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Performance from Experience

Technology and Architecture Trends in Optical Networking

2003 IEEE Distinguished Lecturer Talk

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An SAIC Company

Outline of Presentation: Trends in Optical Networking

- Introduction: snapshot of the industry
- Trends in optoelectronic technologies
- Trends in optical networking architectures
- Research activities in optical packet switching
- Summary and discussion

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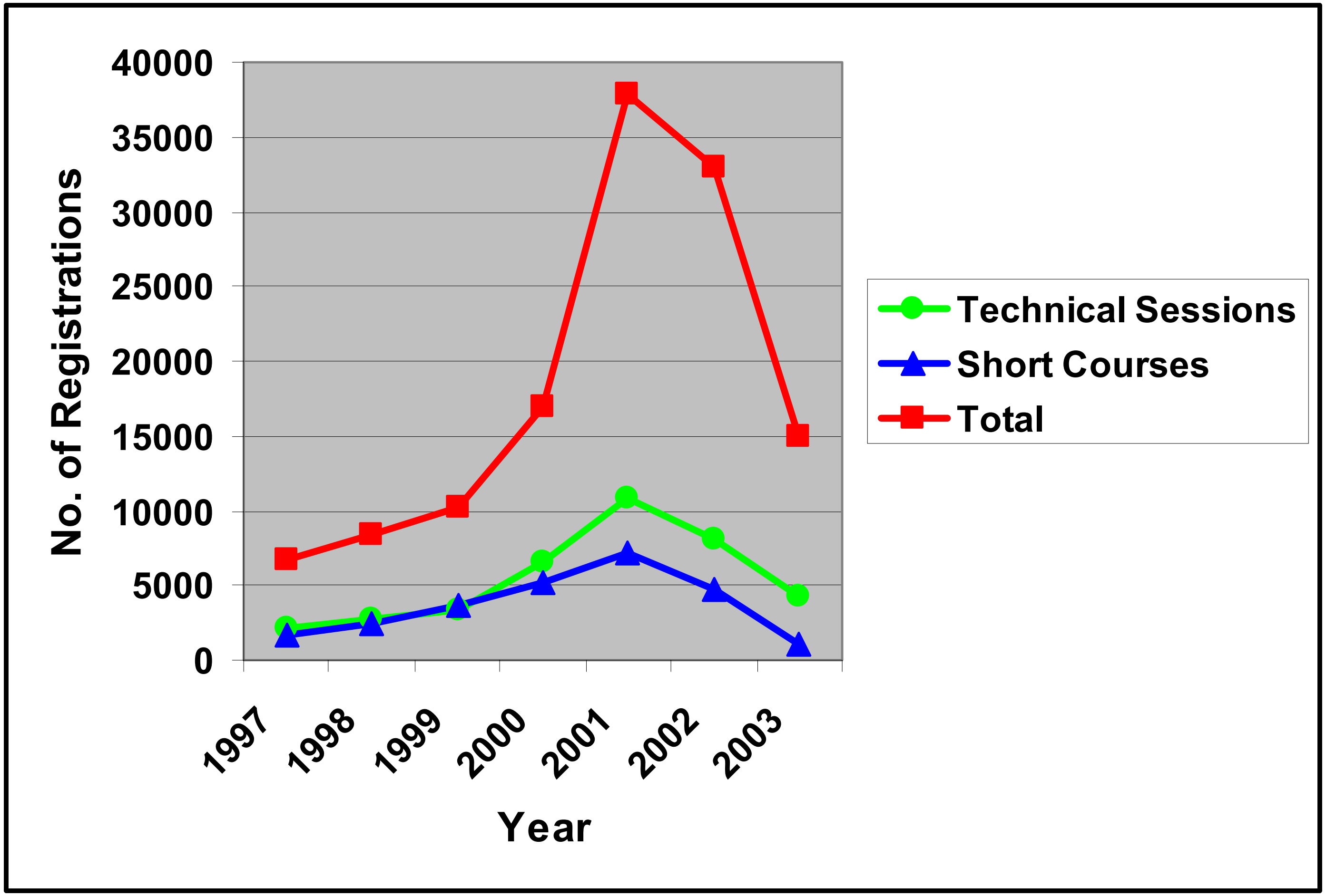
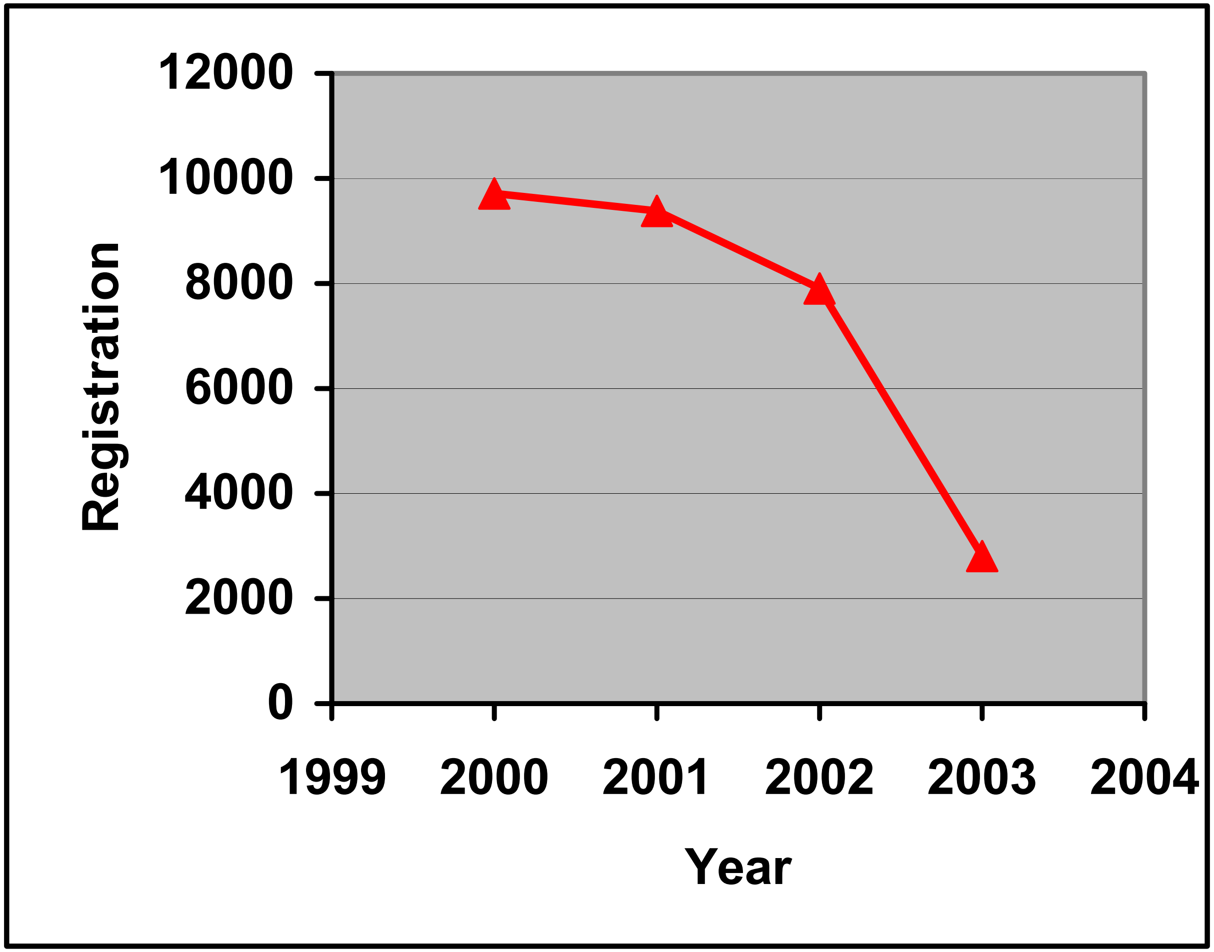
OFC Attendance Trend



NFOEC Conference Attendance



When is the “Telecom Winter” going to end?

“If Winter comes, can Spring be far behind?”

Tingye Li at OFC’02, adapted from
“Ode to the West Wind”, by Percy Bysshe Shelley

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Highlights of Optical Internetworking Forum Meeting

- Most recent meeting held at Scottsdale, AZ (May 6-8, 2003)
- 105 attendees (compared ~140 at 1Q03 meeting)
  - 71 different companies (about same as last quarter, ~60% of year ago)
  - 5 carriers (7 last time)
    - US included AT&T, Verizon, SBC Communications
    - Non-US included T-Systems Nova (DT), KDDI
  - Government-related, including NIST, DoD, Sandia Labs, Booz-Allen
  - Plus many system and component vendors
- Attendance impacted by SARS, War, Economy …
- Review of successful OFC demo on UNI/NNI Interoperability
- Superdemo on interoperability planned at SuperComm
- Tunable laser ballot (2003.048.04) ballot proposed

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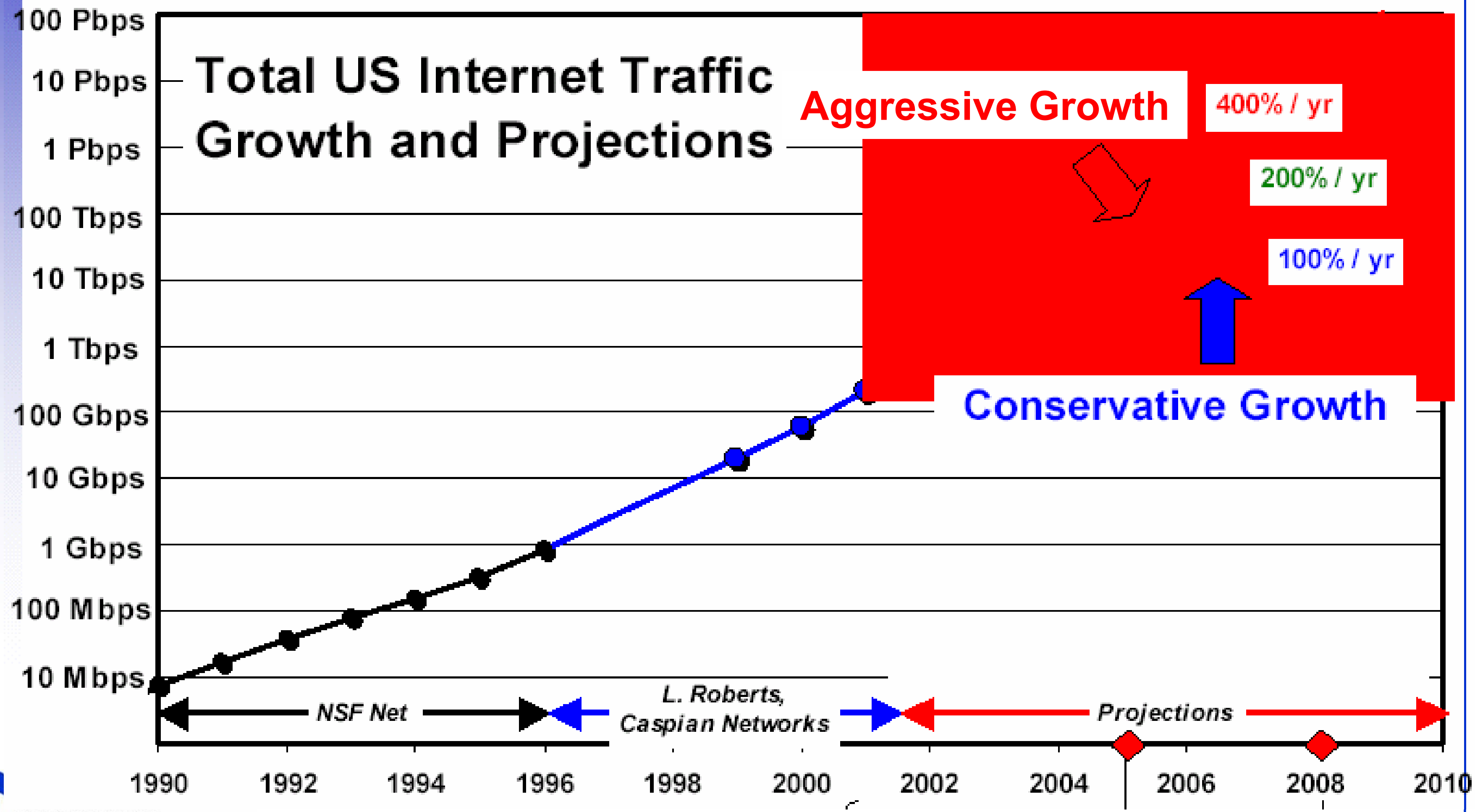
Traffic Growth Scenarios (Source: Ann von Lehman)

Dominance of Internet traffic growth will drive the network toward a more data-centric network architecture over the next 10 years



Traffic growth trend

- Traffic growth rate ranges from 40% per year in the near term in an IXC with a mix of legacy and emerging services to 200% per year growth for smaller, IP-dominated carriers
- New network builds from IP-dominated carriers can leverage new technology specifically for data services while legacy IXCs may consider technology which best supports a mix of services
- The US CapEx market will be flat for a ‘few years’, but CapEx is still large

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Enabling Technologies for Optical Networking

- The transmission medium
- High speed lasers (including tunable lasers)
- High speed light modulators
- High speed detectors
- High speed analog and logic electronics
- DWDM components (including tunable devices)
- Optical amplifiers
- Optical and electronic crossconnect and switches
- Techniques to overcome dispersion and other system degradations
- Systems and networking technologies

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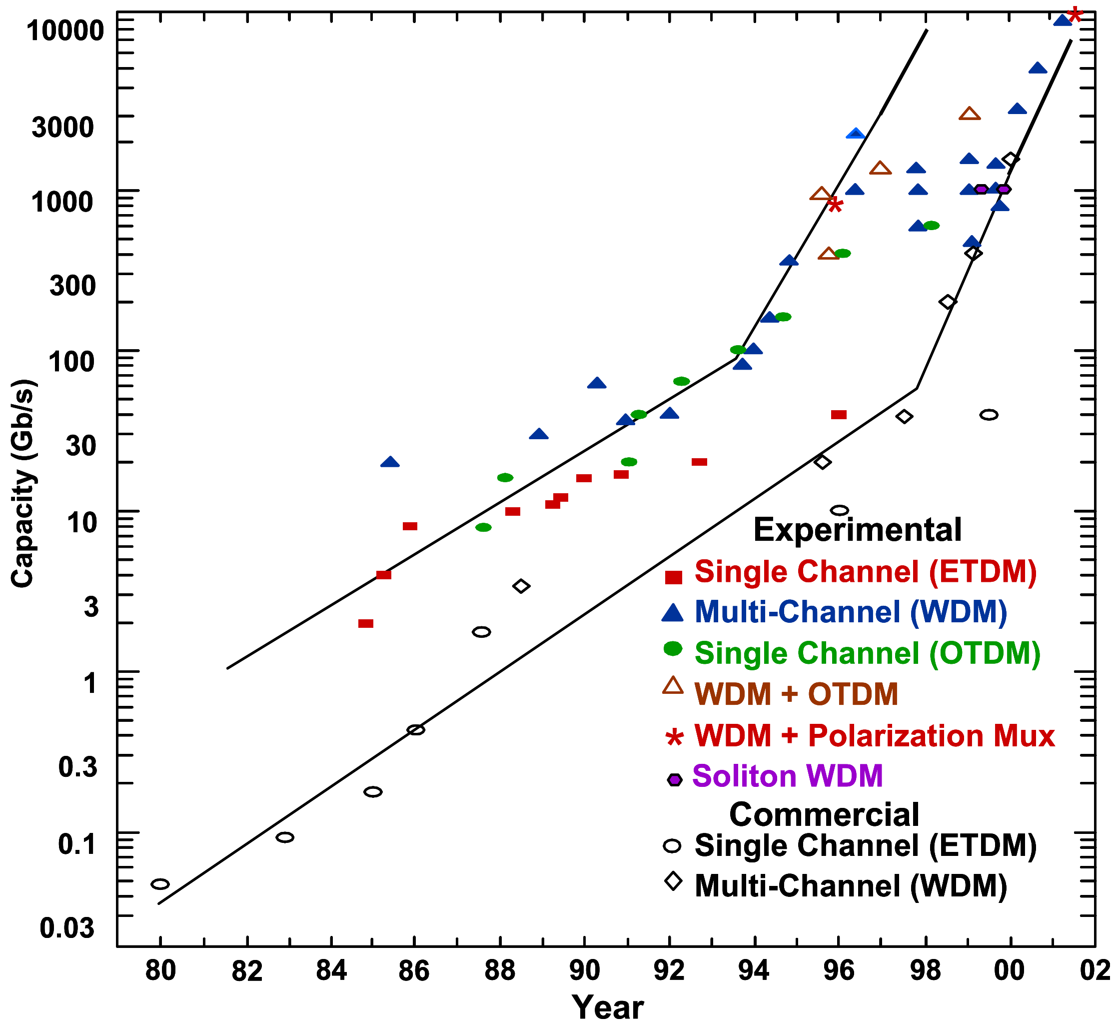
Optical Fiber Capacity



El-Sayed and Jaffe, Communications Magazine, Dec. 2002

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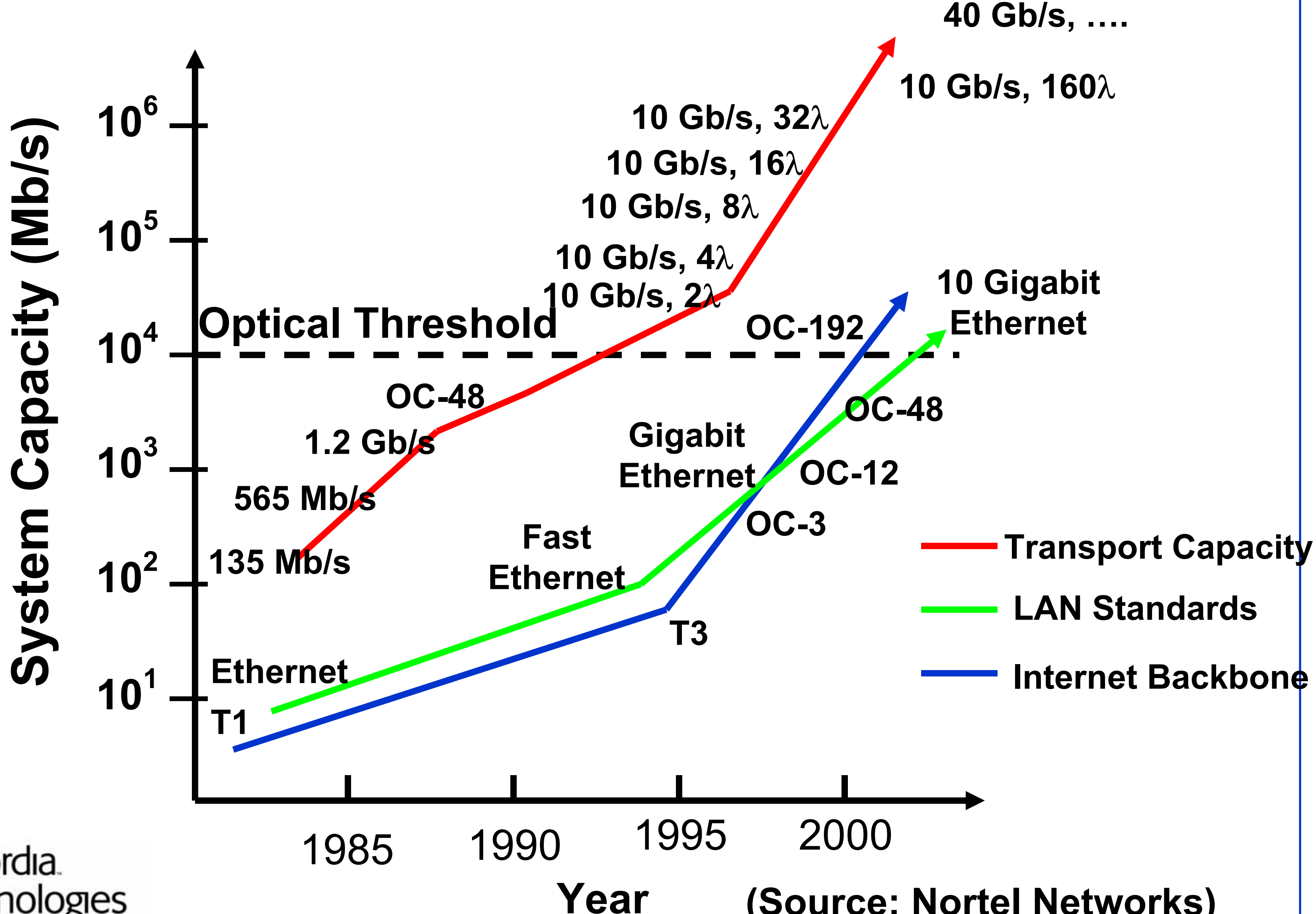
Progress in Optical Networks



(Source: Nortel Networks)

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From WDM to DWDM:
Data Rate and Spectrum Management Tradeoff

Time frame	WDM Type	Channels	Wavelength	Channel Spacing
1970's, 1980's	Coarse	2 to 3	1310 nm, 1550 nm	--
Early 90's	Narrowband	2 to 8	C-band	200 - 400 GHz
Mid 90's	Dense	16 to 40	C-band	100 - 200 GHz
Late 90's	Dense	64 to 160	C-band	25 - 50 GHz
Current	Dense	160 to 320	C/L-band	12.5-25 GHz

S-band 1280 - 1350 nm
C-band 1528 - 1561 nm
L-band 1561 - 1620 nm

UWDM or Hyperfine WDM?

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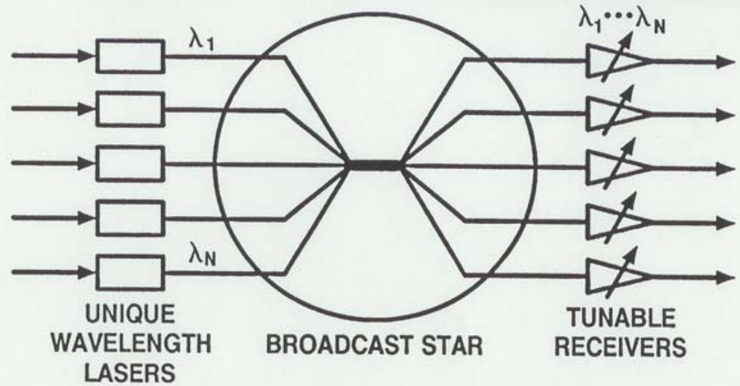
Tunable lasers. Filters and Receivers
A dream came true

Broadcast-And-Select Network



- Simple star implementation
- Orthogonal signals
- High bandwidth
- Circuit and packet switching
- Variety of switch control algorithms
- Multicast services
- I/N splitting losses

MRE88 CCB214.002

1986 broadband access concept and experiment

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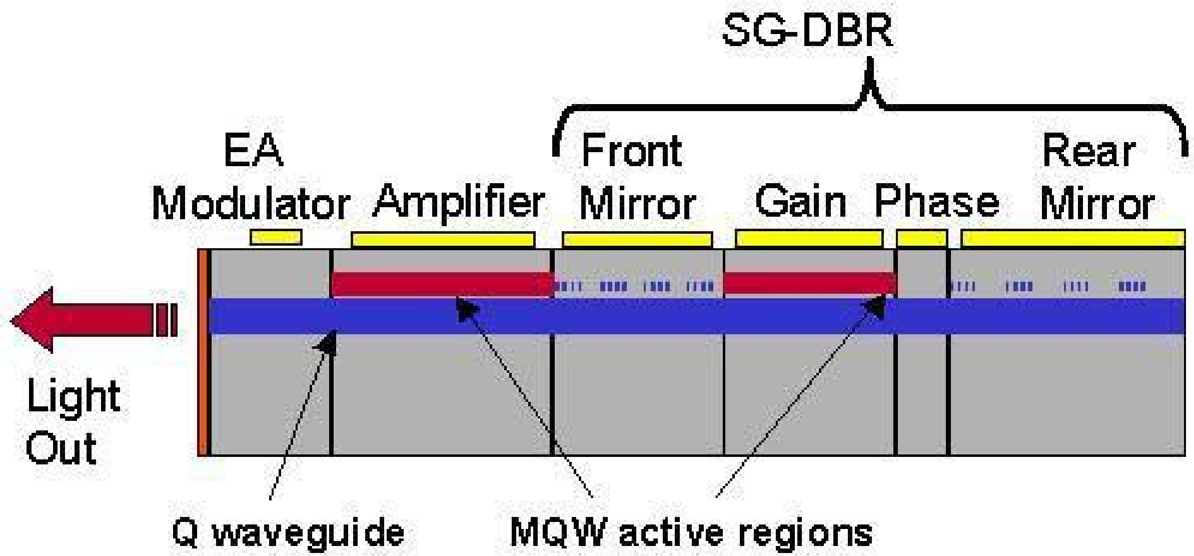
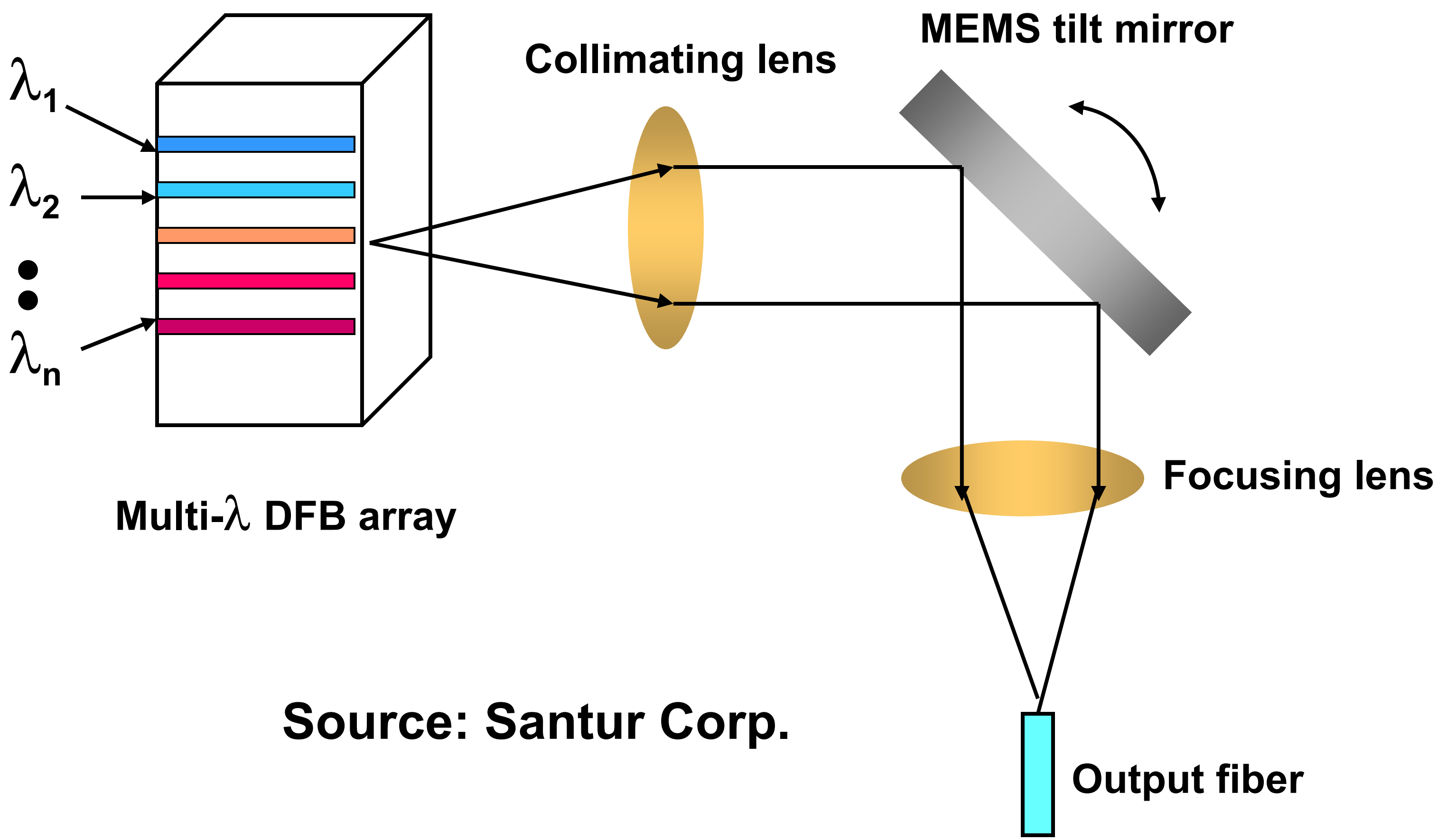
Example of Tunable Laser Implementation (i)



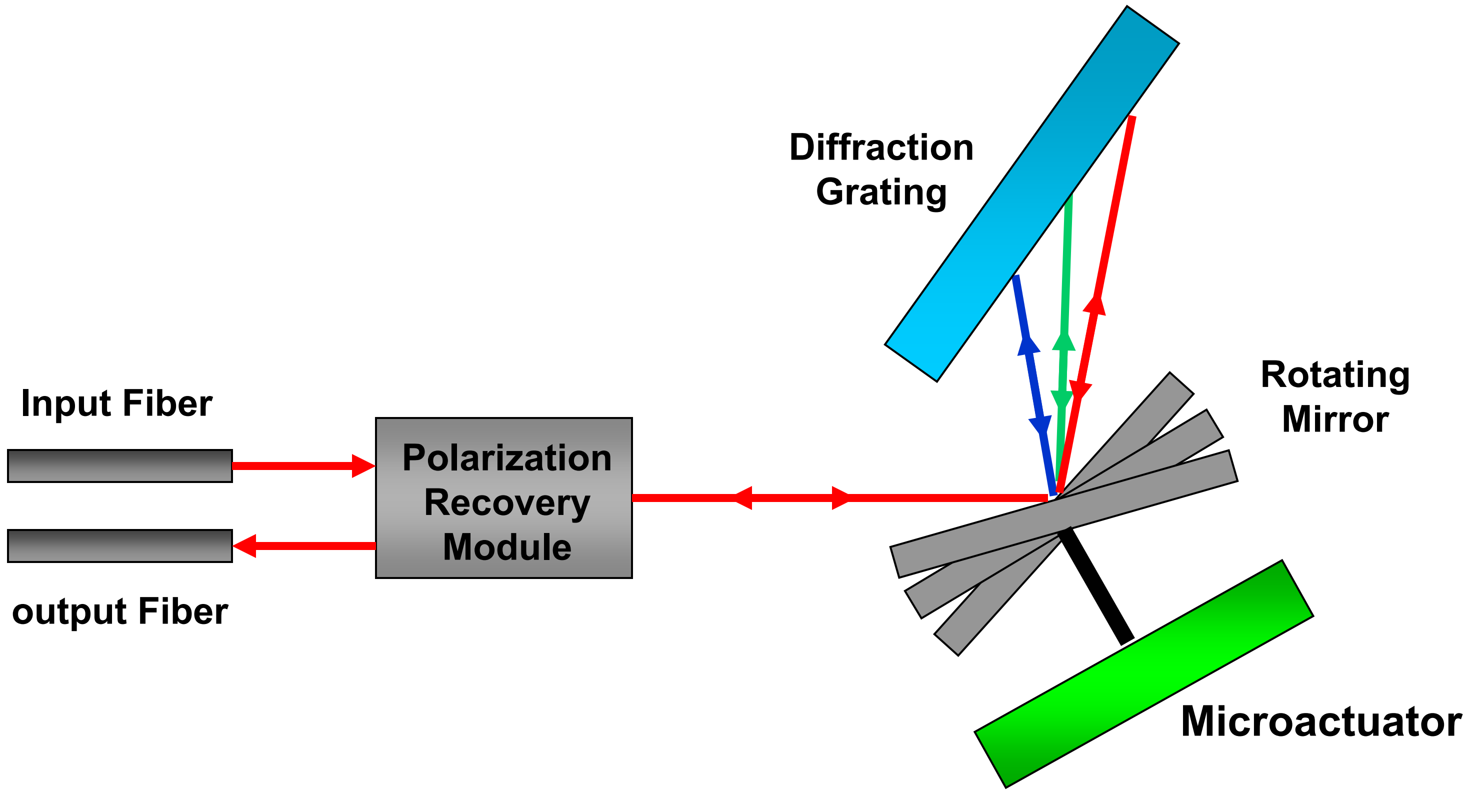
(Source: Agility Communications, Inc.)

Example of Tunable Laser Implementation (ii)



Source: Santur Corp.

Example of Tunable Filter Implementation



(Source: ioλon Inc.)

Applications of tunable lasers/filters/receivers

- Reconfigurable optical networks
  - Reconfigurable add-drop multiplexers
- Inventory reduction – simplifies provisioning and sparing
- Enable new architectures in
  - Optical switching
  - Optical interconnect
  - Wavelength routing
  - Access and metro networks

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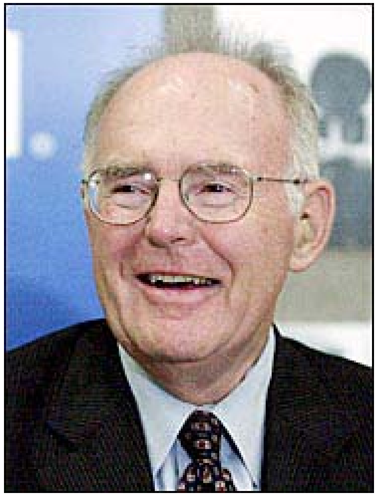
Moore’s Law (1965)
The unsung hero in optical communications

“The number of transistors in an integrated circuit doubles every 18 months.”



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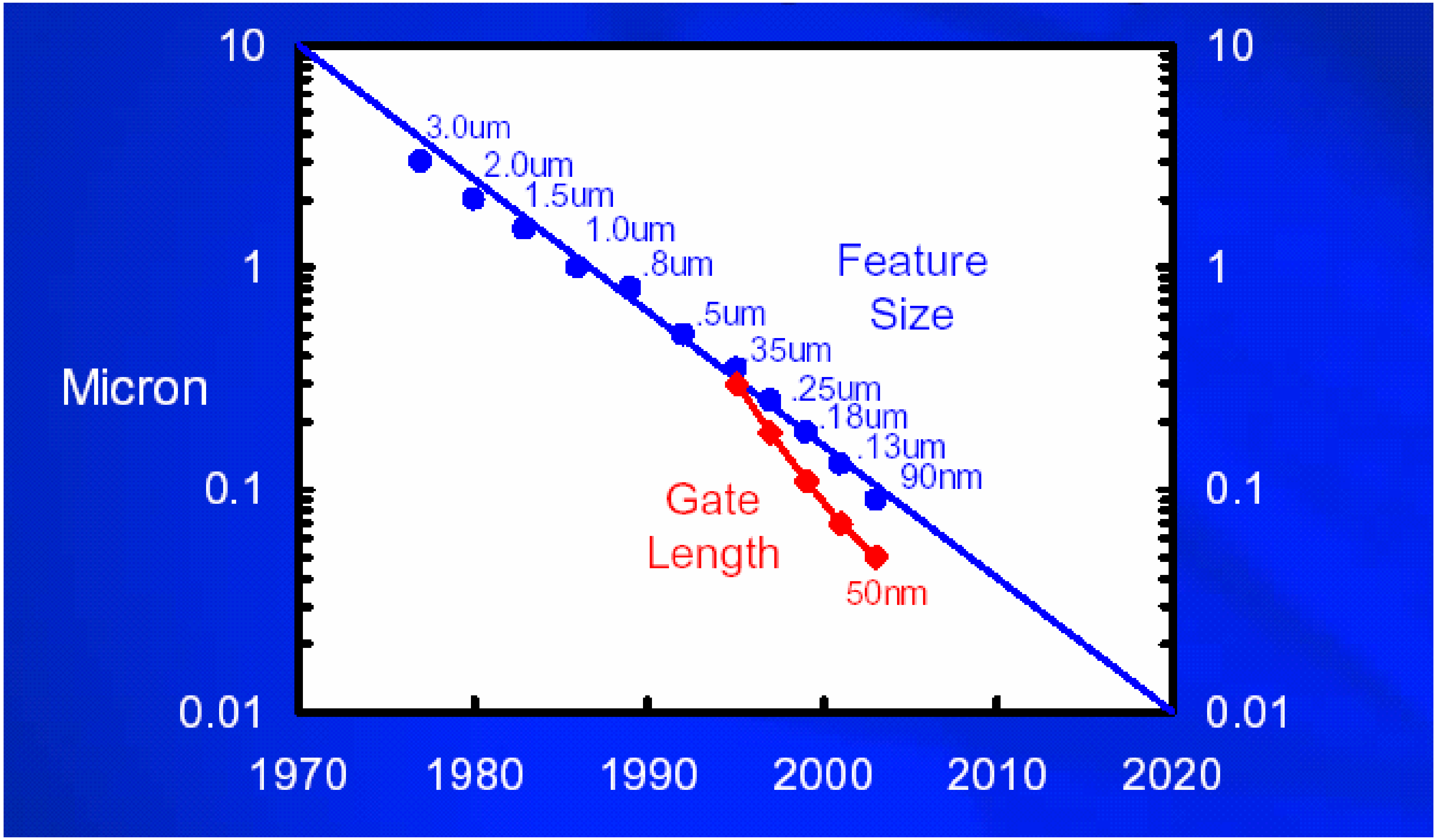
Semiconductor technology minimum feature size trend



Source: Mark T. Bohr, Intel Developer Forum 2002

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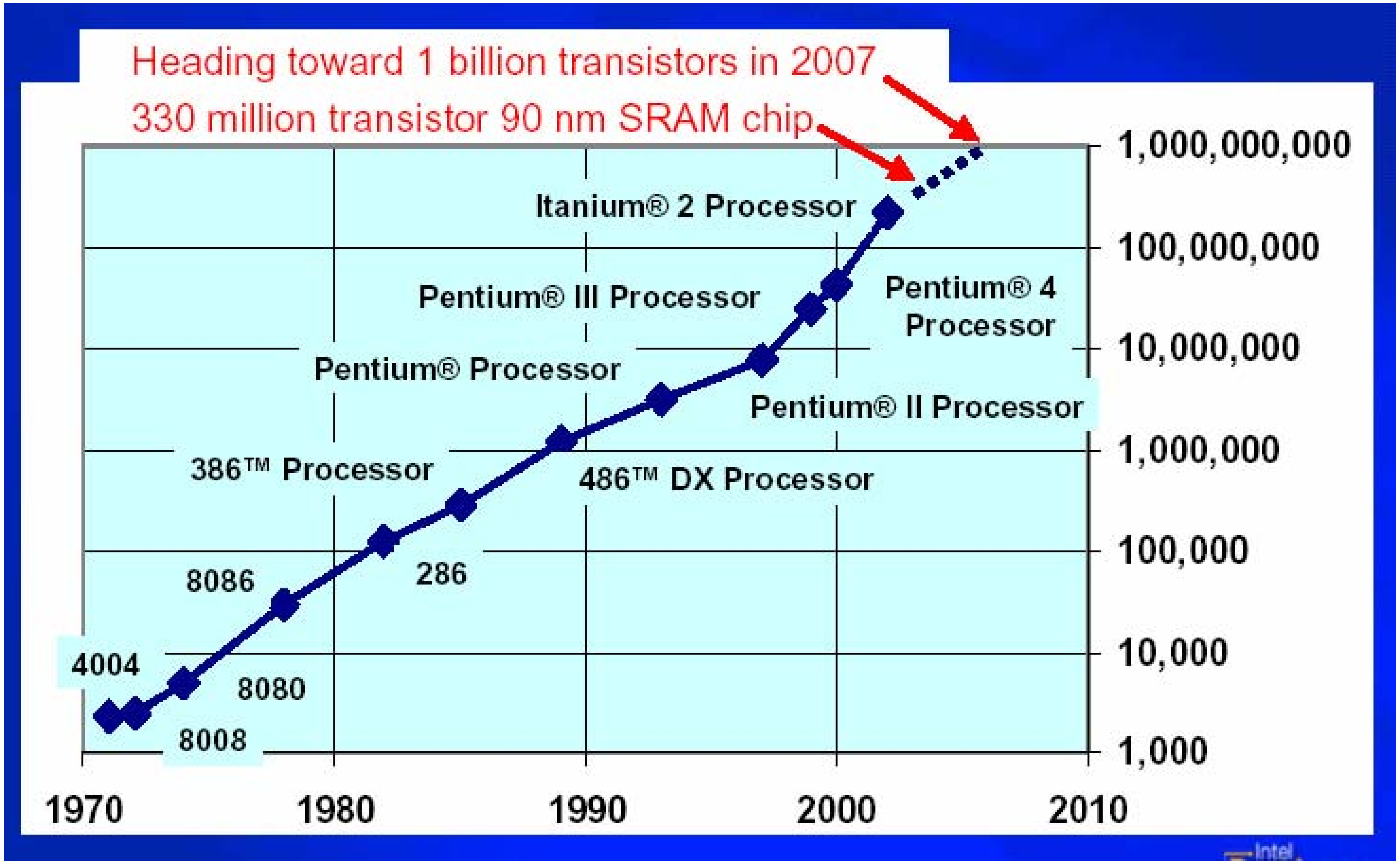
Intel central processing unit (CPU) transistor count trend



Source: Mark T. Bohr, Intel Developer Forum 2002

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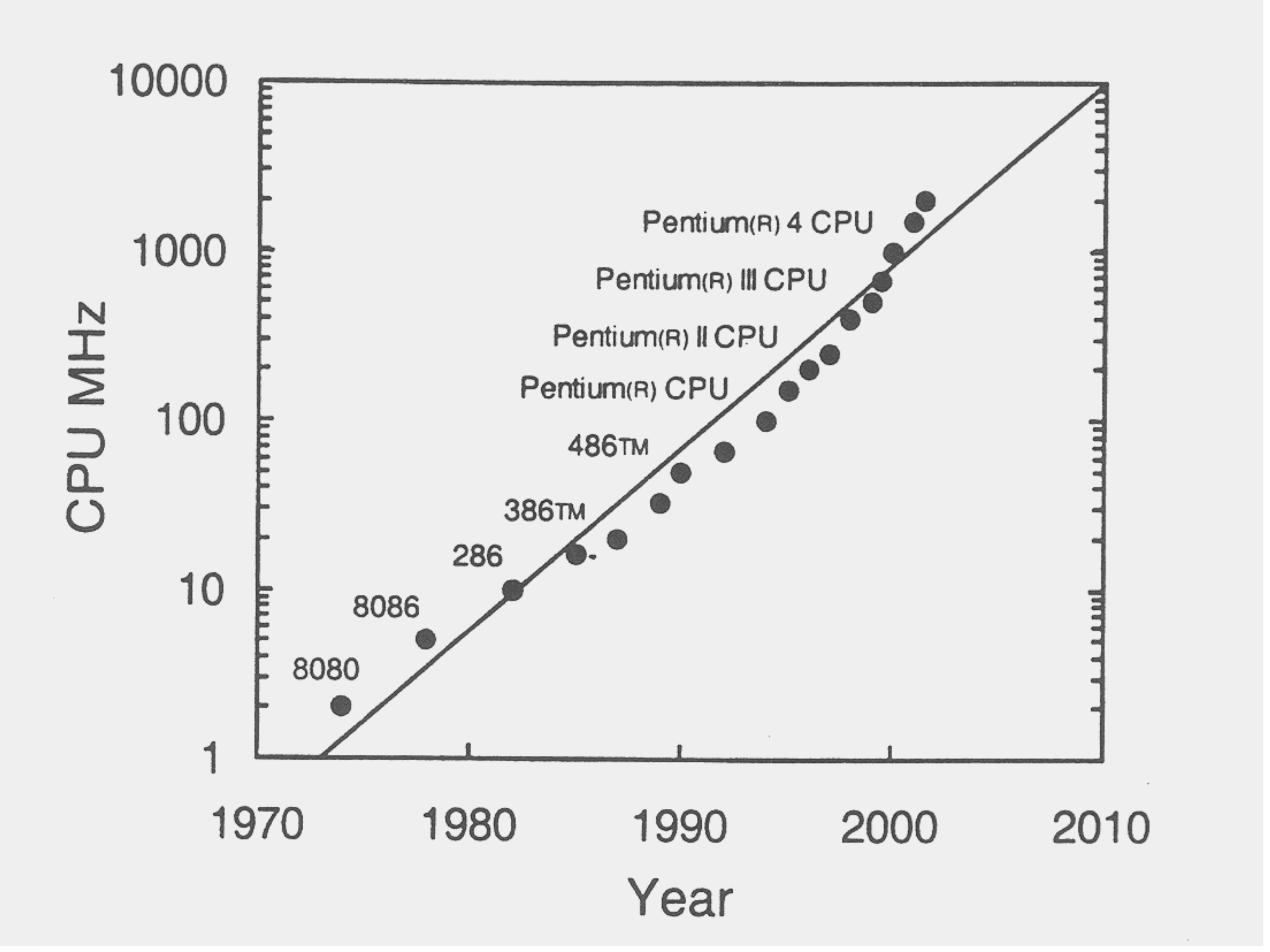
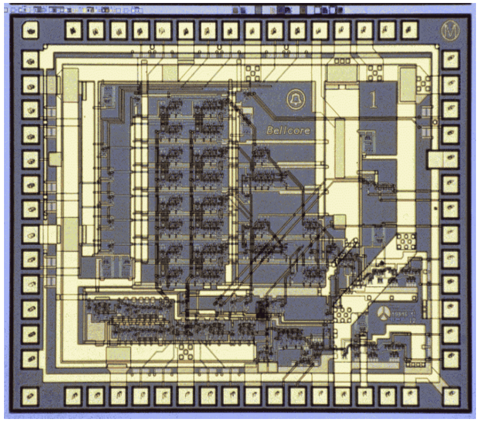
Intel CPU MHz trend



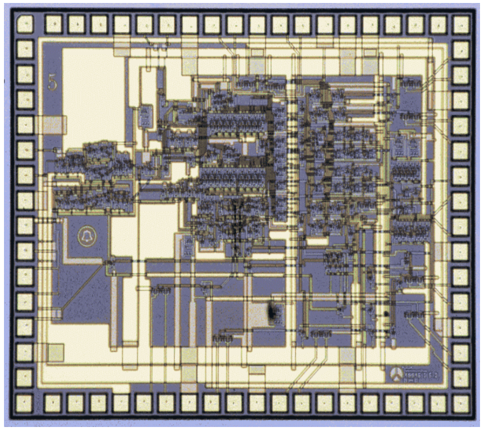
Source: Mark T. Bohr, IEEE Trans. On Nanotechnology, 2002

SONET STS-192 (10 Gb/s) GaAs ICs (Early 1990's)

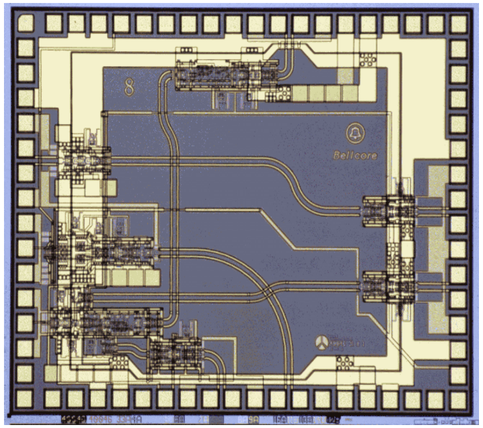
(Rockwell International's AlGaAs/GaAs HBT Technology)



- 10 Gb/s Multiplexer & phase aligner
- 8 input channels
- Power: 2.2 W
- Max Speed: 12 GHz
- Size: 3 x 2.3 mm



- 10 Gb/s Demultiplexer with SONET frame detector
- 8 output channels
- Power: 2.5 W
- Max Speed: 11.7 GHz
- Size: 3 x 2.4 mm



- 10 Gb/s Interface IC with signal / clock processing & conditioning
- Power: 1.75 W (for mux)
  2.2 W (for demux)
- Max Speed: 12 GHz
- Size: 3 x 2.3 mm

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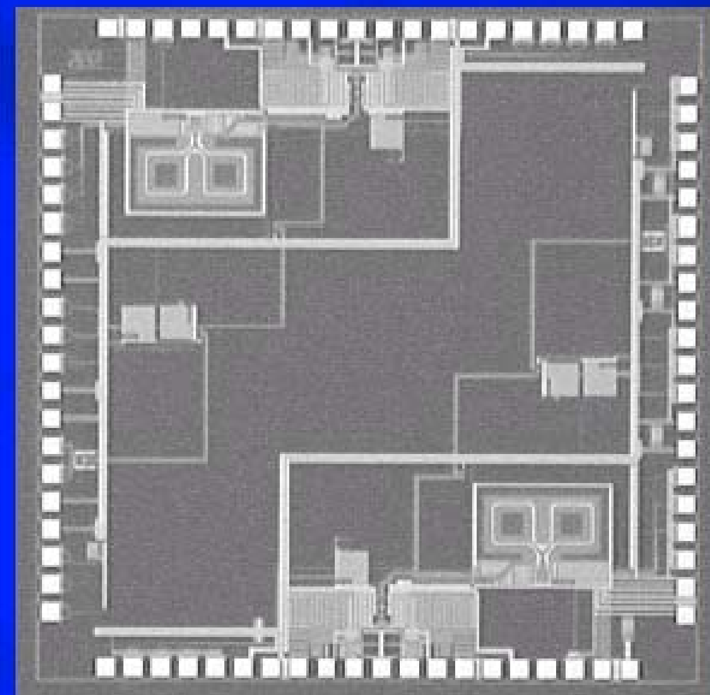
10 Gb/s SerDes Test Circuits

Application of this process to communication products has been demonstrated on test circuits typically used on 10 Gb/s SerDes products (serializer/deserializer)



Communication Test Circuit

Source: Mark T. Bohr, Intel Developer Forum 2002

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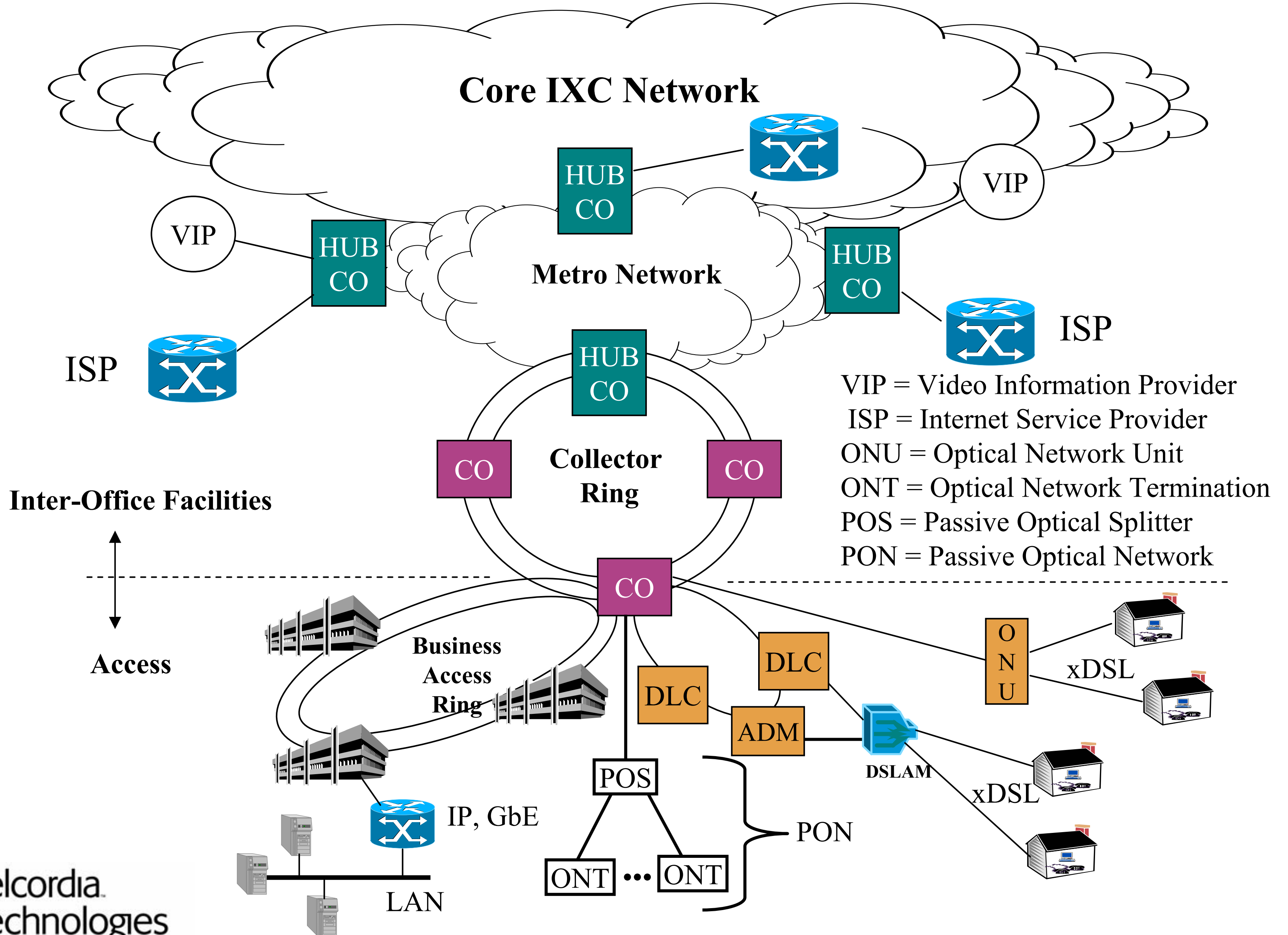
Optical Networking Hierarchy
(Source: H. Kobrinski and R. Runser, Telcordia Technologies)



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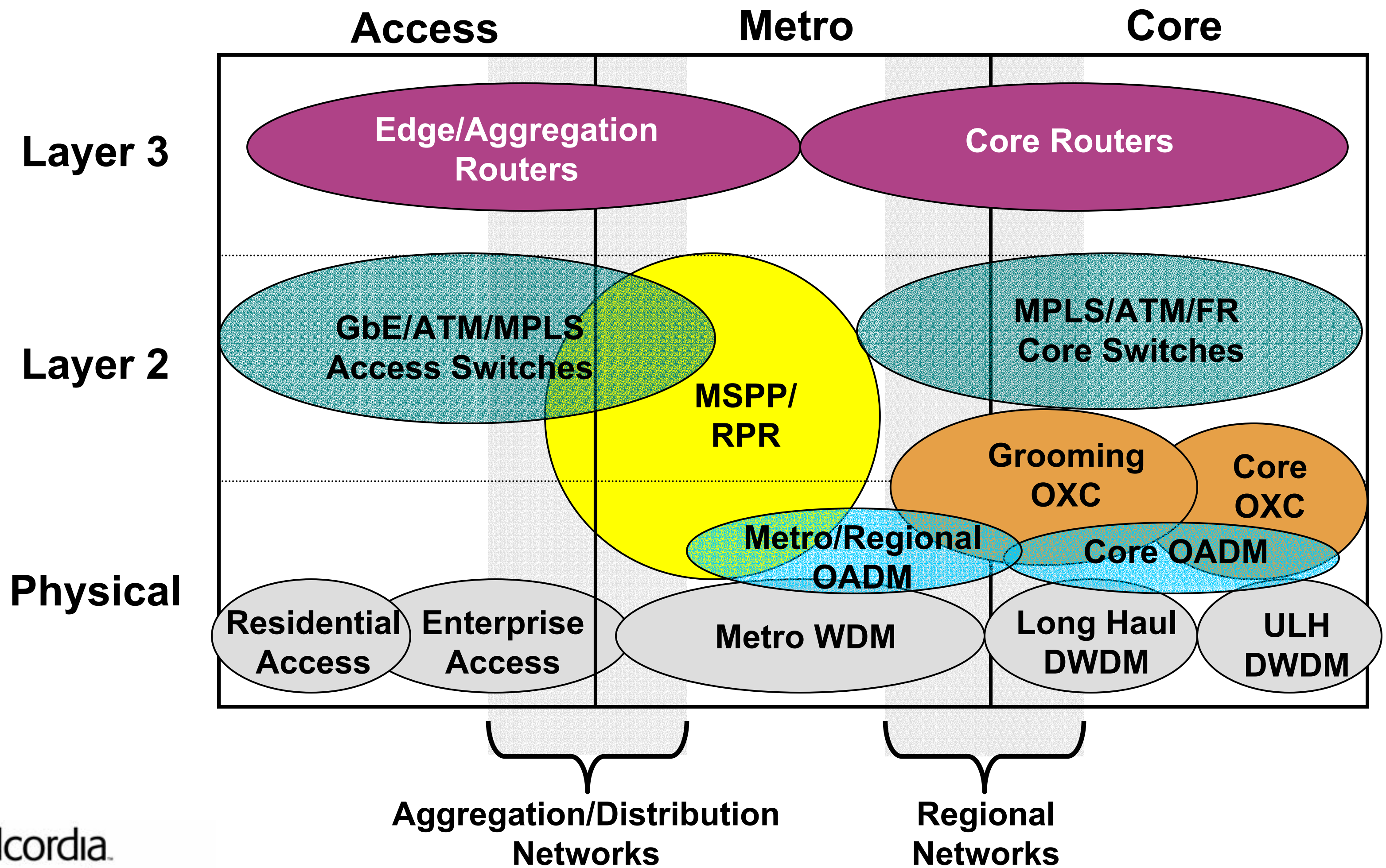
Network Equipment Landscape
(Source: H. Kobrinski and R. Runser, Telcordia Technologies)



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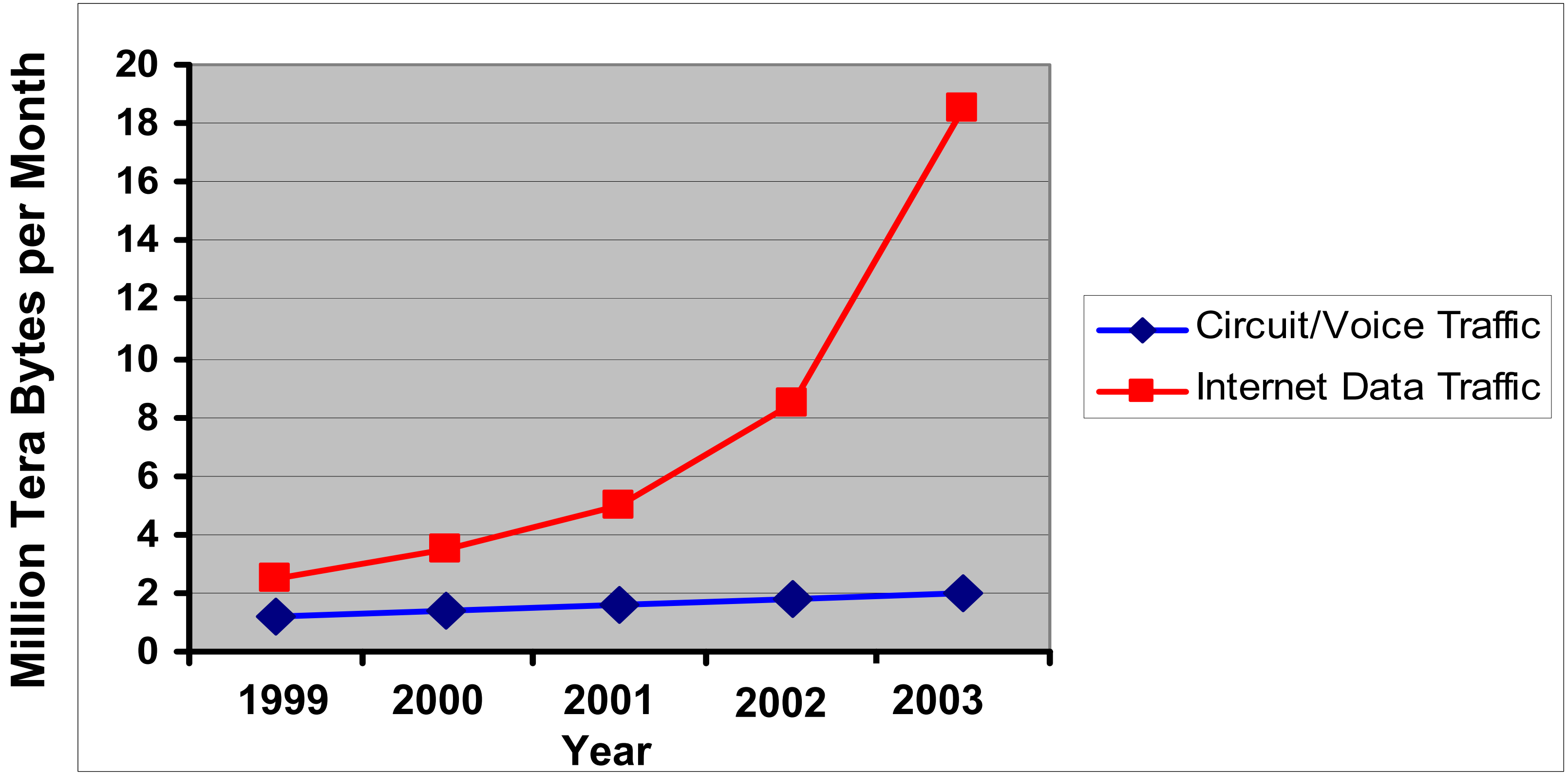
Core Networks

- **Carriers:** IXCs, Backbone ISPs, National and Pan-regional (overseas)
- **Services:** Interconnect ISPs/ILECs/CLECs/corporations, wide area VPNs
- **Geographic Span:** Over 200 km
- **Traffic Characteristics:** highly aggregated circuit traffic (IXCs) and packet/cell traffic (ISPs)
- **Signal Rates/Formats:** few including 2.5G, 10G, 40G and carried in SONET/SDH, PDH
- **QoS:** highest performance levels - BER, packet loss, delay, protection/restoration
- **Critical choices:** minimize cost per bit per mile - ULH vs LH, transparency vs opaque, core switching vs core hybrid routing/switching

Metro Networks

- **Carriers:** ILECs, CLECs, and MAN SPs
- **Services:** ILEC's voice and private lines, link backbone ISPs with access clients packet/cell traffic, enterprise services such as SANs, VPNs, VoIP, and several Ethernet -based services
- **Geographic Span:** < 200 km
- **Traffic Characteristics:** aggregated traffic from access networks and large customers (enterprises)
- **Signal Rates/Formats:** numerous rates from 0.1 to 10 Gb/s carried in SONET/SDH, GbE, PoS, ATM, and proprietary formats
- **QoS:** varies widely from highly reliable to best effort
- **Critical Choices:** challenged to build a scalable, convergent network infrastructure to satisfy the needs of disparate services and choosing among multiple architectures and products. Currently dominated by SONET/SDH ring technologies optimized for TDM services (voice, private lines)

Metro traffic Trend



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Access Networks

Carriers: ILECs, CLECs, DLECs IXCs/local and CATV

Services: legacy local exchange voice, data (web hosting, Internet access, file transfer, email, SAN), and video (broadcast, PPV)

Geographic Span: < 20 km from user to POP or CO

Traffic Characteristics: huge number of sources/destinations with low capacities per channel (DS0 to GbE)

Critical Issues: Enterprise Access

- substantial shift to IP services (VPN, MPLS)
- telecom and computing equipment is churned and upgraded frequently
- bandwidth management, security are important functions

Critical Issues: Residential Access

- highly sensitive to deployment costs
- dominated by voice and video traffic but with growing Internet access demand
- 'killer' residential applications (e.g., Internet VOD) will most significantly impact all the network segments

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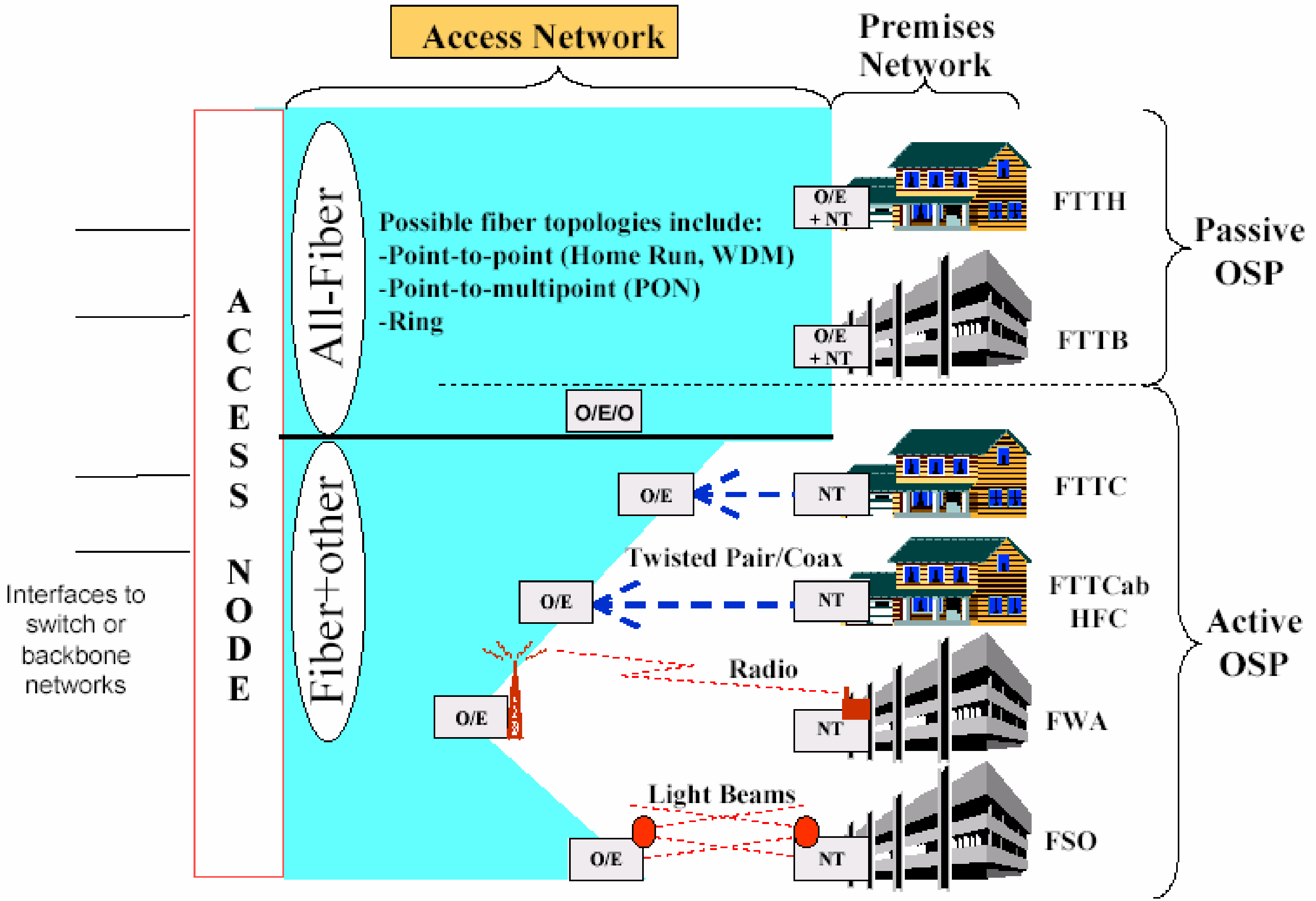
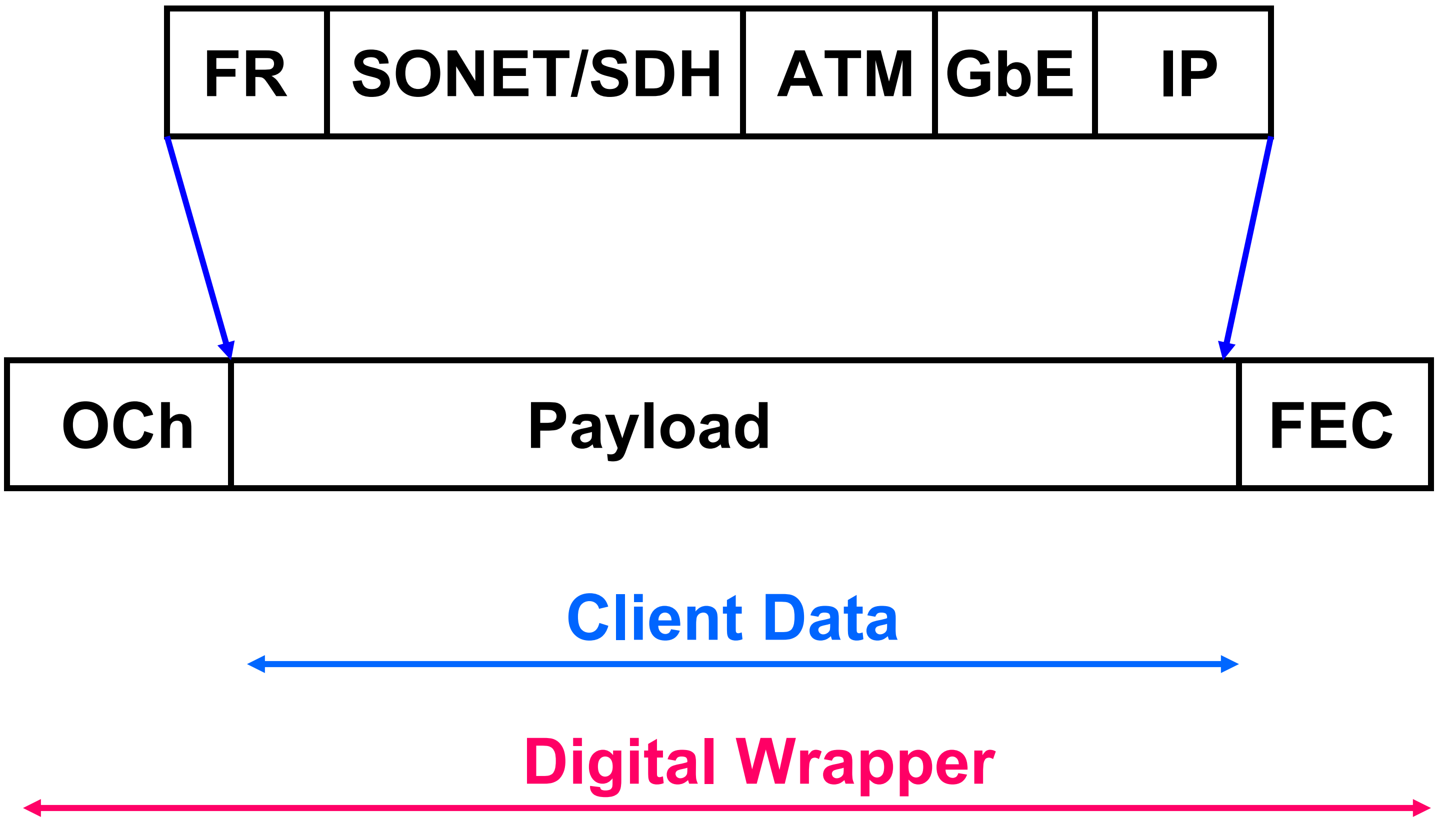
(Source: A. von Lehman)

Physical Access Network Options



Digital Wrapper Format (ITU-T G.709)
Framing/encapsulation technique for DWDM networks

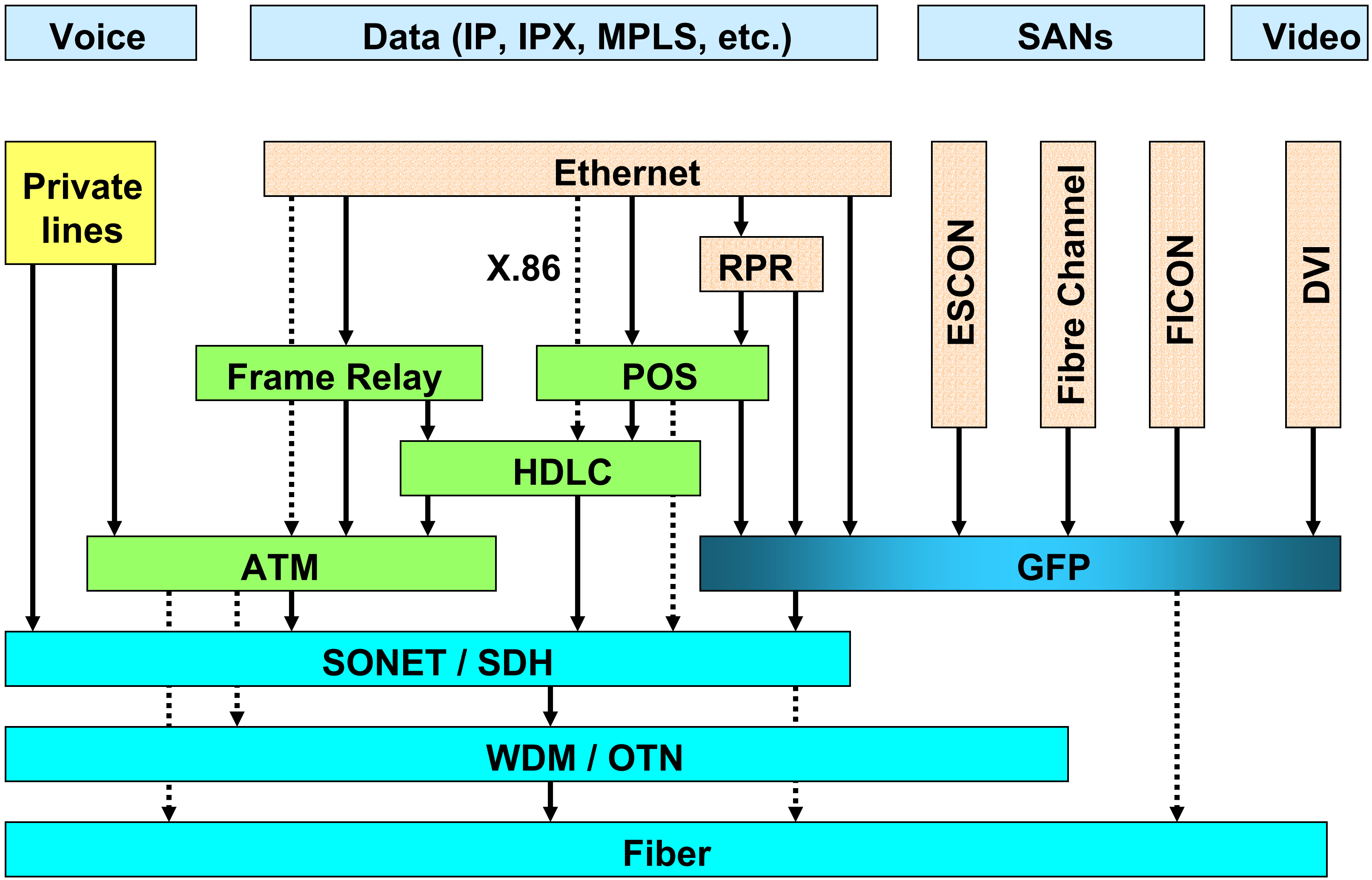


Towards a data-friendly public transport network

Recent standardized techniques to enhance SONET/SDH networks

- Virtual Concatenation (VC) – offers more flexible channel capacities
- Link Capacity Adjustment Scheme (LCAS) – procedures for dynamically changing channel capacities
- Generic Framing Procedure (GFP) – encapsulation technique for frame-organized data traffic

Protocol stacks over the public network



(Source: ITU, E. Hernandez-Valencia, et al, P. Bonenfant et al)

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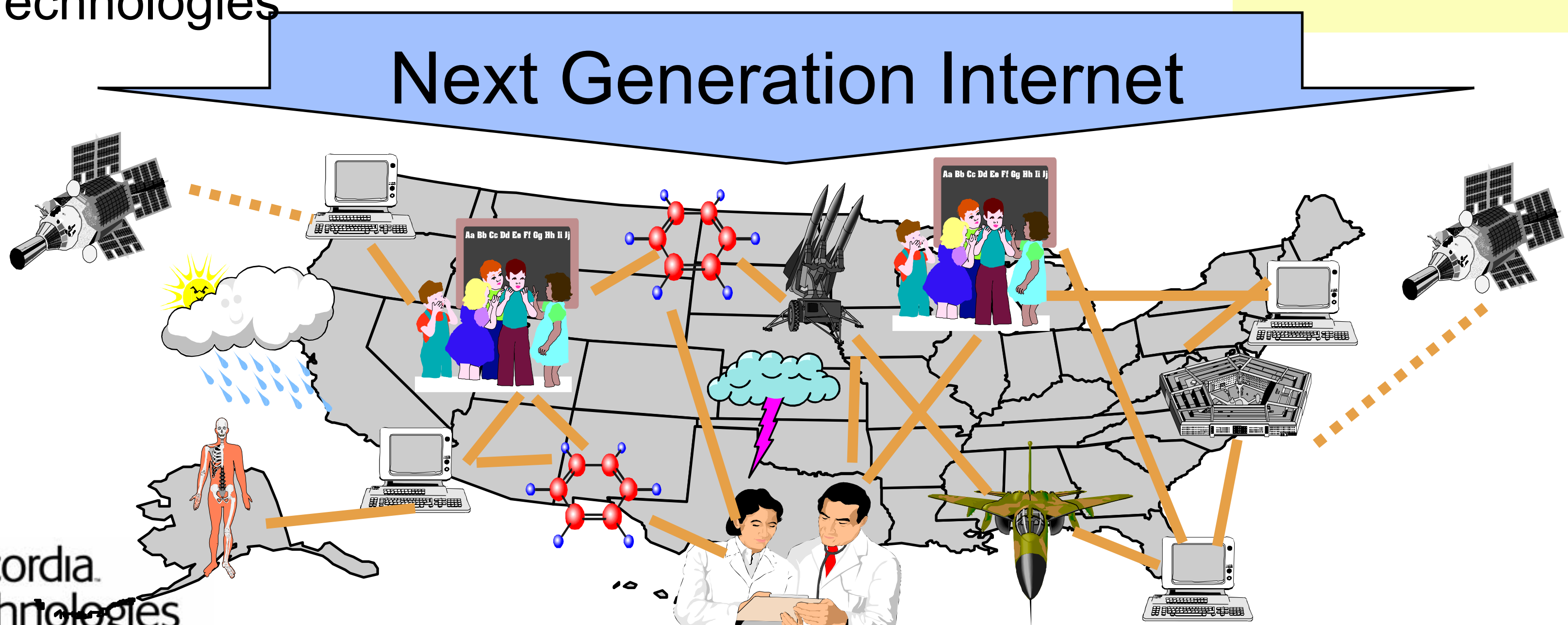
NGI VISION

NSF DOE DARPA NASA NIST

Goal 1	Goal 2.1	Goal 2.2	Goal 3
Advanced Network Technologies	High Performance Connectivity	Ultra-High Performance Tech	Revolutionary Applications



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Various Shades of Transparency (H. Dardy, NRL)

- "Strict" Transparency
  - transparency to any optical signal w/o amplitude, phase, or frequency modulation (probably not solitons!)
- "Amplitude" Transparency
  - transparency to intensity-modulated digital or analog signals
- "Digital" Transparency
  - transparency to intensity-modulated digital signals of arbitrary bit-rate, format, and protocol

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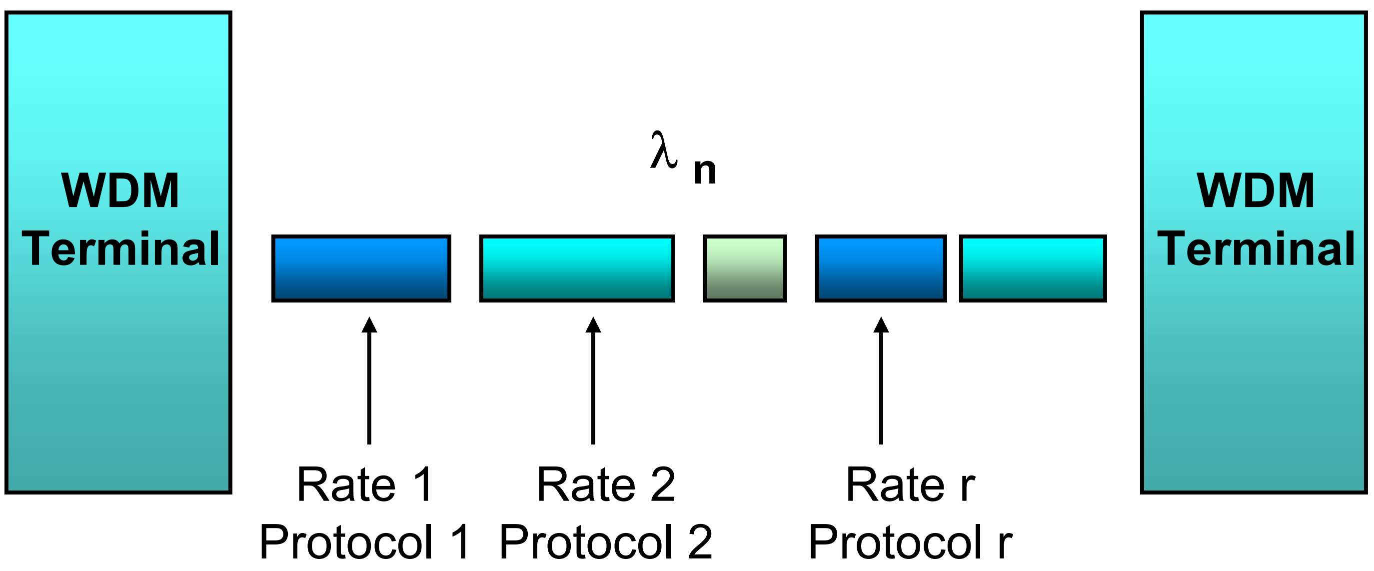
NGI Experiment: Variable Bit Rate Burst Mode



Goal: Bit rate and protocol agile

How can we achieve “transparency”?

Need to automatically identify (in real time)

- λ channel
- bit boundary -- clock recovery
- byte boundary -- e.g. A1, K28.5
- frame boundary -- e.g. A1A2
- packet boundary -- e.g. CRC, FCS
- other applications and content identifiers

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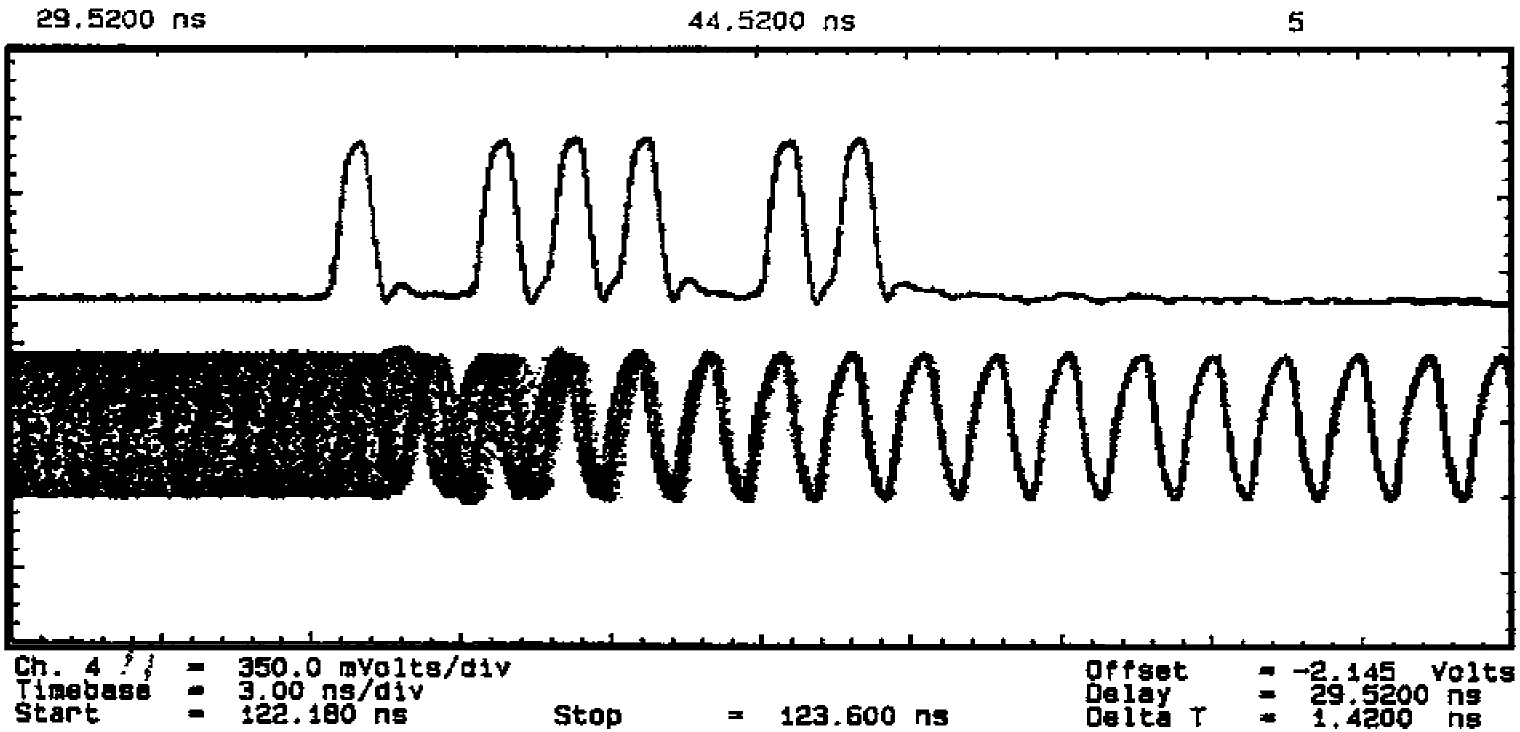
Performance of improved burst mode VBRI Circuit



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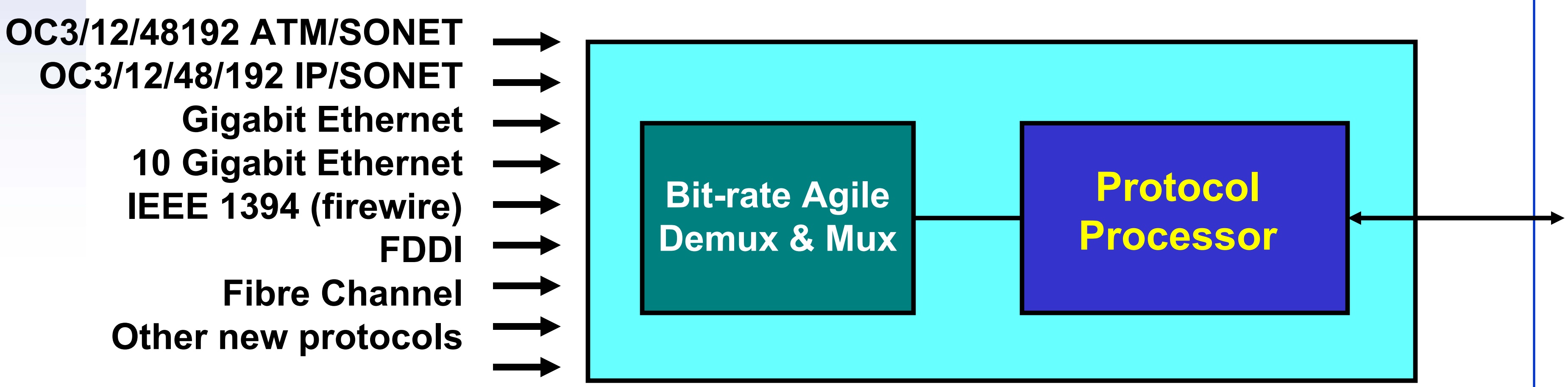
Universal Network Access Module

Optoelectronic IO modules at the core and periphery of the network that can:

- recognize and lock to the bit rate (bit-rate adaptability)
- recognize and handle different protocols (protocol agility)
- provide transparent IO functions for dynamically reconfigurable or burst switched optical networks



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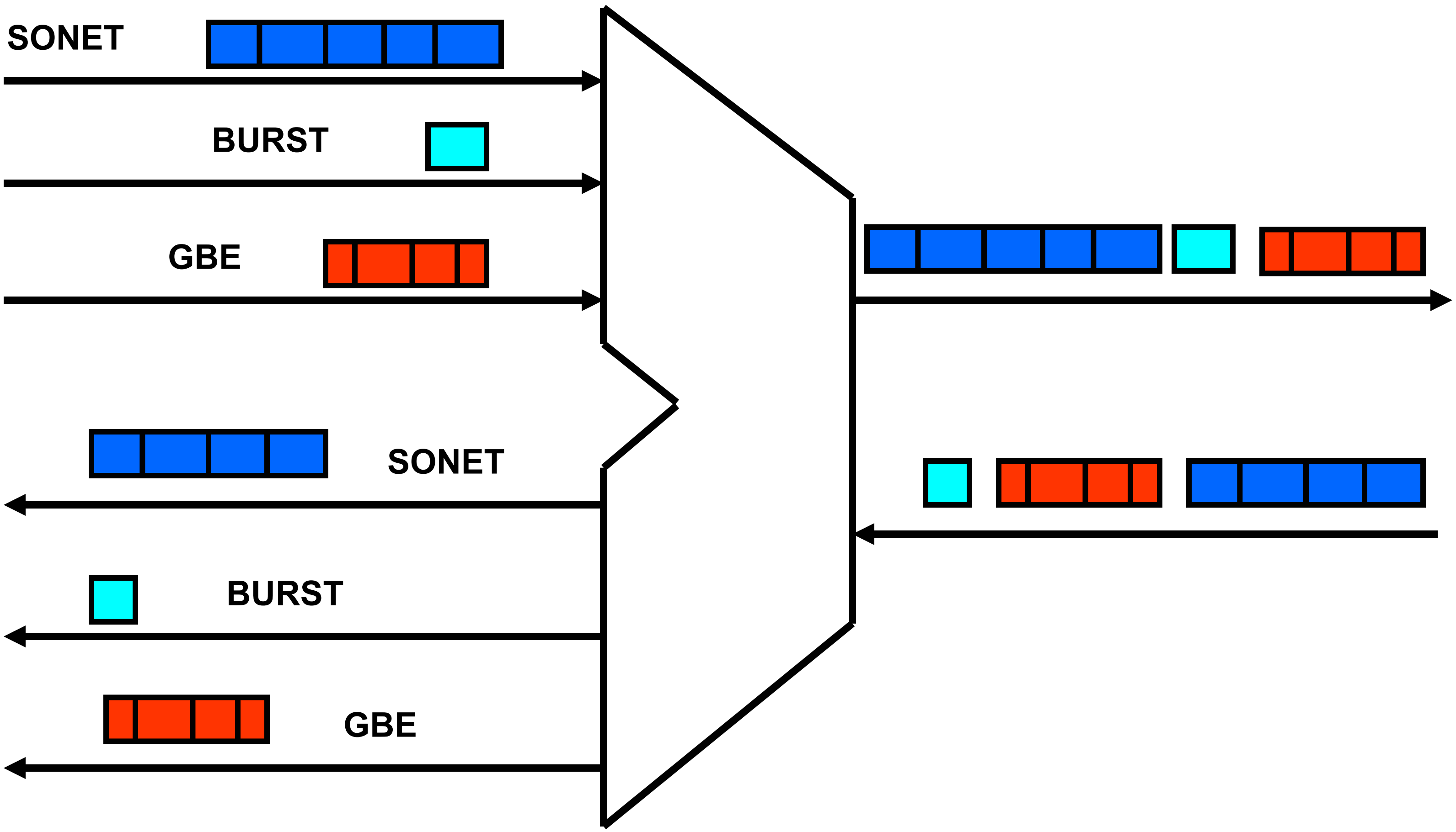
Multi-protocol Access Multiplexer



Dynamic Optical Switching

	Holding Time	Switching Speed
Reconfig. Opt. Networking	Days, Months	50 msec to secs
Optical Flow Switching	> 100 msec	~ msec
Optical Burst Switching	> 10 msec	~ nsec
Optical Packing Switching	> msec	~ nsec
All-Optical Switching	> nsec	~ psec

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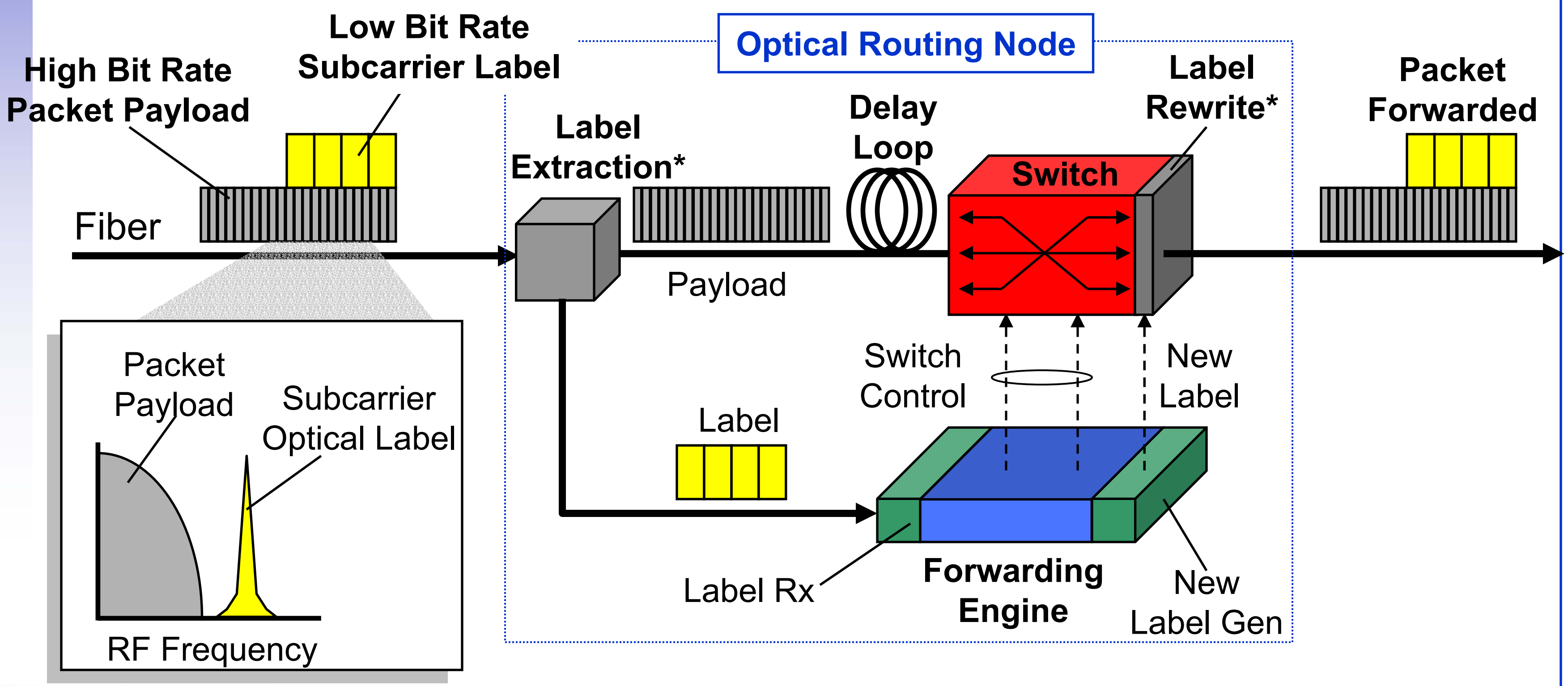
OLS Packet/Burst Routing Technique (G. K. Chang)

- Packet payload and optical label are decoupled through the use of subcarrier multiplexing technology
- Simplified label processing hardware achieves significant cost savings for packet processing interfaces
- Truly enables transparent optical packet switching



*Label removal and re-write are optional depending upon the architecture

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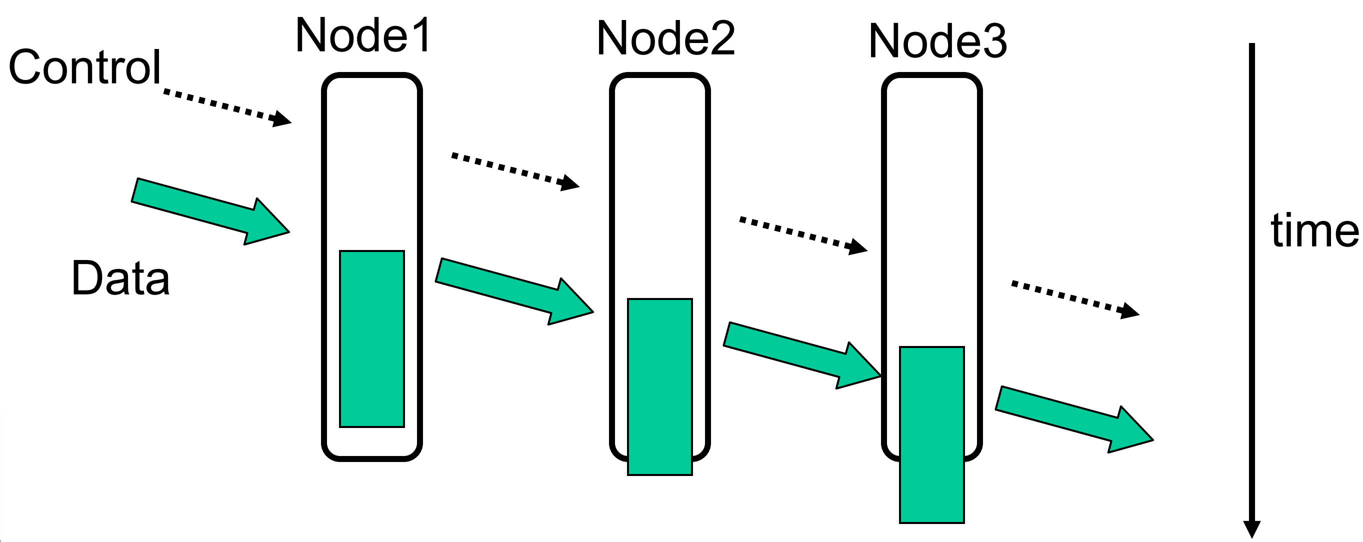
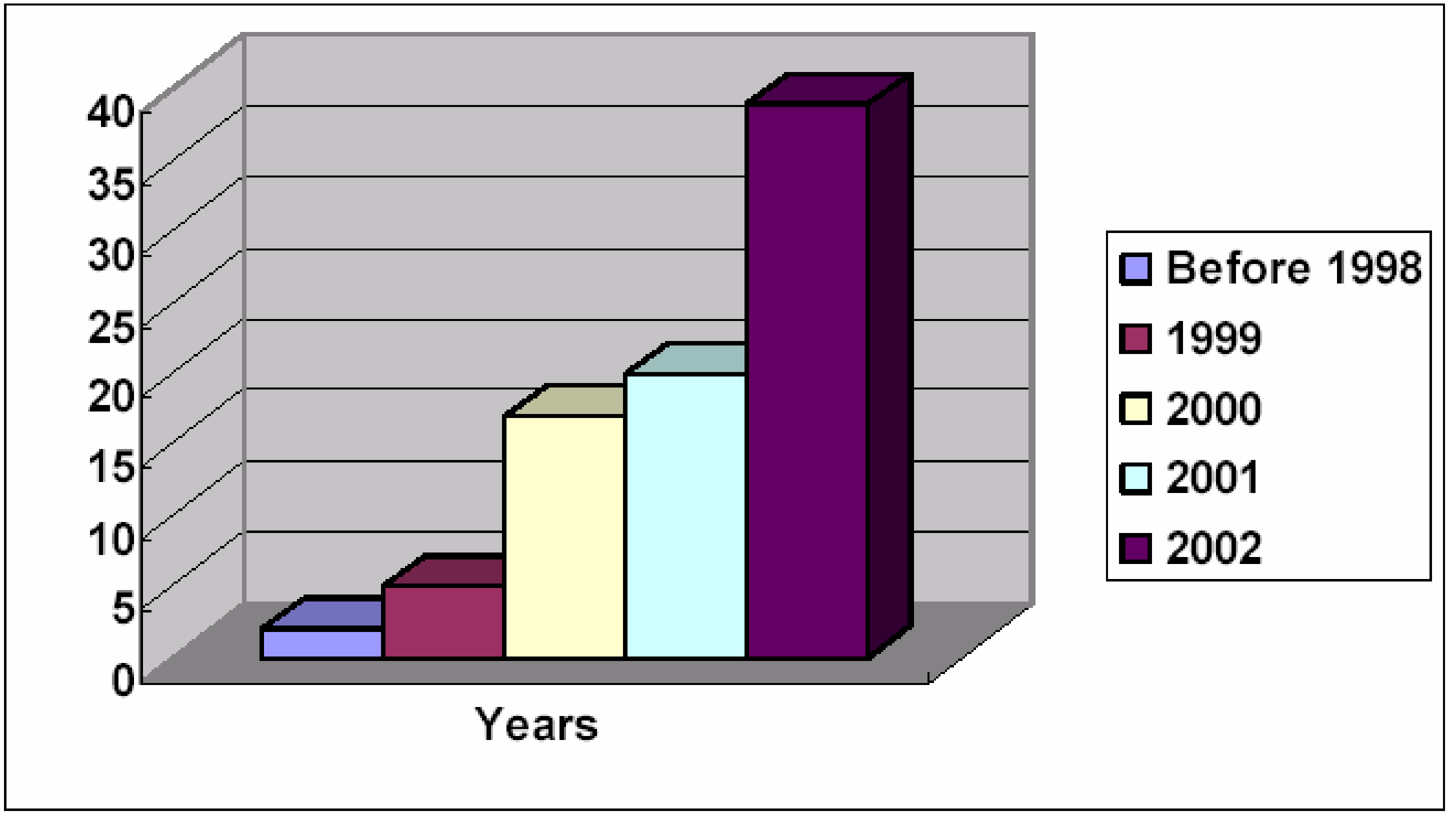
Terabit Burst Switching (J. Turner, Washington U.)

- A novel architecture for Terabit Burst Switching
- Send Burst Header Cell (BHC) on control channel, followed by burst on free data channel
- BHC contains VCI or host address, channel #, burst offset and length
- Switches forward BHC and setup switch to route burst using free data channel
- Store burst if necessary
- Channels released as end of burst flows through

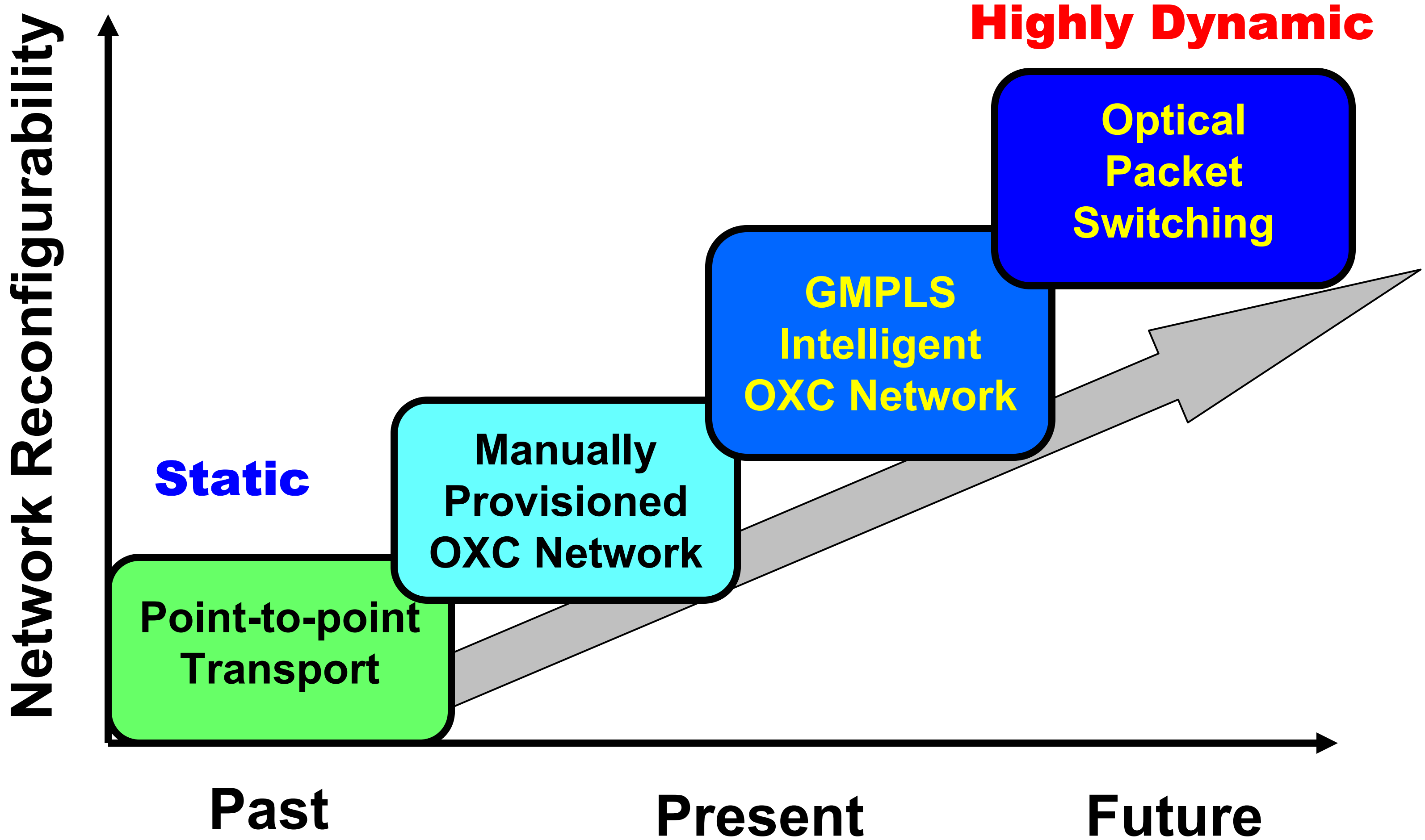


Optical Burst Switching Papers in Major Conferences



(Source: Chungming Qiao, OFC2003)

Optical Network Evolution (Source: R. Runser)



Summary

- Optical communications industry remains vibrant despite severe economic downturn
- The industry continues to make great strides in technical innovation
- Worldwide telecom traffic continue to grow at a steady rate
- Activities driven more by applications and market needs. More emphasis on valued-added propositions
- Growth expected in metro and access networks, and non-telco applications

Backup Slides

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