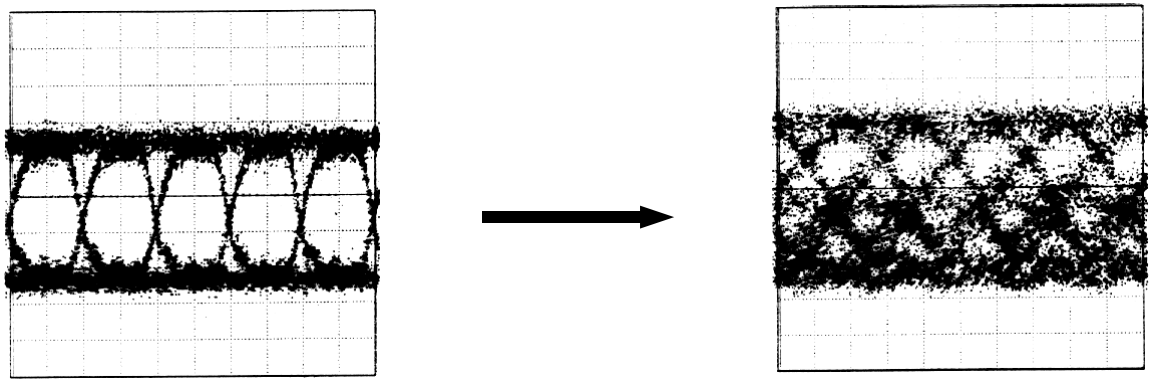
DWDM is Hard

- Linear Impairments
  - Chromatic Dispersion
  - Polarization Mode Dispersion
- Nonlinear Impairments
  - Self Phase Modulation
  - Four-Wave Mixing
  - Cross Phase Modulation



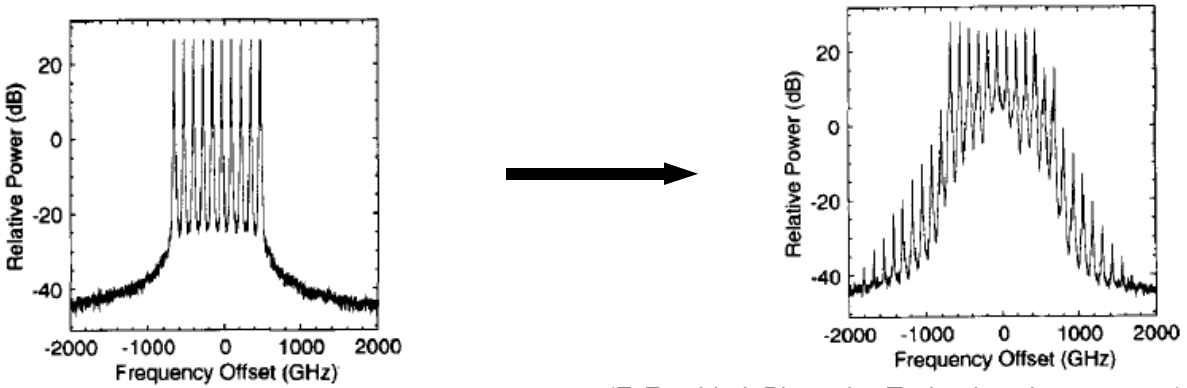
DWDM is *Really* Hard

Dispersion



(J. Perino, Electronics Letters 1994)

FWM

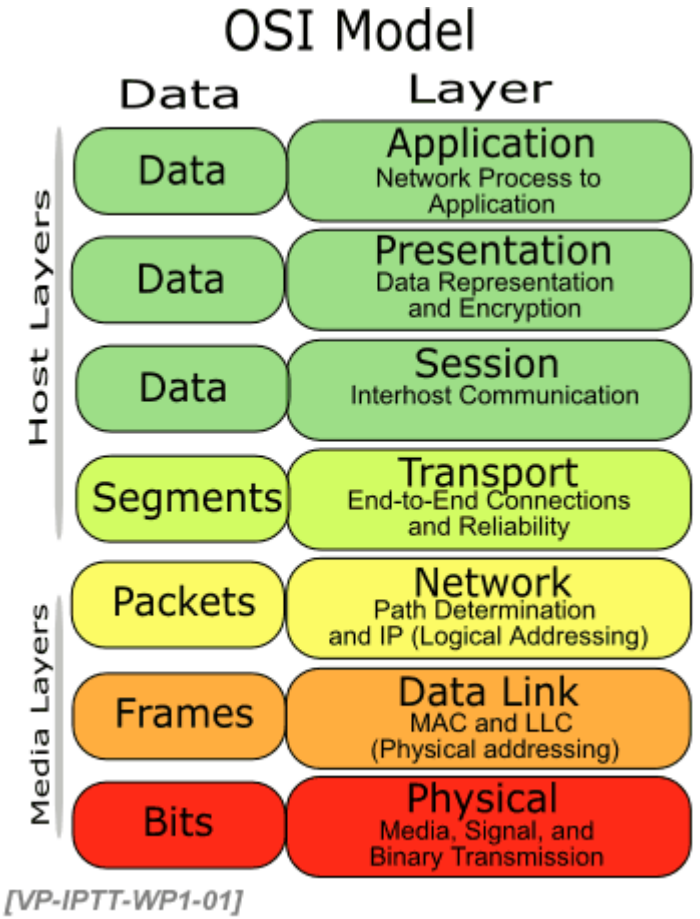


(F. Forghieri, Photonics Technology Letters 1994)

Gets worse with higher bitrates and channel densities!

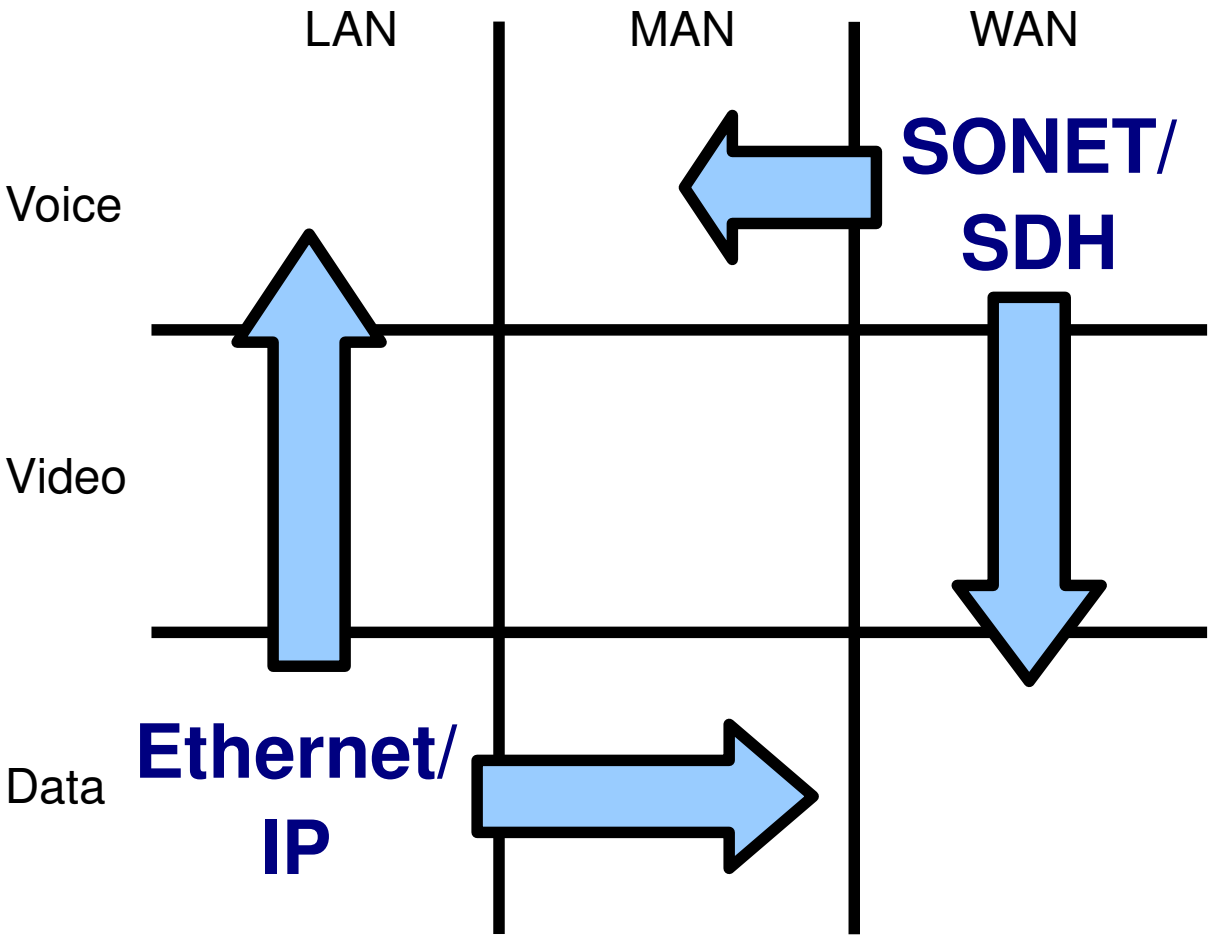
Network Layering Wildly Successful

- Ethernet: 1973
- WWW: 1989
- Google: 1998
- DWDM transmission: 1987

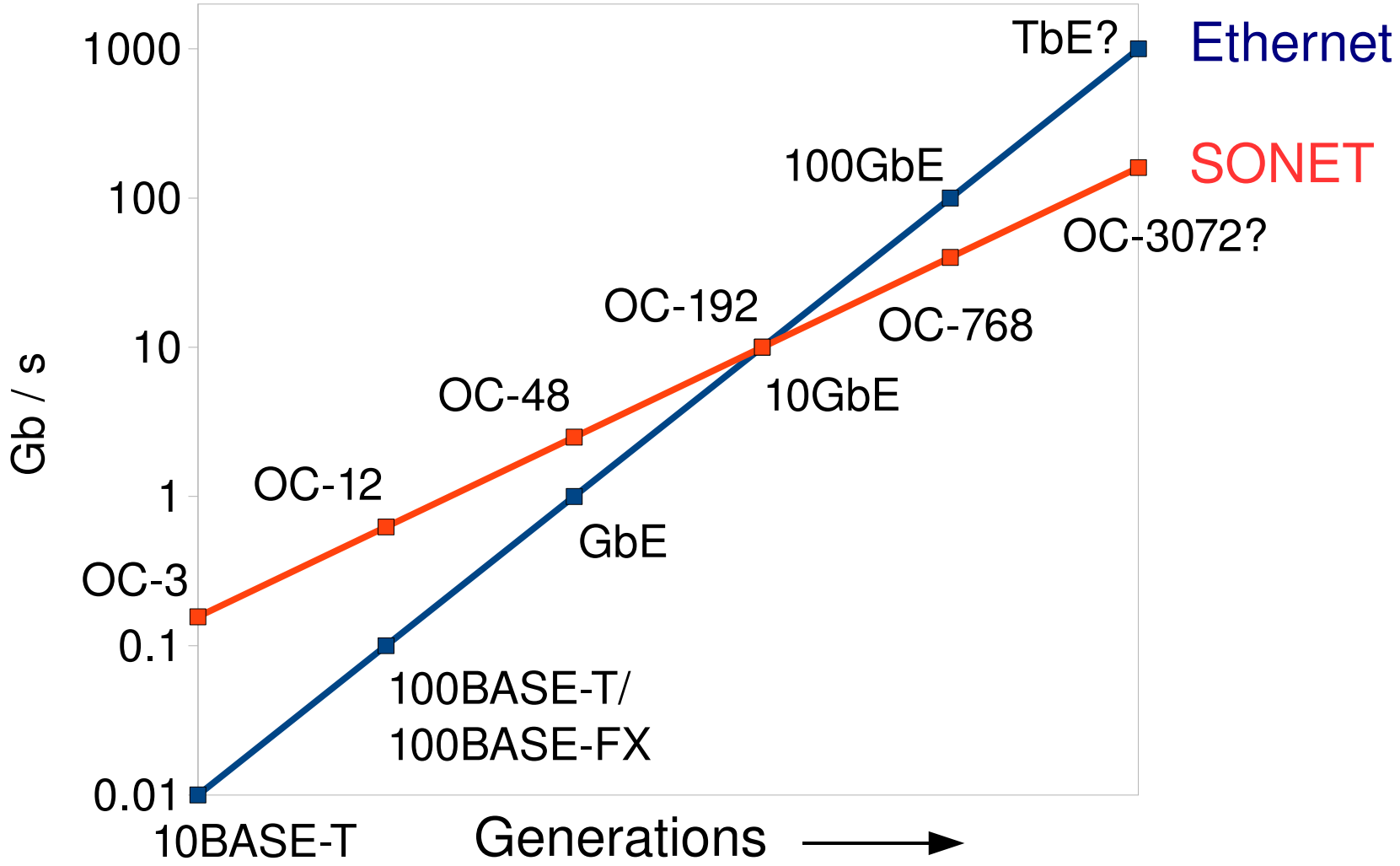


[VP-IPTT-WP1-01]

Network Convergence



Line Speed Convergence

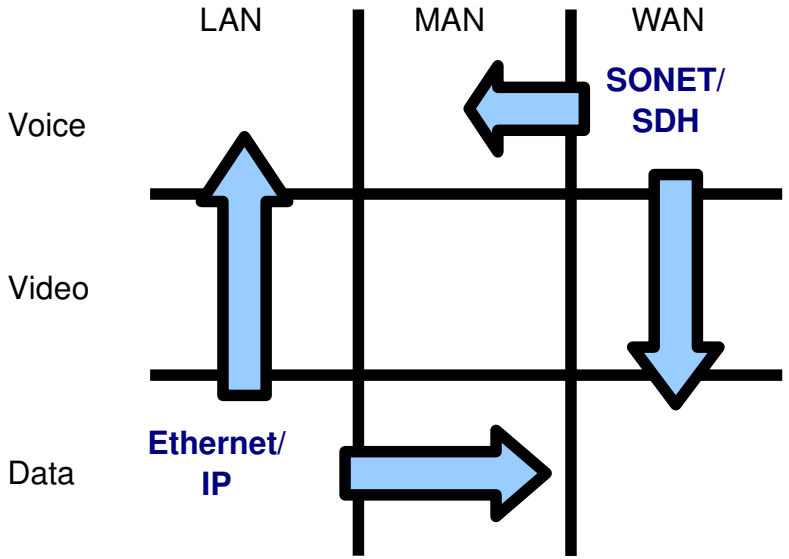


Why the Push for Ethernet?

- Rigorous standardization
  - Everyting that is not allowed is prohibited
- Vendor interoperability
  - Enables fierce competition
- Rapid evolution
  - Media, speeds
- Installed base preservation

Convergence to Packets

- Core converges to IP or Ethernet
- Increasingly, services independent from transport layer
- But: Ethernet was not designed for video



Different Traffic has Different Needs

Type of video

- High speed
- Long distance (video download)

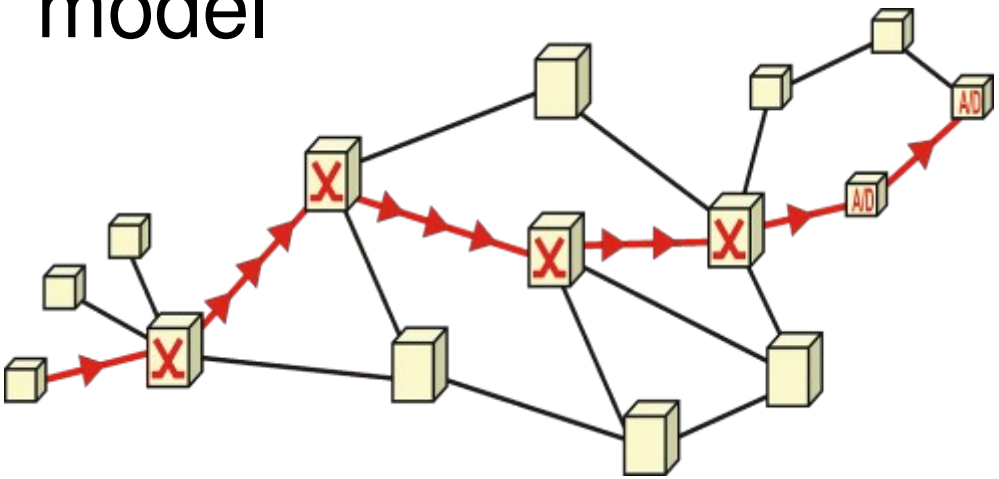
- QoS (streaming)

- Latency (interactive)

DWDM is Hard

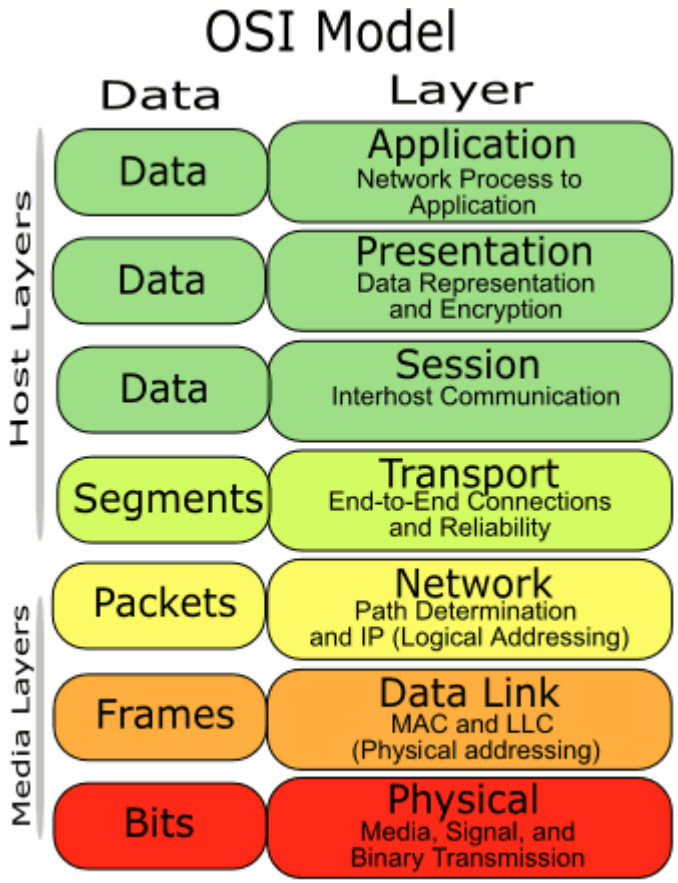
... Also in the Next Generation Network

- Linear Impairments
- Non-Linear Impairments
- Bottom three layers of OSI model



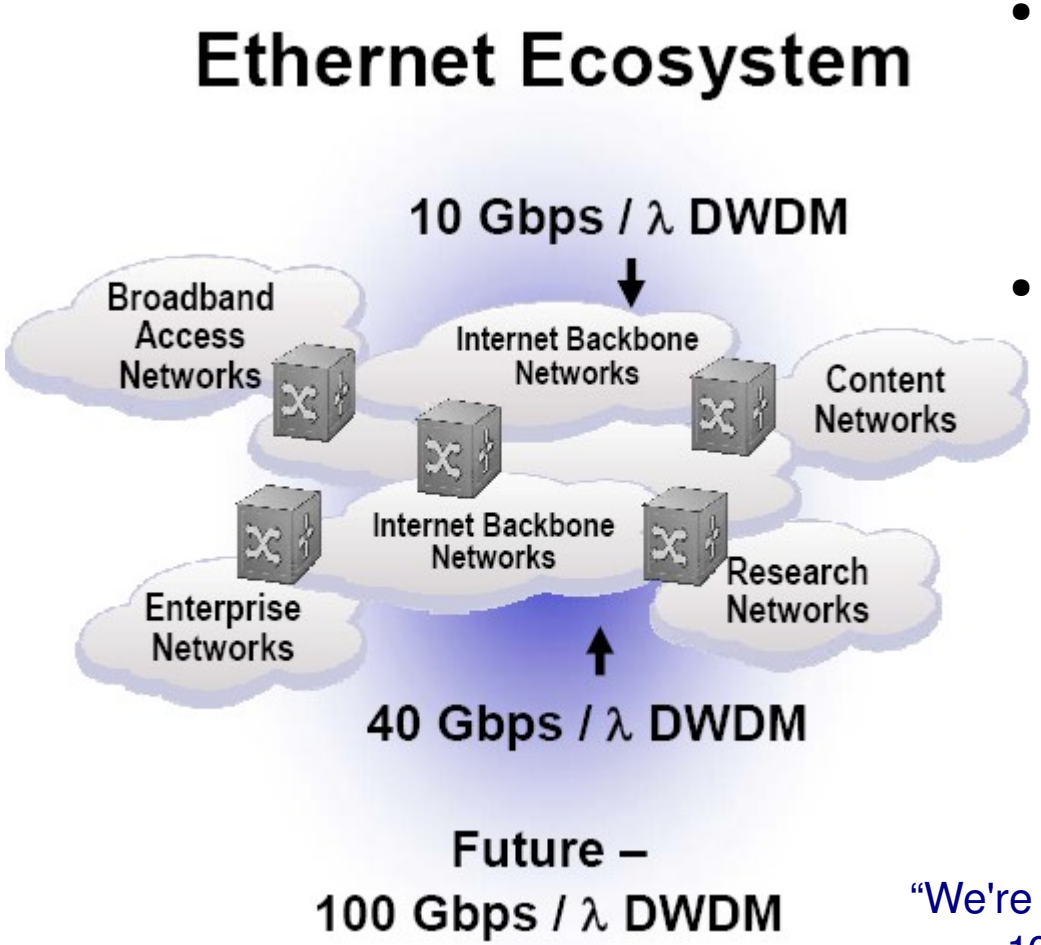
X cross-connect

A/D add/drop



[VP-IPTT-WP1-01]

100 Gb/s is Next?



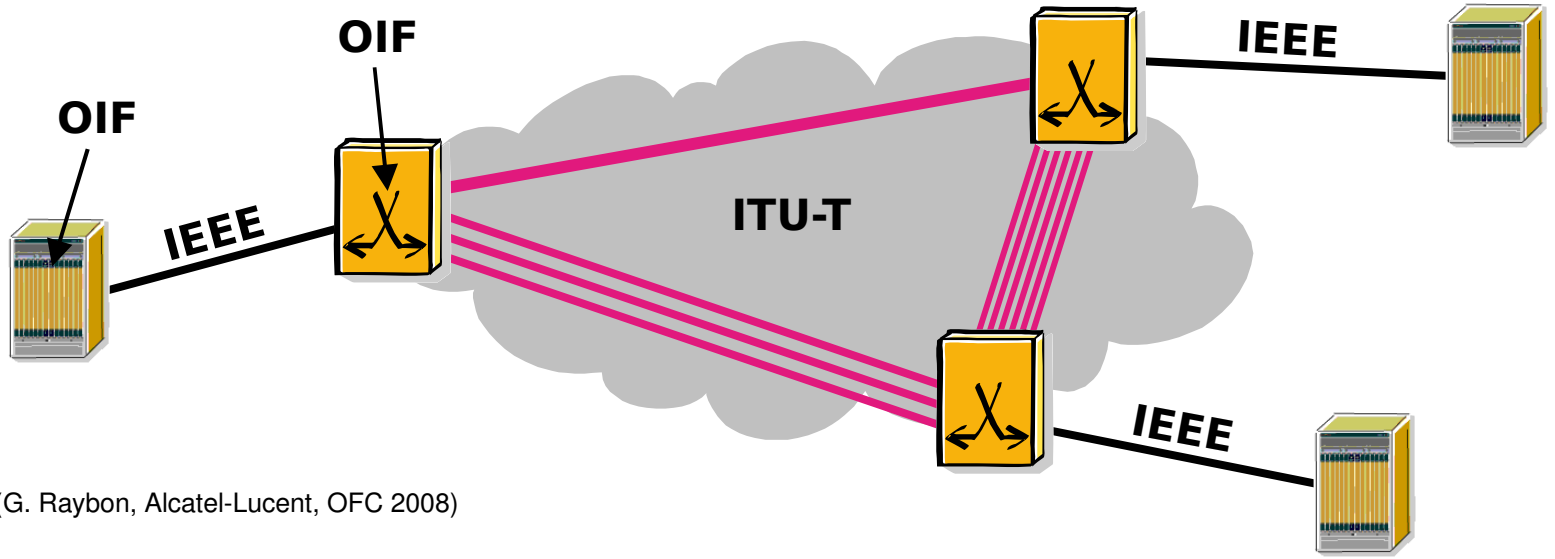
(G. Raybon, Alcatel-Lucent, OFC 2008)

- 100G Ethernet will come, driven by applications (e.g., video-on-demand)
- 100-Gb/s transport will have several flavors
  - Ethernet transport (IEEE) for local area and access networks
  - OTN transport (ITU-T) for wide-area networks

"We're upgrading our network to 40 Gbit/s, but we will go to 100 Gbit/s as soon as possible and we hope to deploy early next year,"
-- Fred Briggs, executive vice president for network operations and technology at Verizon, Lightreading September 2007.

100 Gb/s Standardization Activity

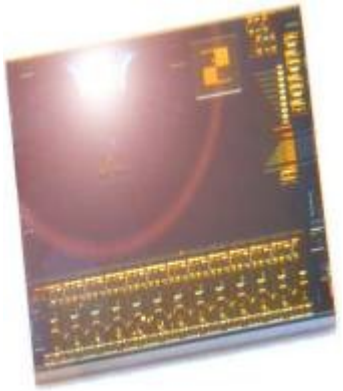
- **IEEE-Higher Speed Study Group (HSSG)**
  - Ethernet transport for local area and access networks
  - Presentations found at http://grouper.ieee.org/groups/802/3/hssg/index.html
- **Optical Internetworking Forum (OIF)**
  - Common Electrical Interface (CEI) enable high speed signaling for backplanes and chip to chip communications
- **International Telecommunications Union-Telecommunications Standardization Sector (ITU-T)**
  - Define standards for Optical Transport Network (OTN)

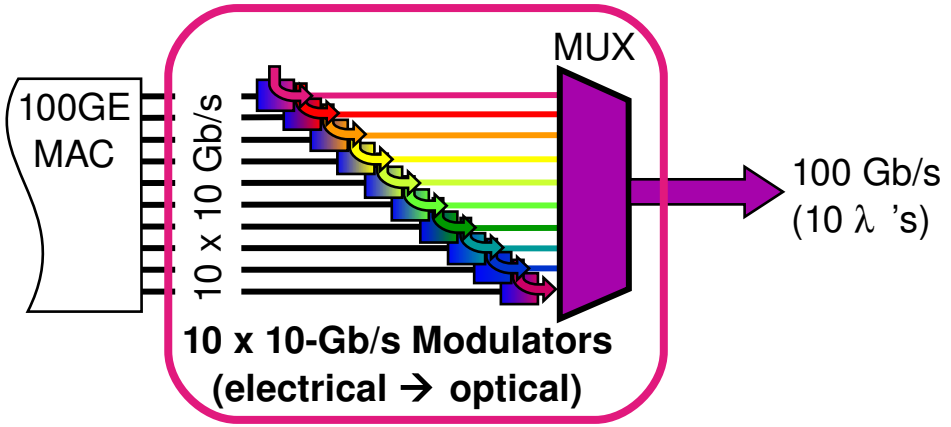


(G. Raybon, Alcatel-Lucent, OFC 2008)

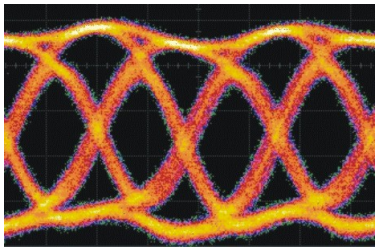
100 Gb/s *per channel*

100G parallel transport
(= inverse multiplexing)

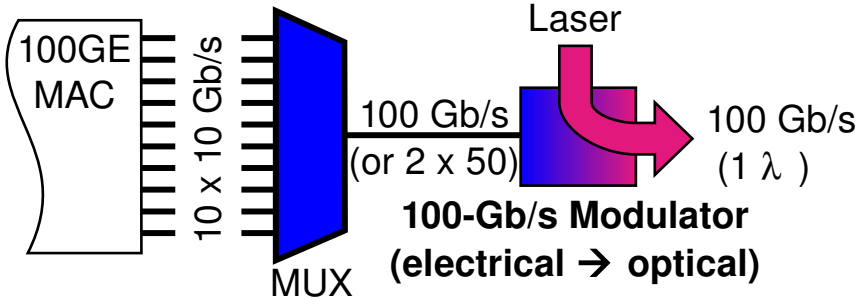




100G serial transport



10 ps / bit



Choice depends on lowest cost per bit:

- Targeted system *capacity* (*spectral efficiency*)
- Targeted system *reach*
- Wavelength *management* and *networking* aspects (ROADMs, etc.)

(P. Winzer, Alcatel-Lucent, OFC 2008)

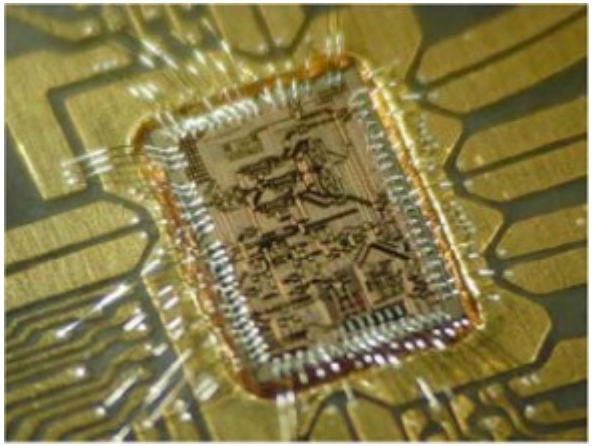
100 Gb/s *per wavelength*

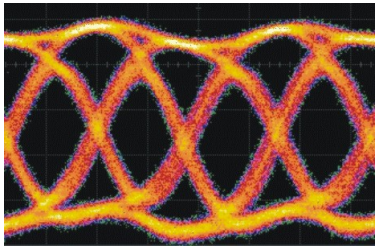
1 bit/symbol → **2 bits/symbol** → **4 bits/symbol and up**

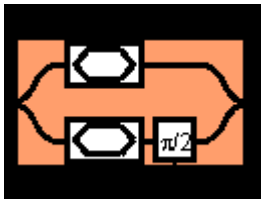
107 … 131 Gbaud
(OOK, DPSK, DB/PSBT, …)

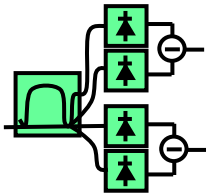
54 … 66 Gbaud
(DQPSK, pol-muxed OOK, …)

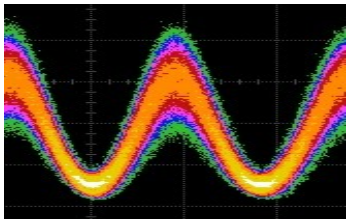
27 … 33 Gbaud
(pol-muxed (D)QPSK, 16-QAM, …)



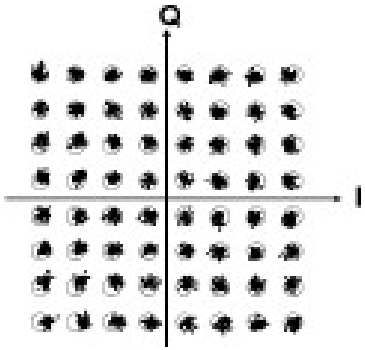








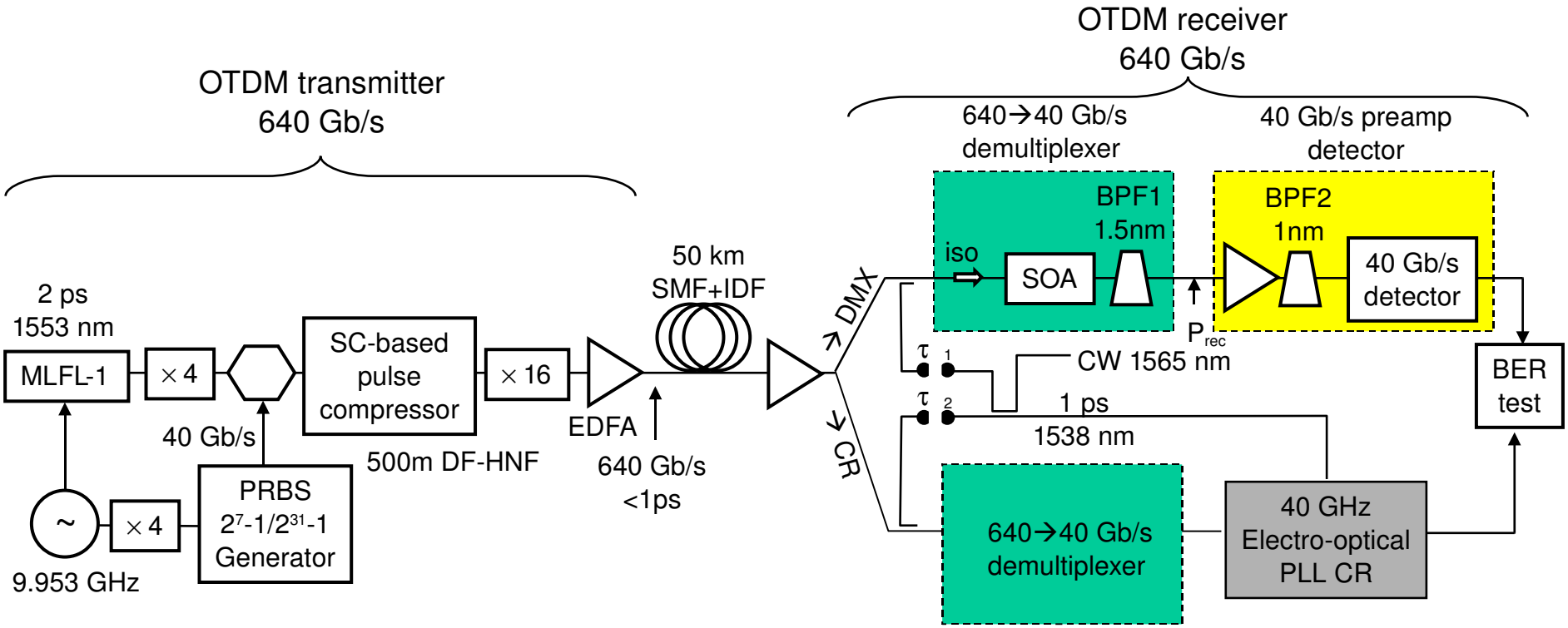
RZ-DQPSK

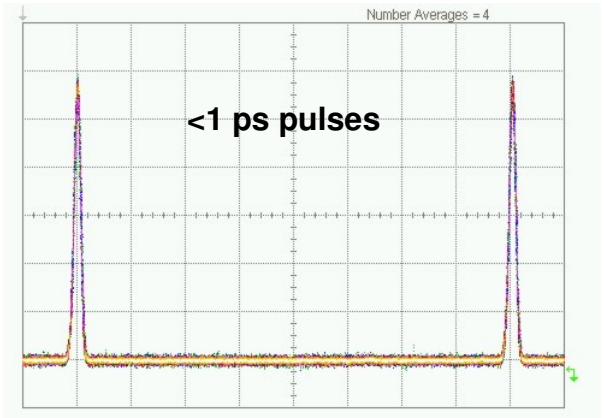


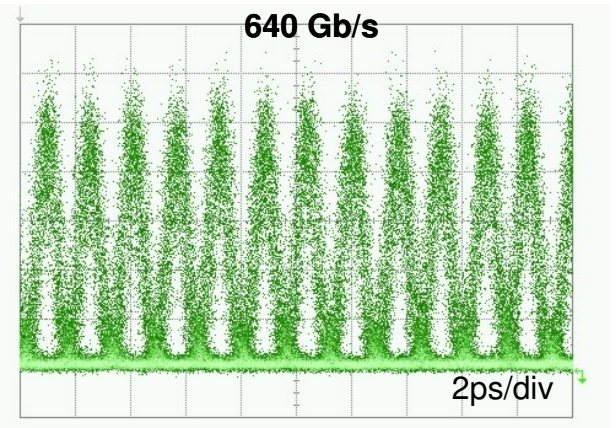
64-QAM

(G. Raybon, Alcatel-Lucent, OFC 2008)

Towards 1 Tb/s



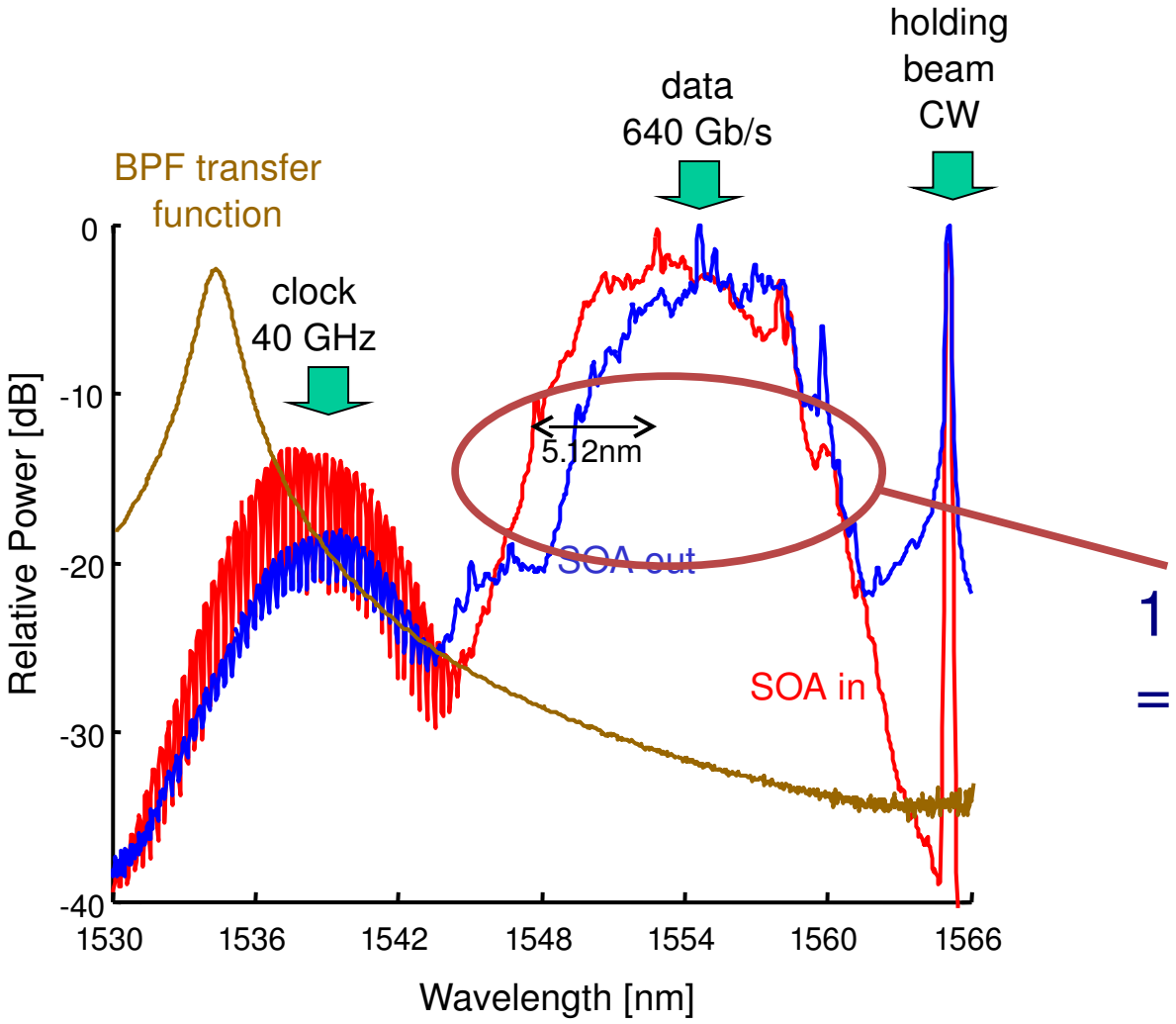




COBRA

(E. Tangdiongga, Technical Univ. Eindhoven, ECOC 2007)

1 Tb/s = a lot of optical bandwidth



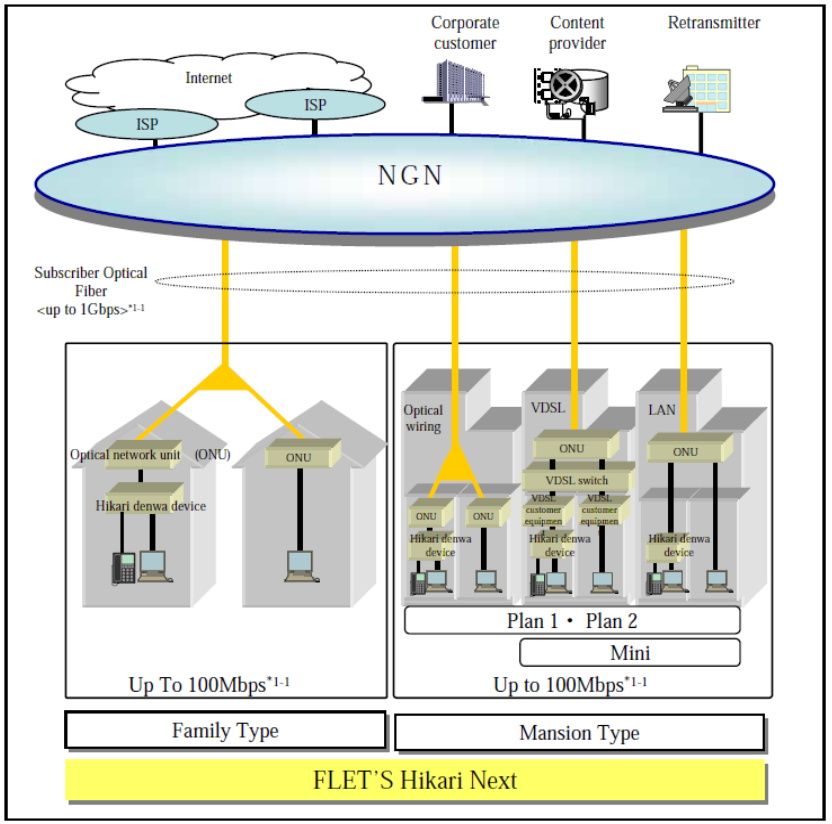
1 Tb/s modulated
= 16 nm of BW

COBRA

(E. Tangdiongga, Technical Univ. Eindhoven, ECOC 2007)

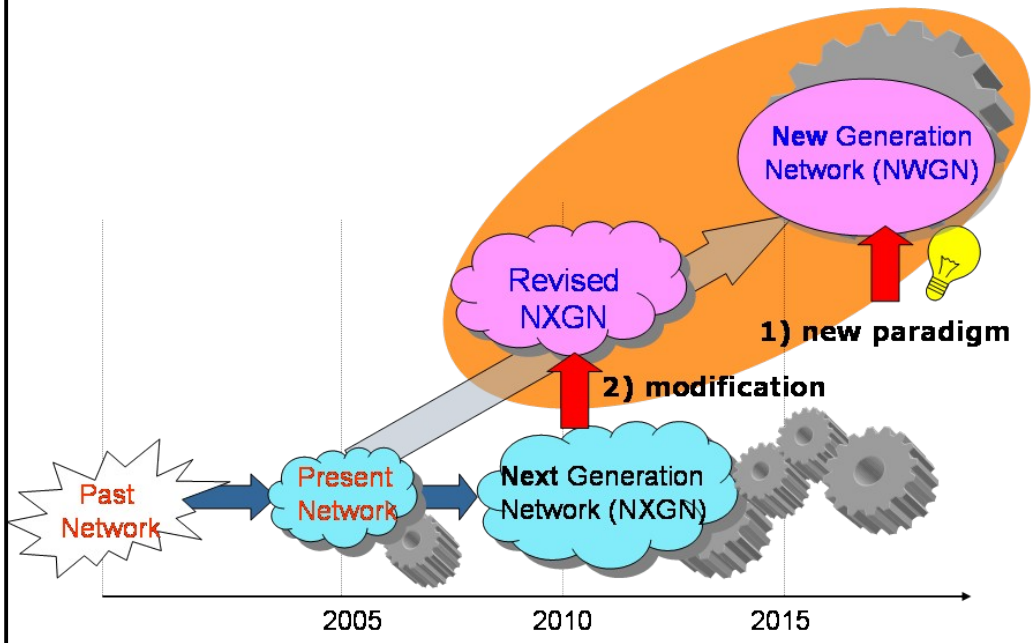
NGN in Japan

NGN: Next Generation Network. Everything over IP



NTT East taking orders as of March 31, 2008

NWGN: New Generation Network. New paradigm in R&D



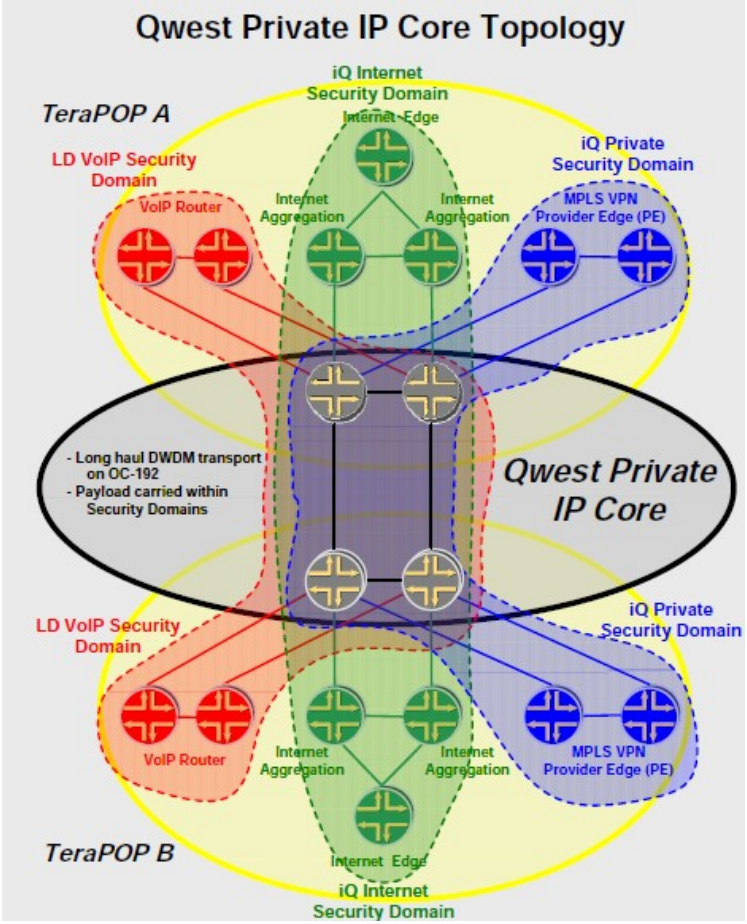
"Development of core network control and management technologies to support Peta-bit/s-class large-scale new generation networks, unify path/packet networks, and lead international standardization activities"

(http://nag.nict.go.jp/index_e.html)

NGN in the US

Qwest Spirit of Service®

All IP based, but
OC-192 over DWDM in core



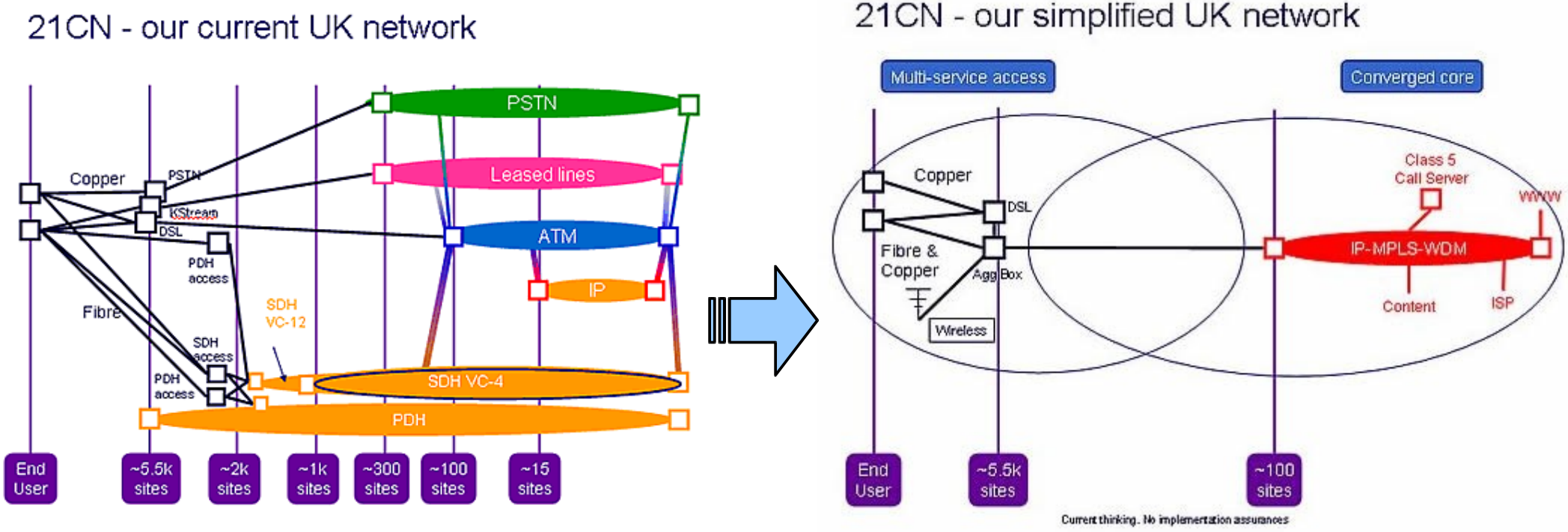
(P. Poll, Qwest, OFC 2008)

verizon

Verizon FiOS

NGN in Europe

British Telecom: 21st Century Network

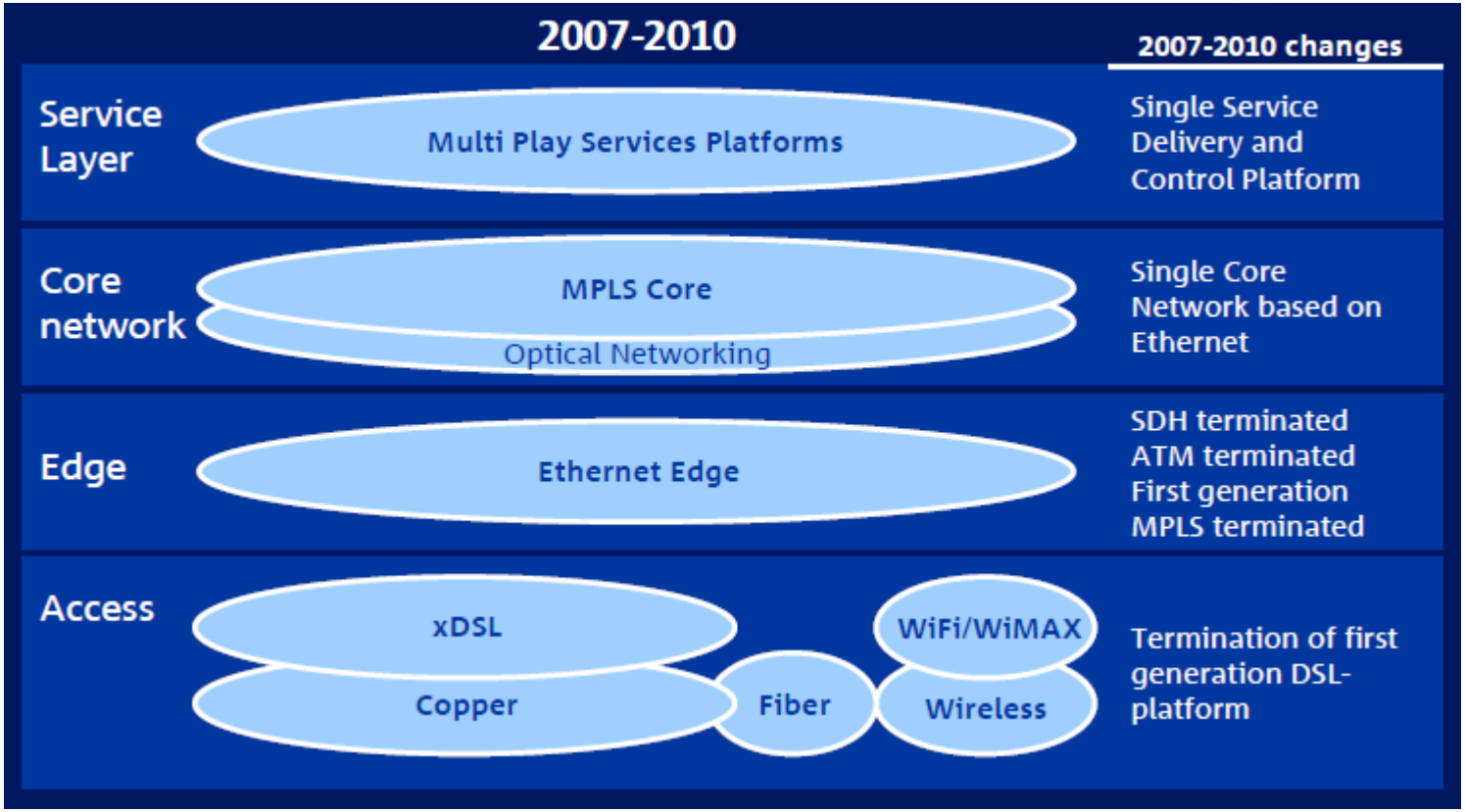


Convergence to everything over IP

MPLS in Core

NGN in Europe

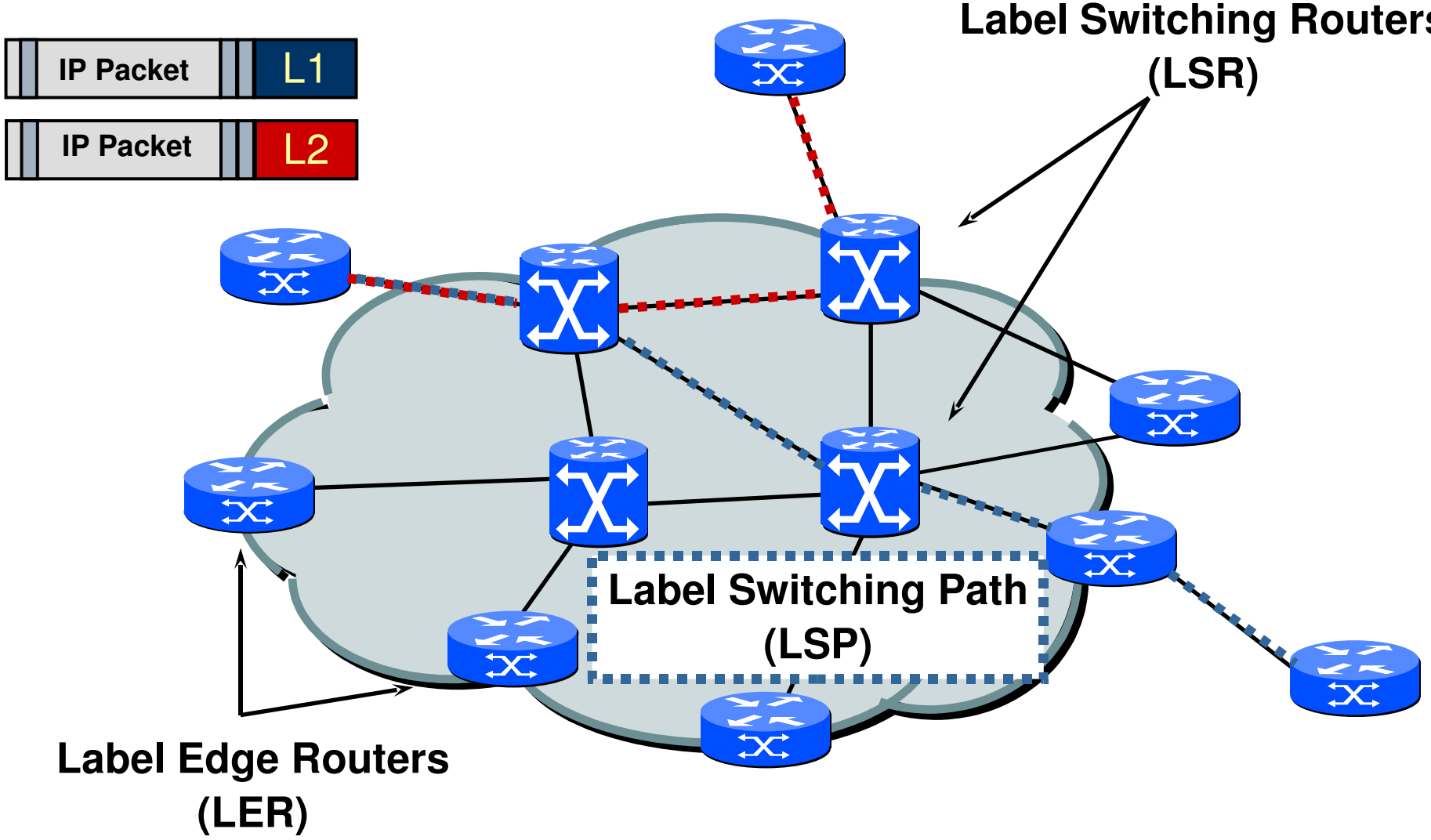
The Netherlands: All-IP



Core network based on Ethernet

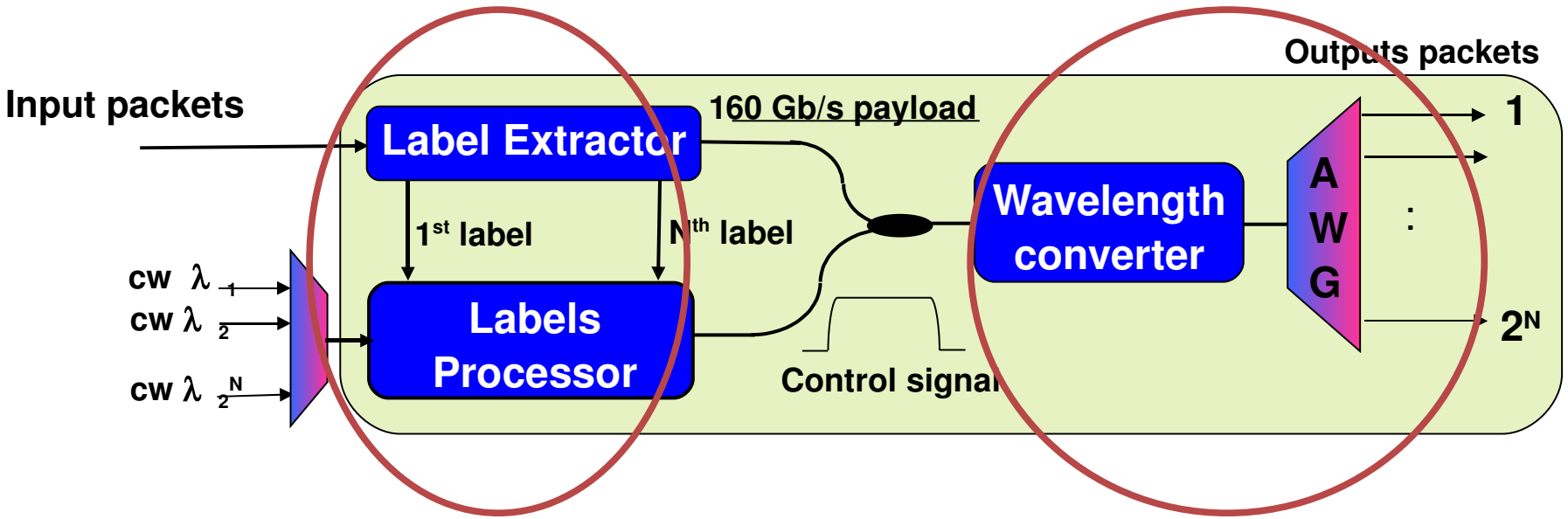
IP over MPLS

Multi-Protocol Label Switching



(G. Cincotti, Roma Tre University, OFC 2006)

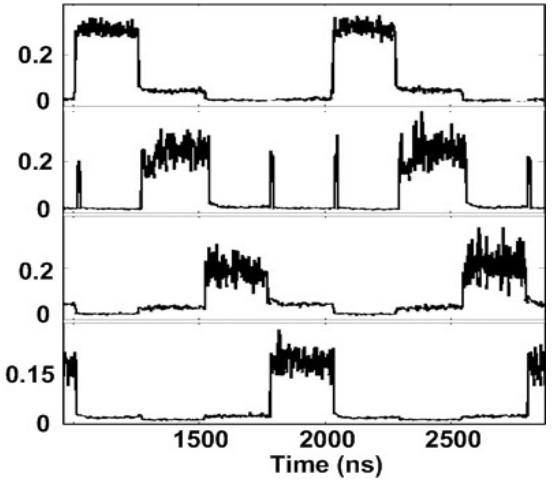
Future: Optical Packet Switching



Fast Label Recognition

Fast All-Optical Switching

Packets at output

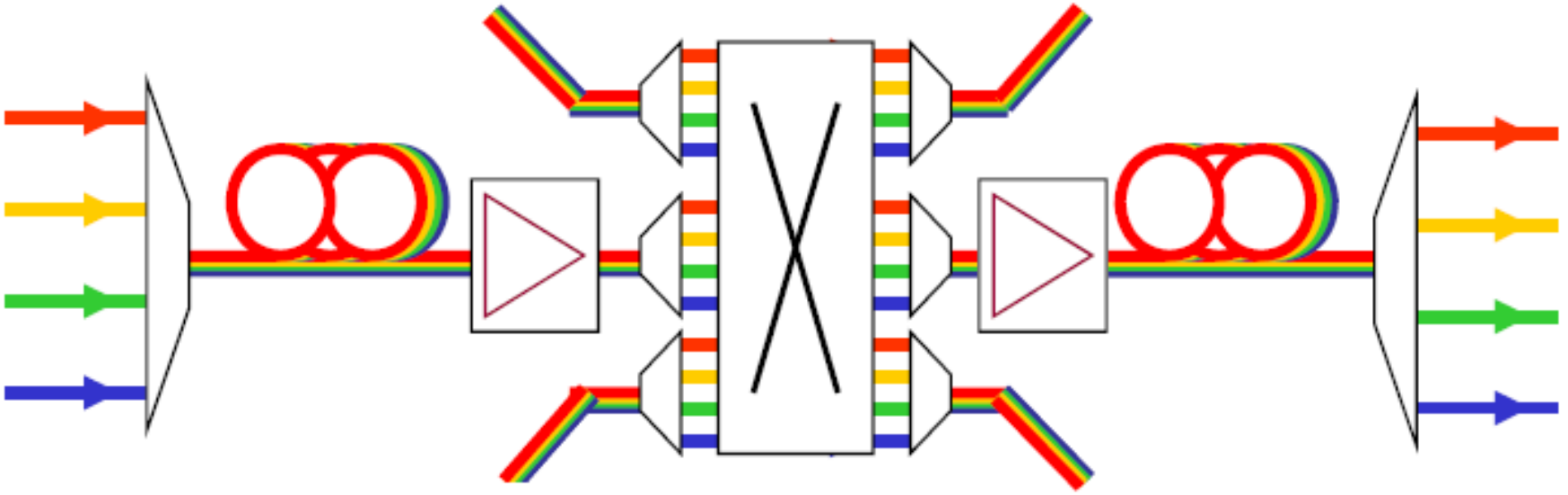


(N. Calabretta, Technical Univ. Eindhoven, OFC 2008)

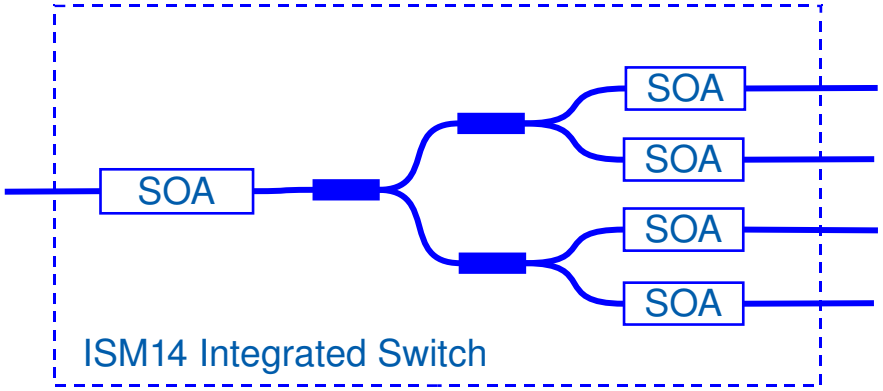
Why All-Optical?

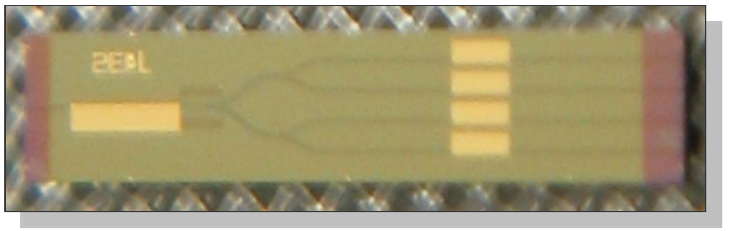
Same reason ROADMs / OXCs offer express lanes in circuit switched networks:

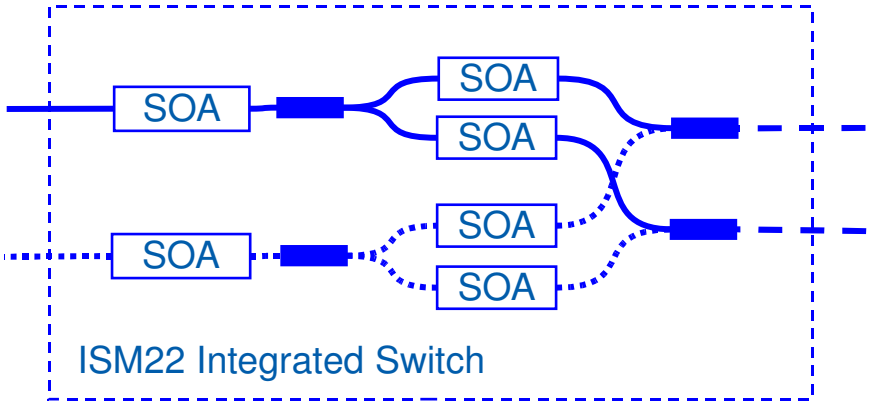
- Less complexity
- Lower power consumption

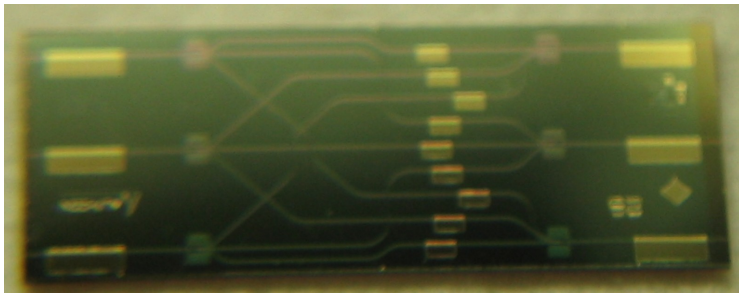


Fast All-Optical Switching





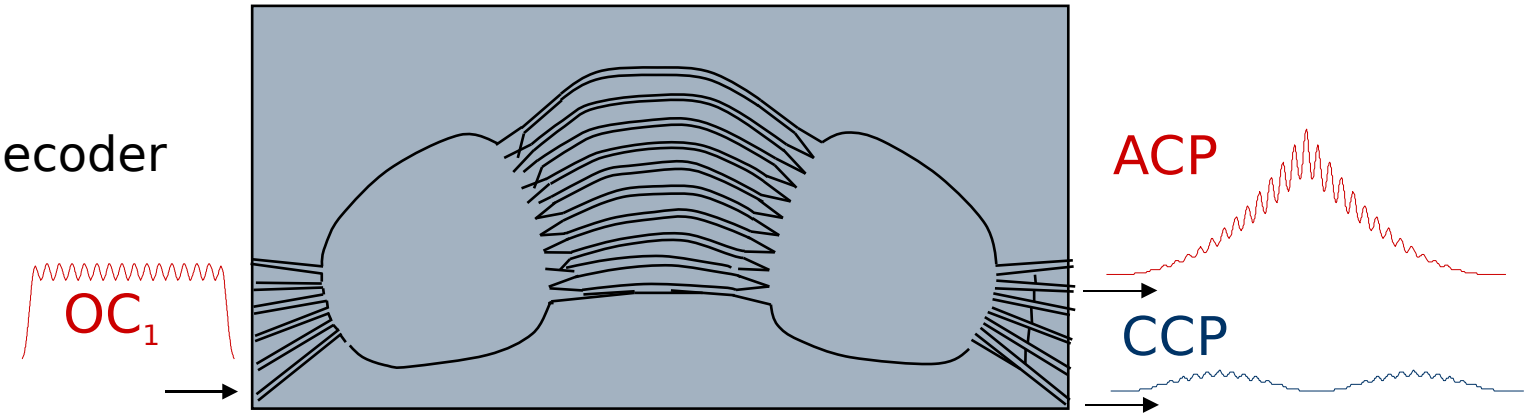


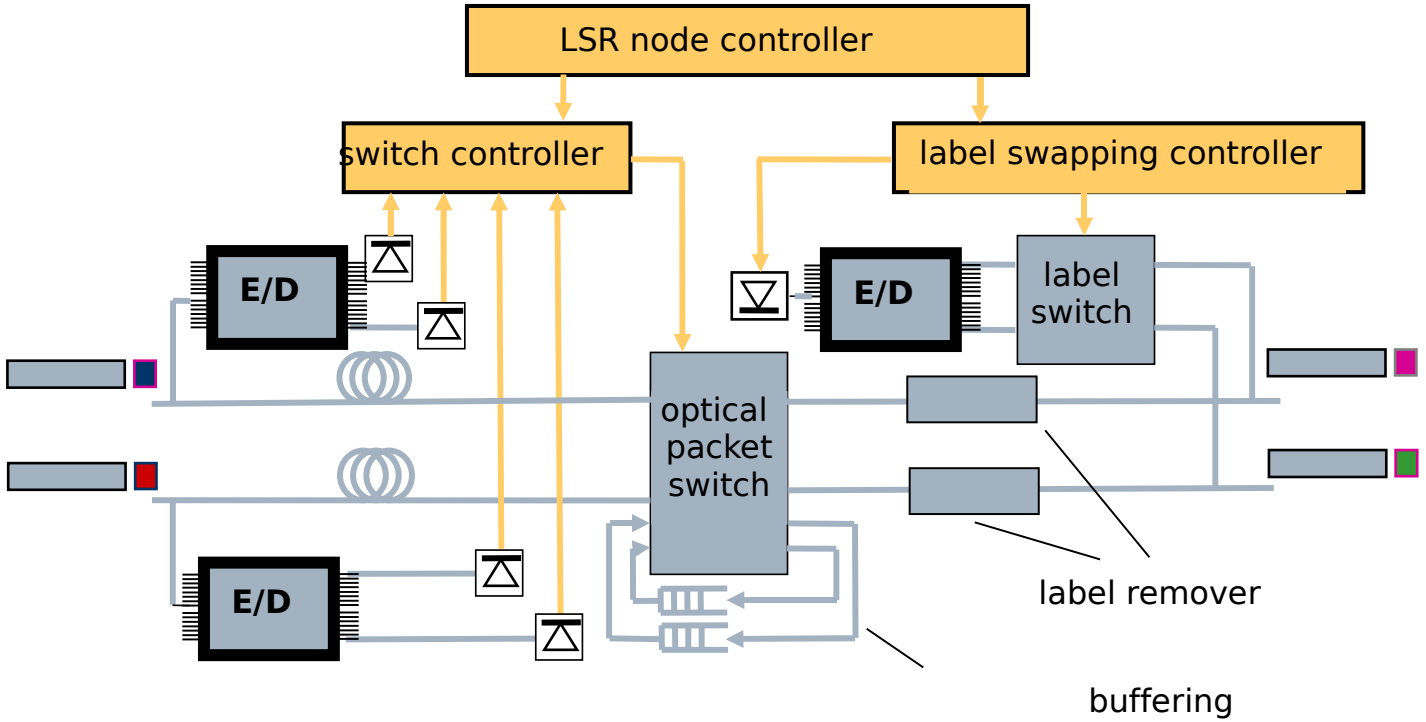


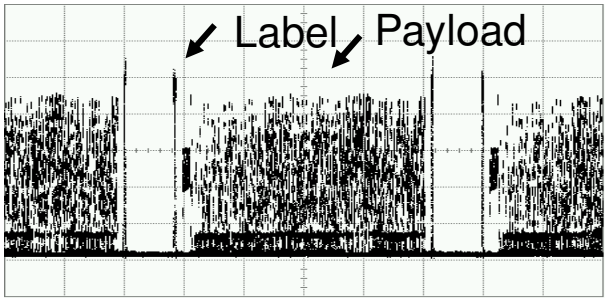
- SOA Switching Elements
  - High Extinction Ratio
  - Nanosecond Switching

Fast All-Optical Label Recognition

Single-Chip
Multiport
Encoder / Decoder

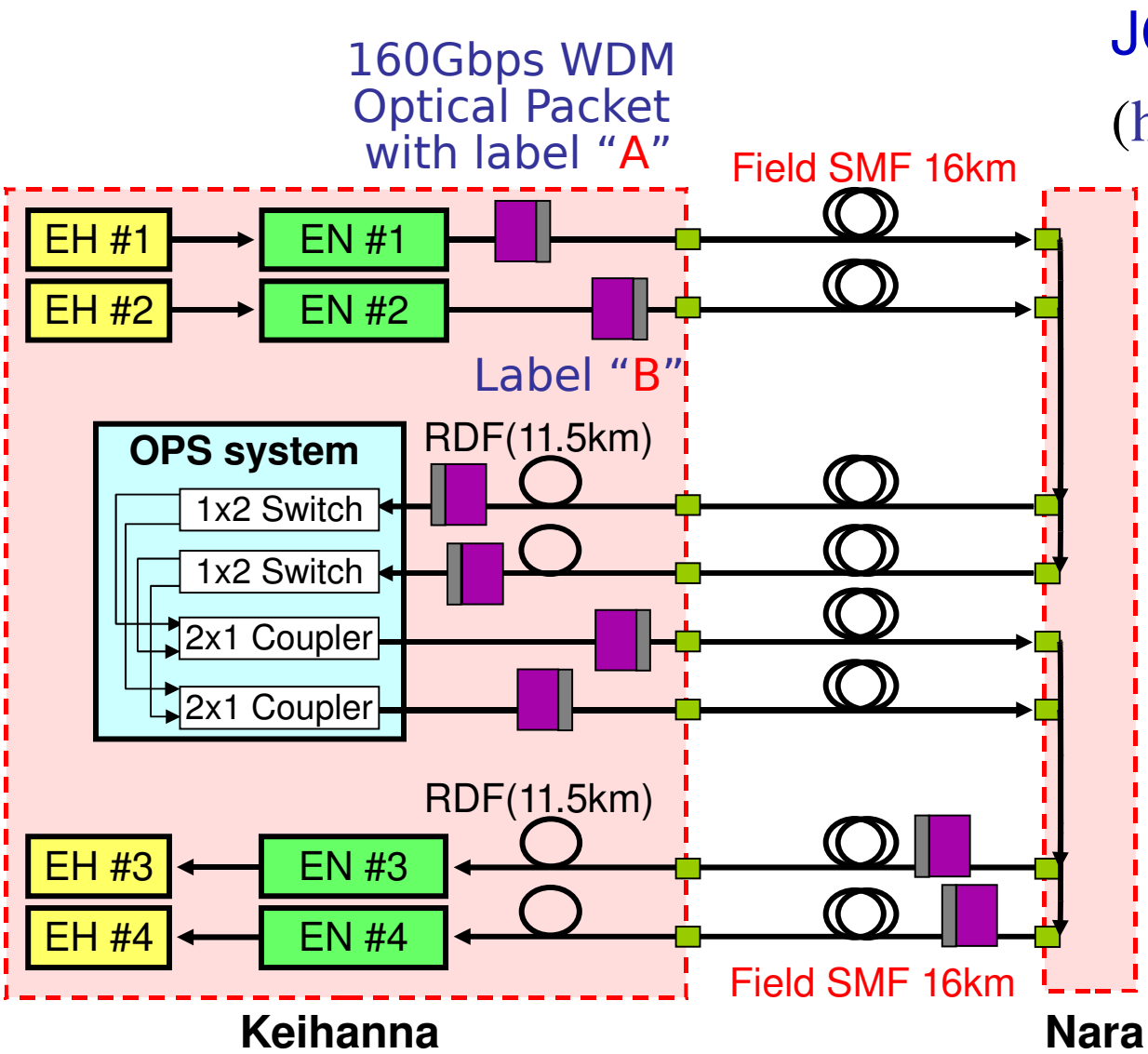






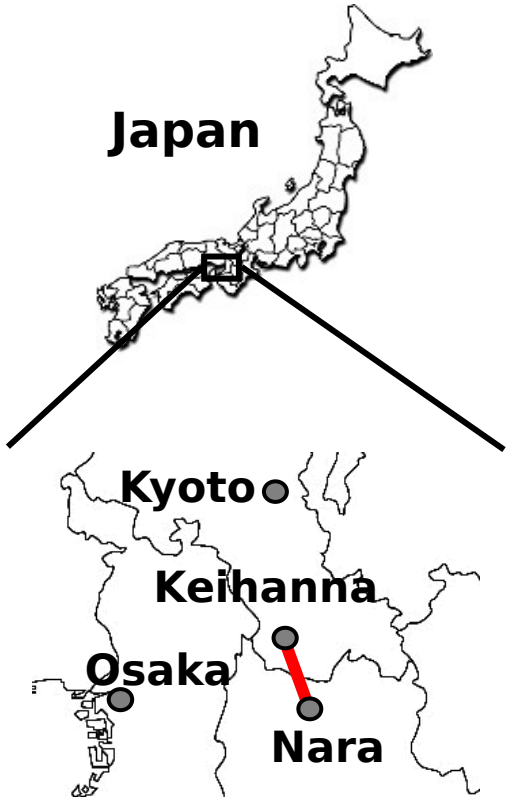
(G. Cincotti, Roma Tre University, OFC 2006)

Optical Packet Switching Field Trial



JGN2 testbed network

(http://www.jgn.nict.go.jp)

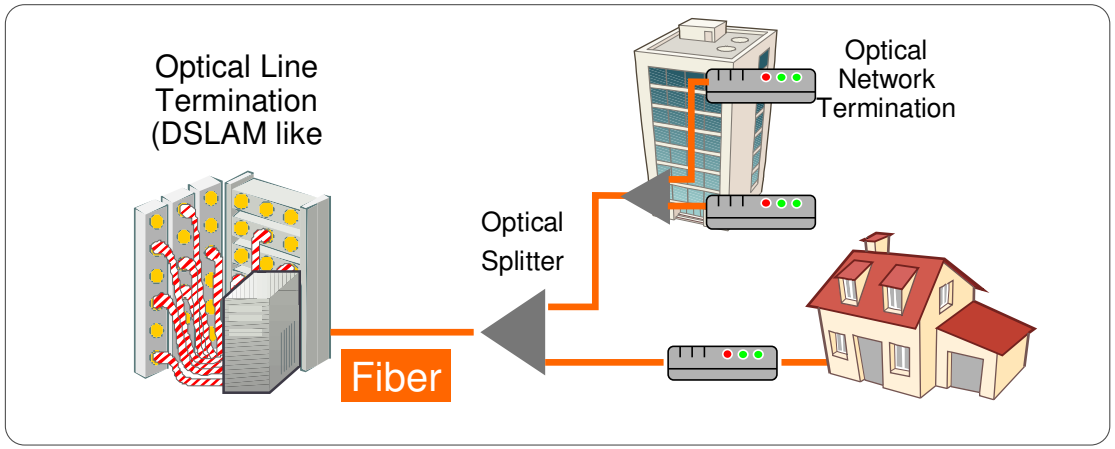


(N. Wada, NiCT, OFC 2008)

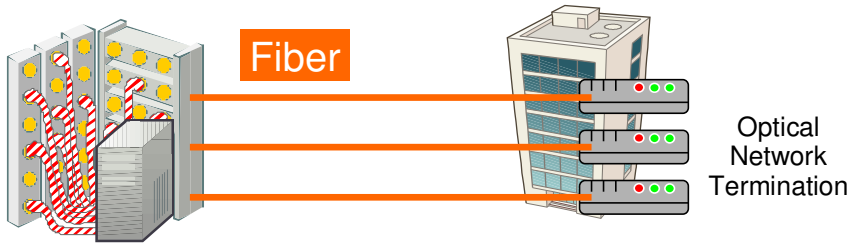
Access Networks: PON or P-t-P?

GPON a maturing technology ready for roll-out

PON - Point to multipoint



Point to Point



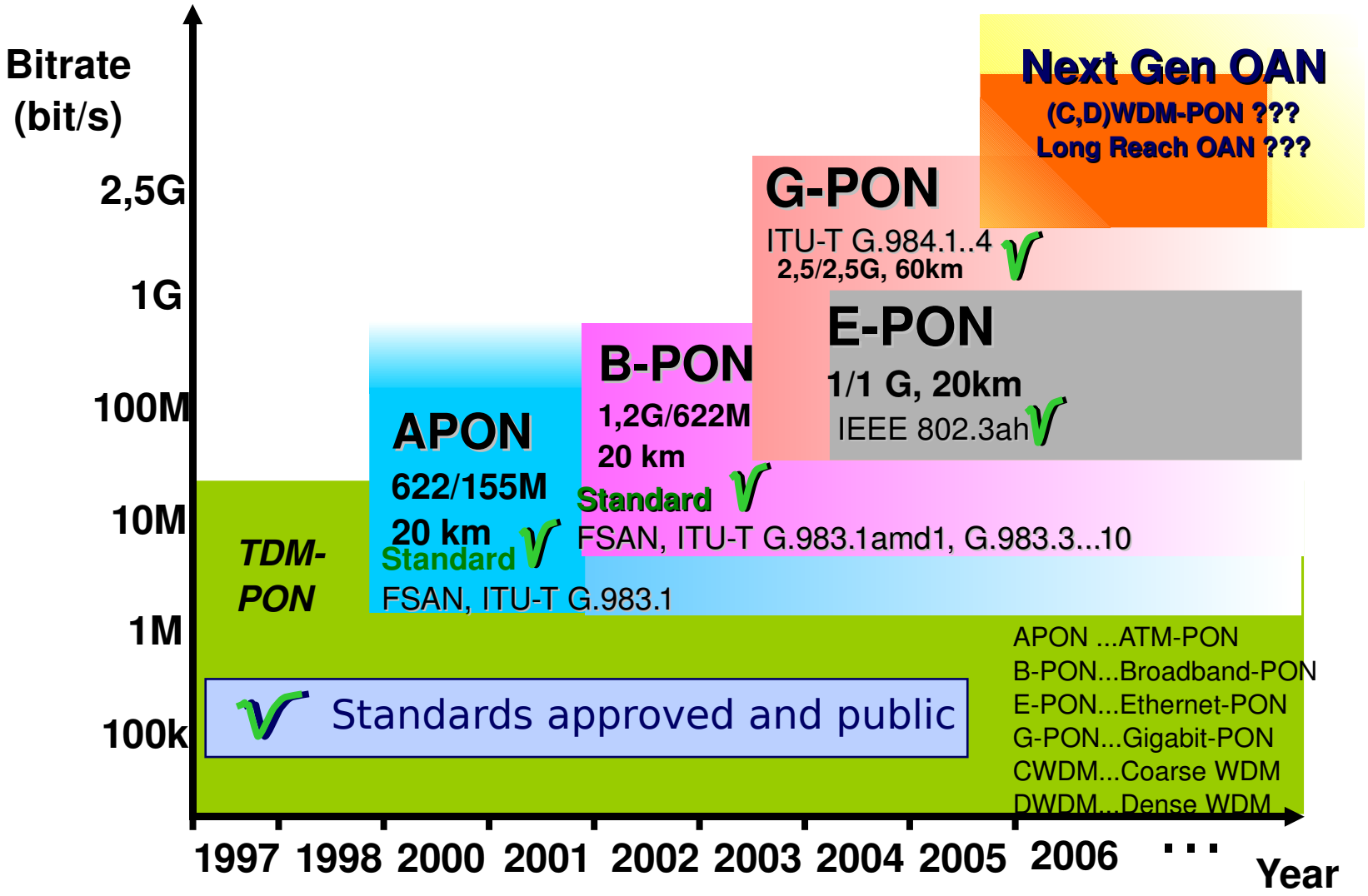
Passive Optical Network (PON) has 3 main advantages

⇒ **Less capex in optics & equipment**
⇒ **Less opex in provisioning**
⇒ **Wholesale offer available**

PON is High Density in CO

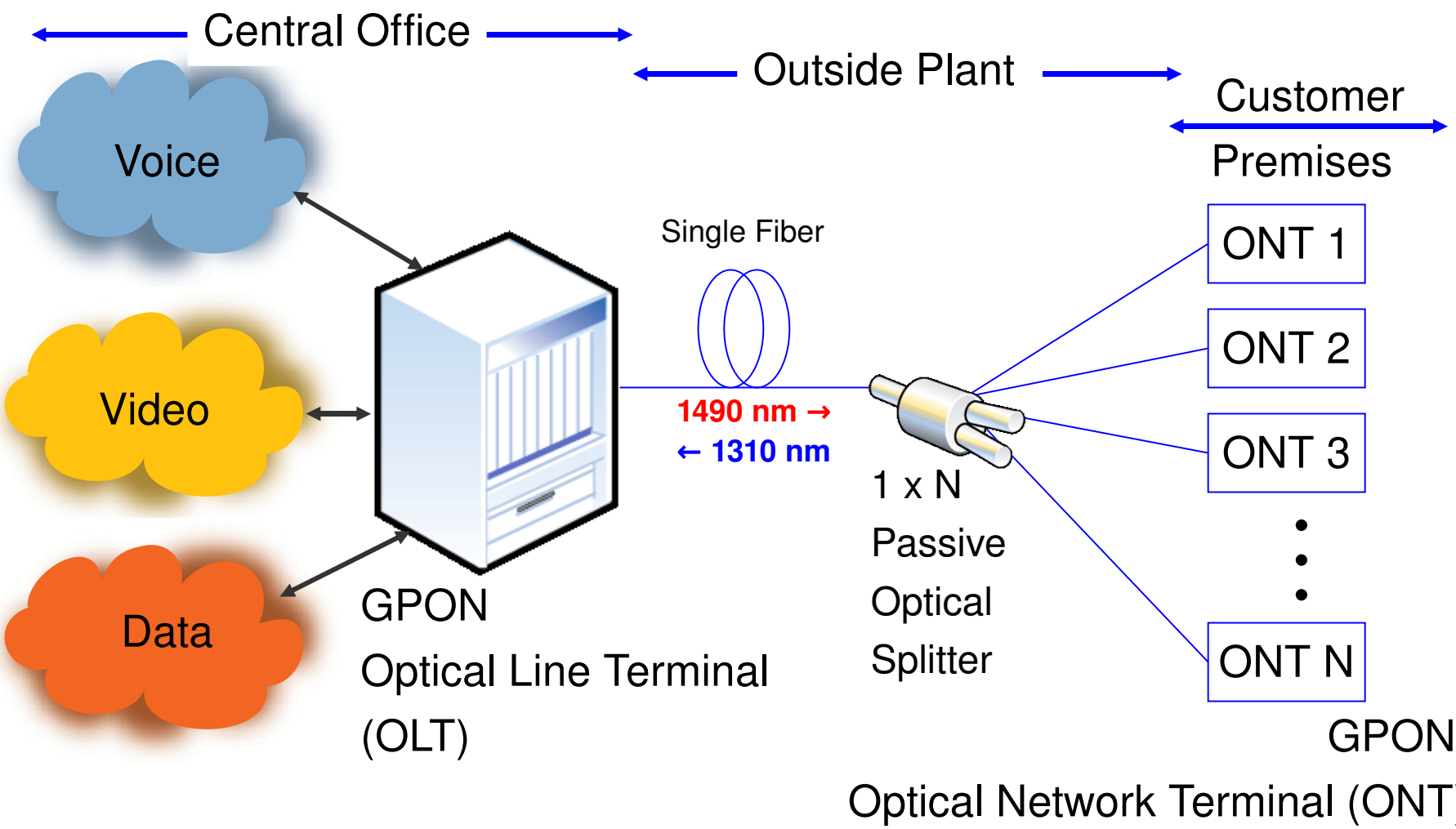
10 Linecards x 4 PON ports x 128 ONTs = 5120 ONTs per shelf

PON Roadmap



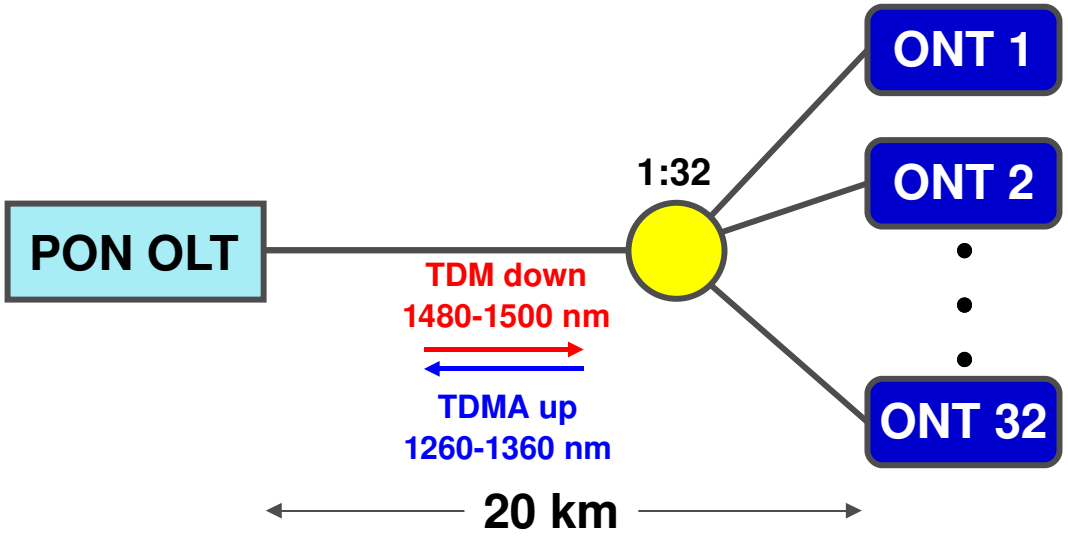
(A. Srivastava, OneTerabit, 2008)

State of the Art: GPON



(D. Piehler, Alphion, 2008)

GPON with Reach Extender

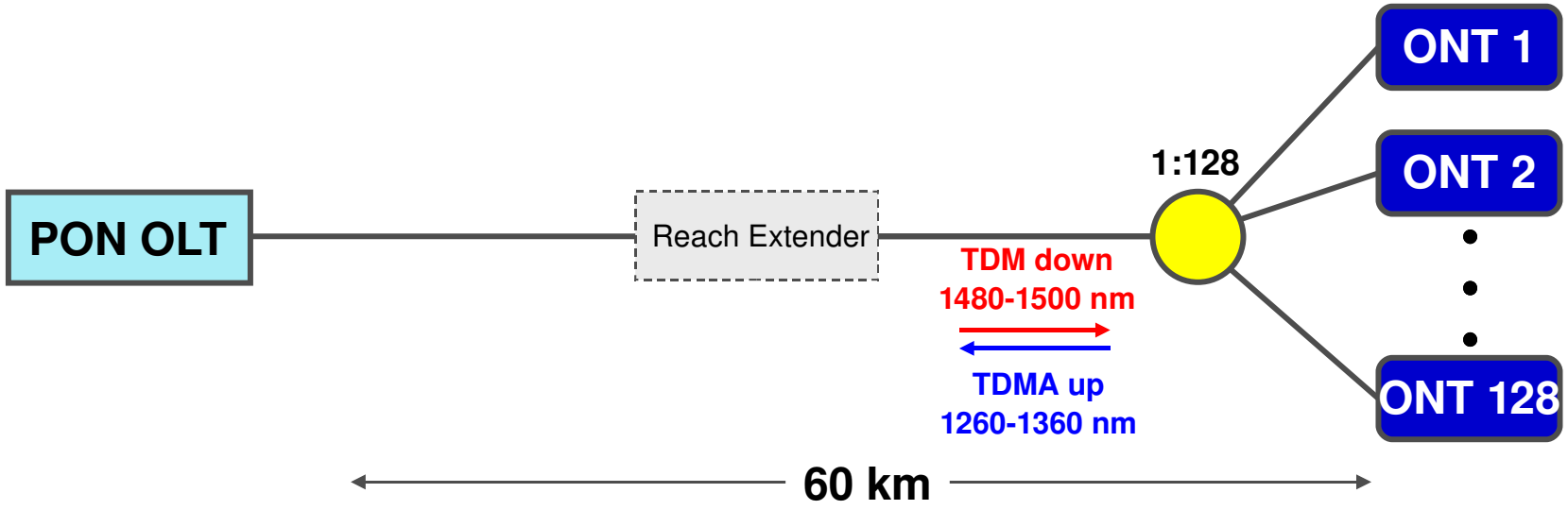


- Increased reach (will require an OEO or optical amp-based reach extender)
  - Near-term (tactical): avoid current practice of "remoting" the OLT to go beyond practical 20 km limit
  - Long-term (strategic): may permit consolidation of central offices (local exchanges)*

*** D. Payne and R. Davey, "The future of fibre access systems?," *BT Technol. J.*, 20, 104-114, 2002.**

(P. Iannone, AT&T, OFC 2008)

GPON with Reach Extender



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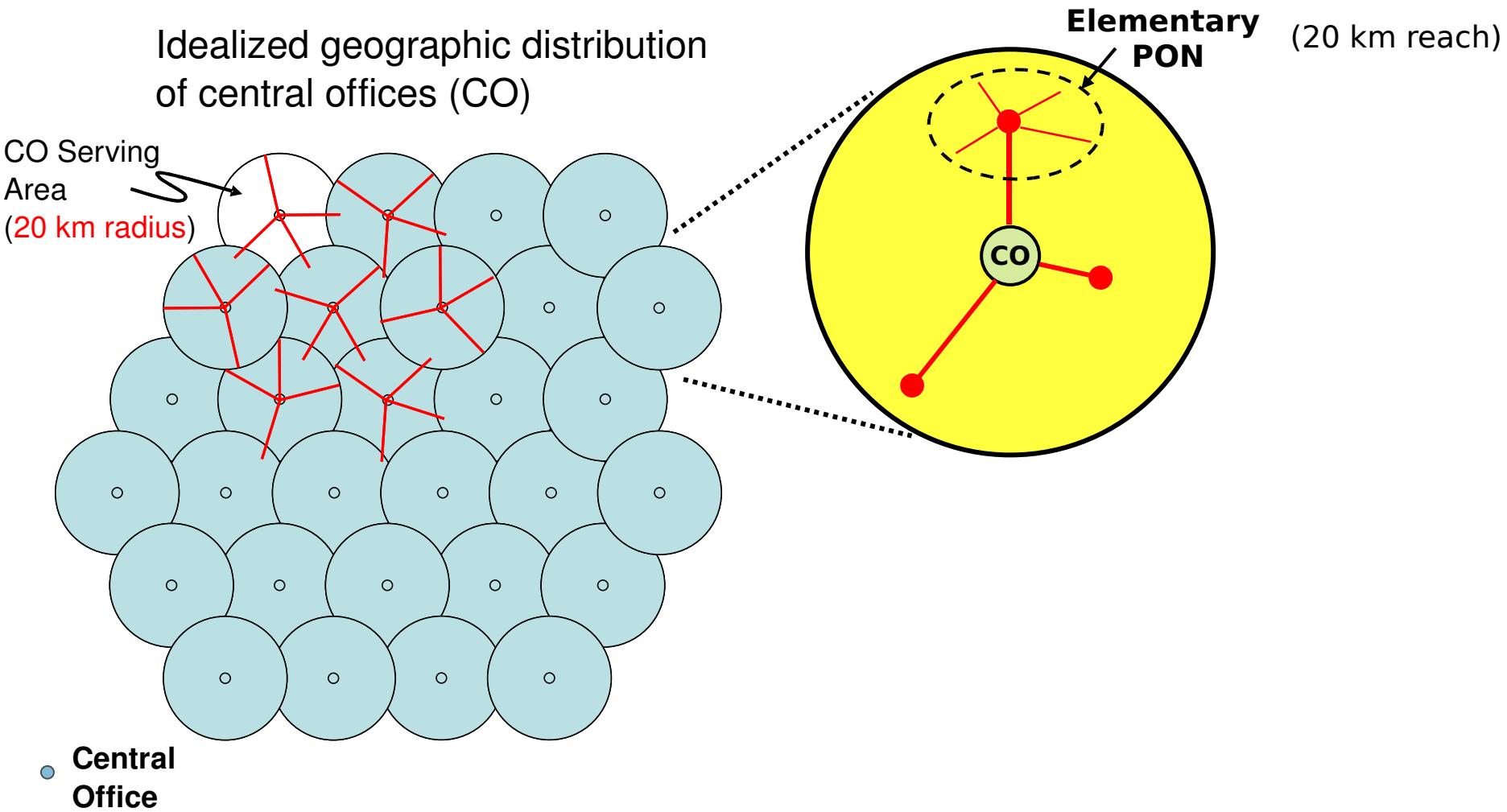
(P. Iannone, AT&T, OFC 2008)

Strategic Use of Reach Extender

Long-reach PONs enable CO consolidation



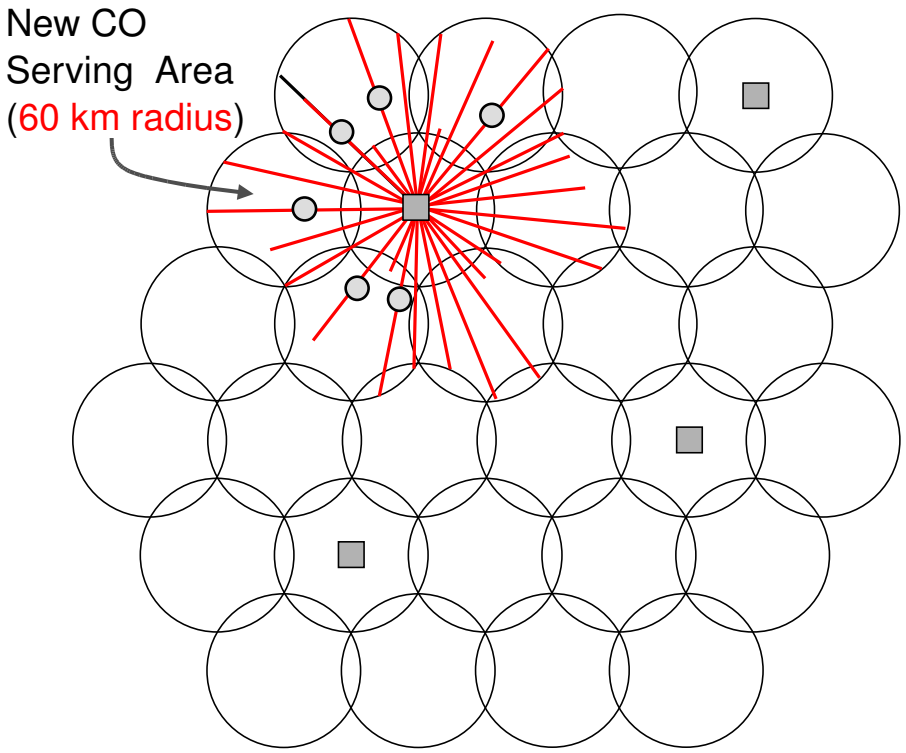
Red lines represent subset of individual PONs within each CO serving area

(P. Iannone, AT&T, OFC 2008)

Strategic Use of Reach Extender

Long-reach PONs enable CO consolidation (60 – 100 km reach)

Idealized geographic distribution of central offices

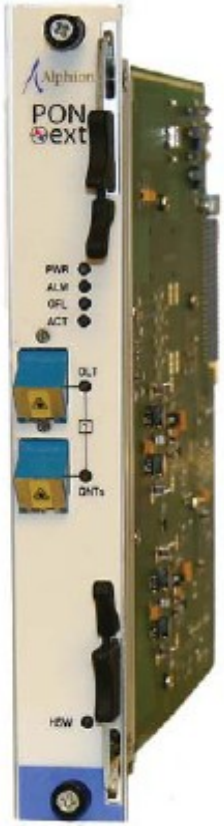


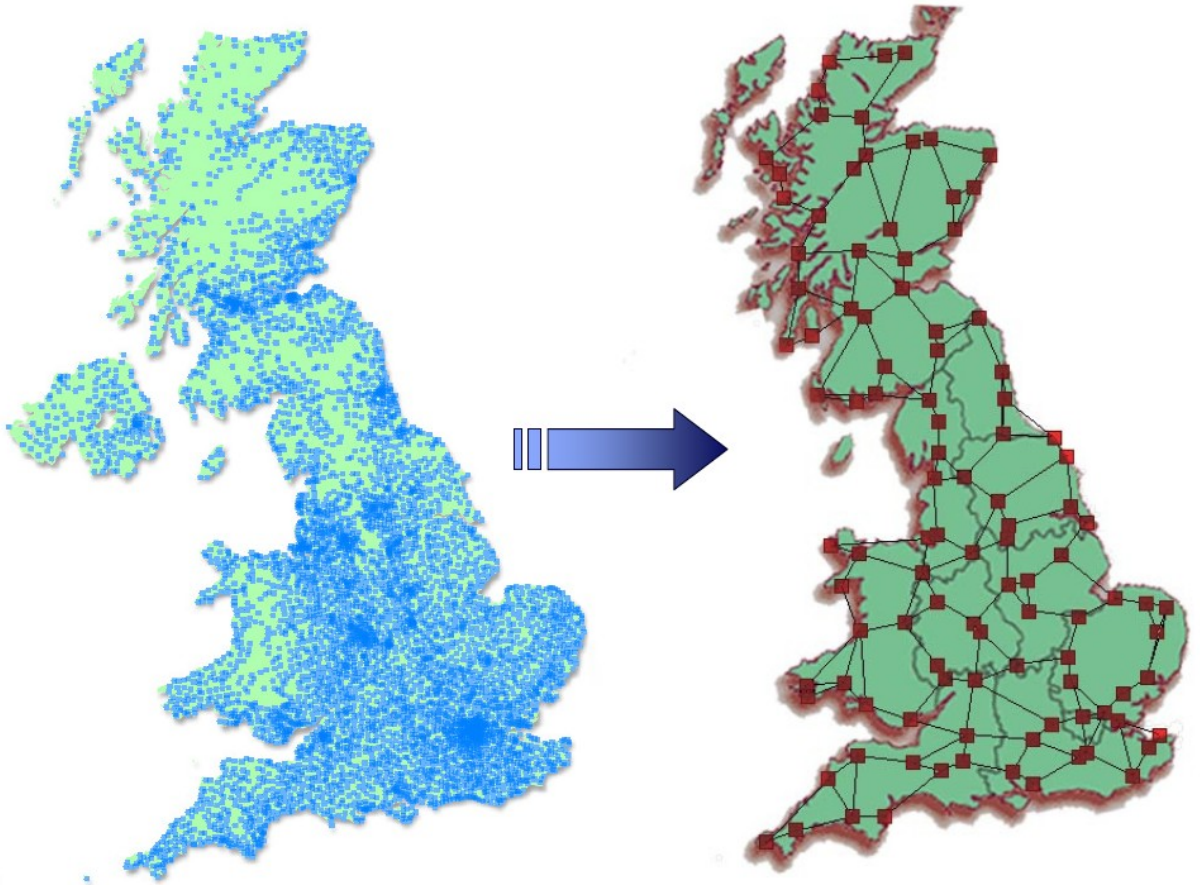
(P. Iannone, AT&T, OFC 2008)

- Eliminate majority of central offices
- Powered extender box on feeder
- Possibly increase split per PON
- Saves on:
  - Powering
  - OpEx
  - Real estate
- This strategy benefits from WDM or TDM muxing between OLT and PON extender
  - Lots of technology options (CWDM, DWDM, higher rate TDM, λ conversion, etc)
  - case for all-optical extender box may be more compelling for multi wavelengths

Power and Space Savings

Effect on Locations for Head-Ends (OLTs)





UK With All Exchanges

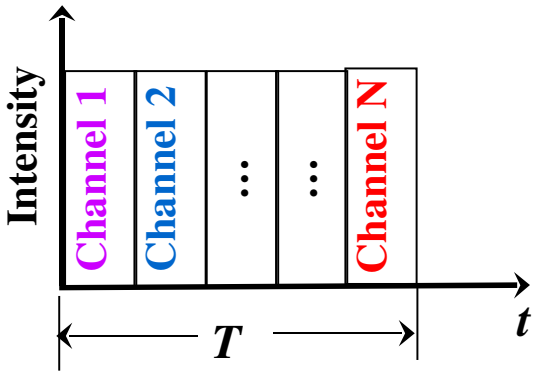
UK with~100 21cn nodes

The Institute of Telecommunications Professionals

Future: PON Capacity Increase

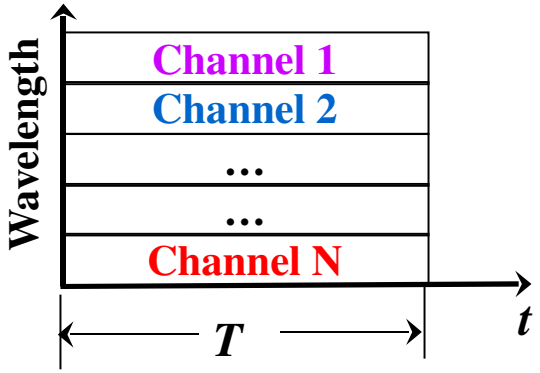
TDMA

Time-Division-Multiple-Access



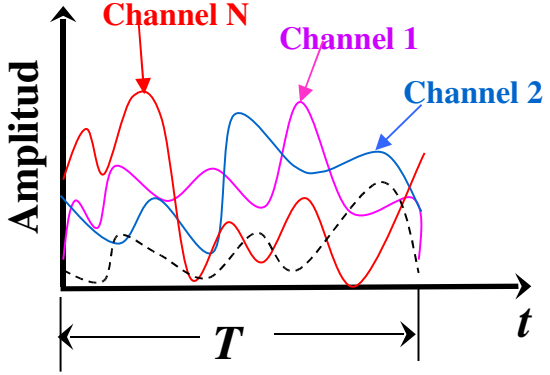
WDMA

Wavelength-Division-Multiple-Access



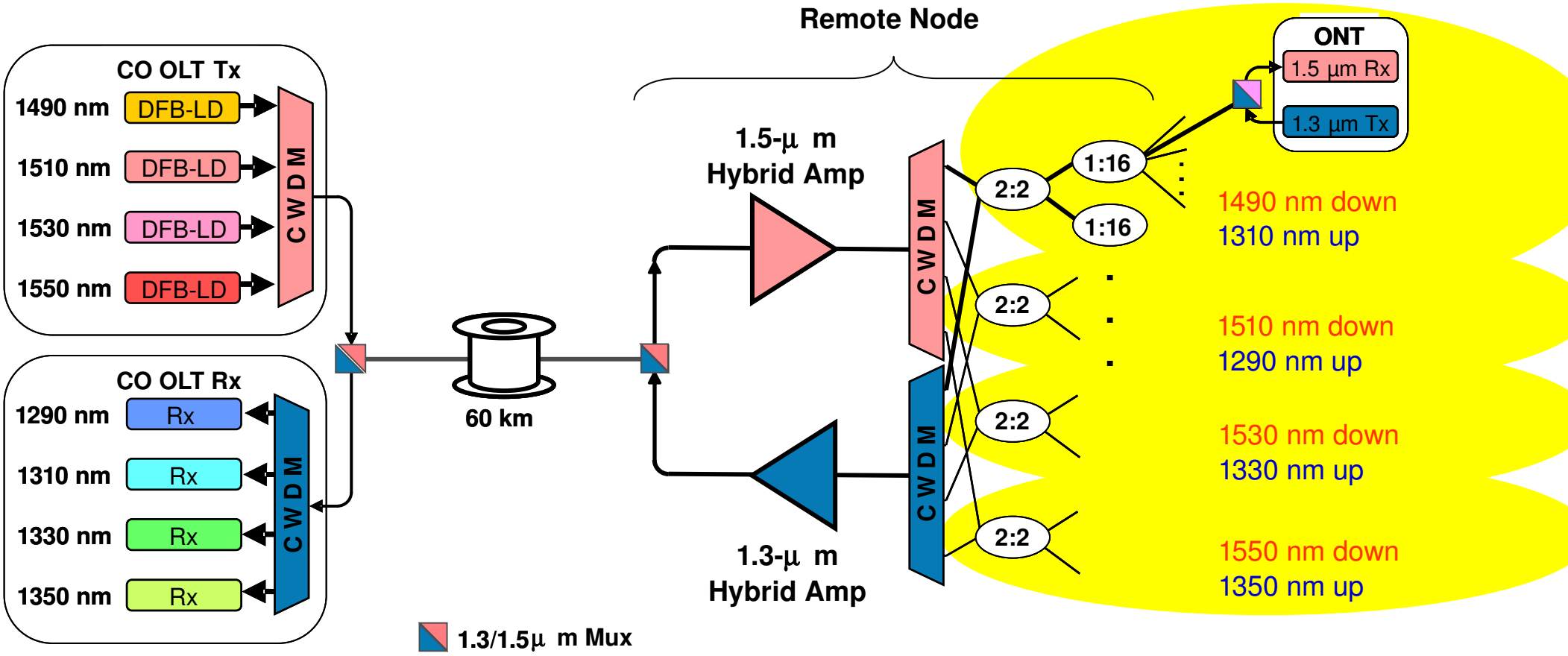
OCDMA

Code-Division-Multiple-Access



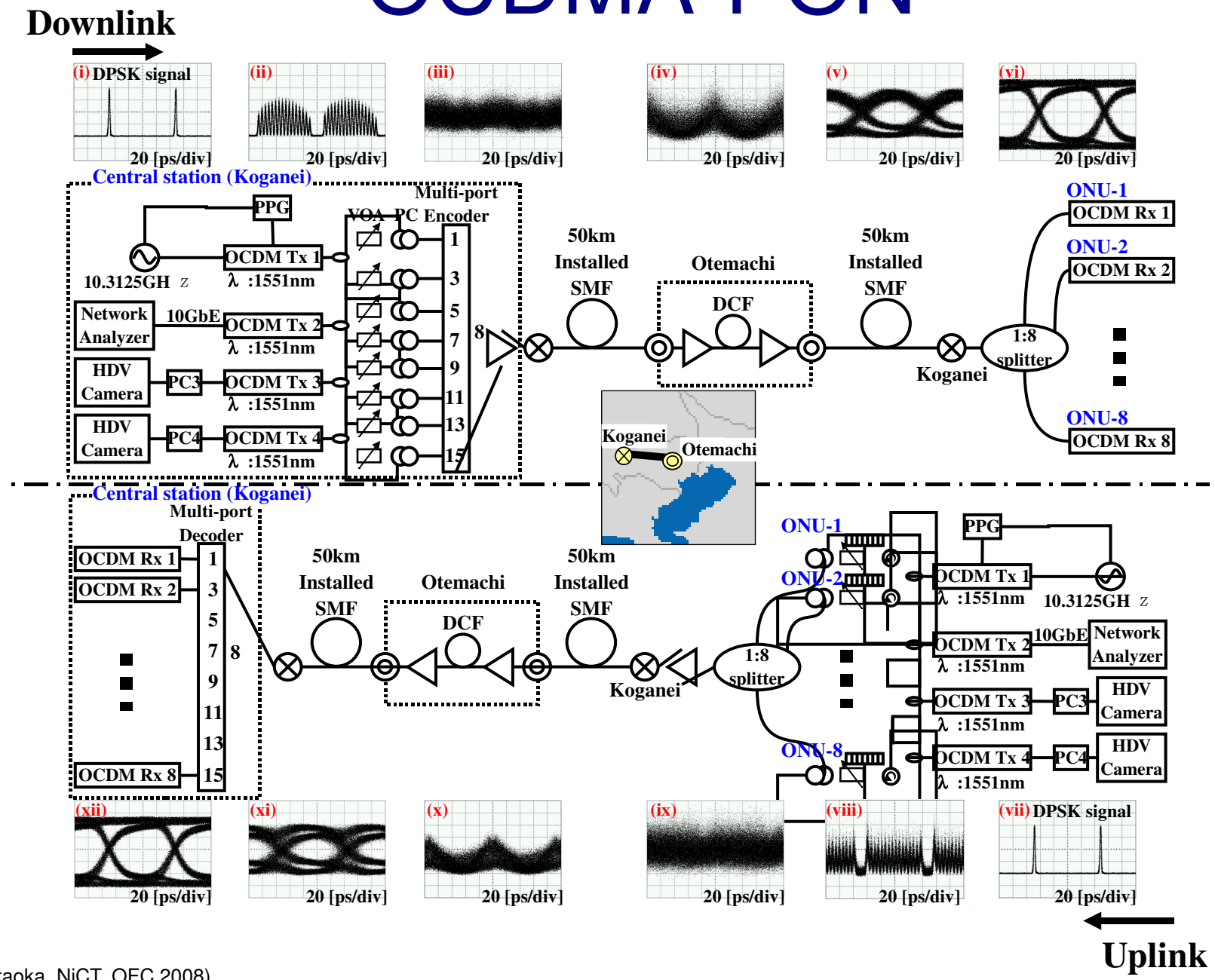
(N. Kataoka, NiCT, OFC 2008)

WDM-PON



(P. Iannone, AT&T, 2008)

OCDMA-PON



(N. Kataoka, NiCT, OFC 2008)

Summary

- Convergence to packet networks
- Standardization is essential
- IP in the core already here
- Future: Optical packet switching???
- Access networks are running on GPON
- Extended reach GPON is coming
- Future: WDM-PON? OCDMA-PON?

Thanks:

- David Piehler, Alphion Corp., USA
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- G. Cincotti, Roma Tre University, Italy
- N. Wada, NiCT, Japan
- P. Iannone, K. Reichmann, AT&T Labs Research, USA
- A. Srivastava, OneTerabit, USA