Dynamic Optical Networking to Enable Scalability of the Future Internet

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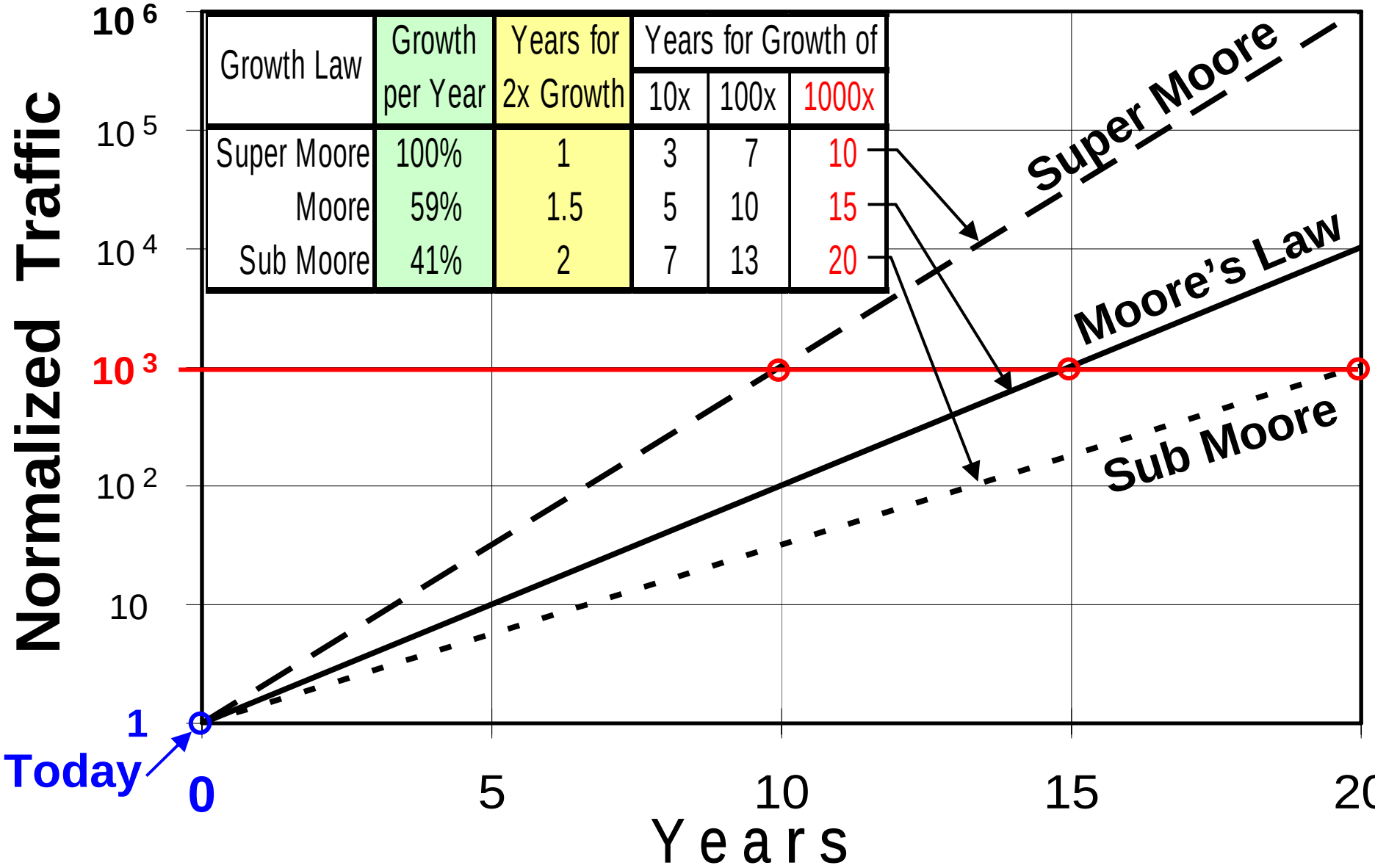
How Fast will the Internet Traffic Grow?

Strategic Technology Office

Growth Law	Growth per Year	Years for 2x Growth	Years for Growth of 10x	100x	1000x
Super Moore	100%	1	3	7	10
Moore	59%	1.5	5	10	15
Sub Moore	41%	2	7	13	20



An Interesting Quote !

"I never said 18 months. I said one year, and then two years. ... Moore's Law has been the name given to everything that changes exponentially. I say, if Gore invented the Internet, I invented the exponential."

Gordon Moore (2000)

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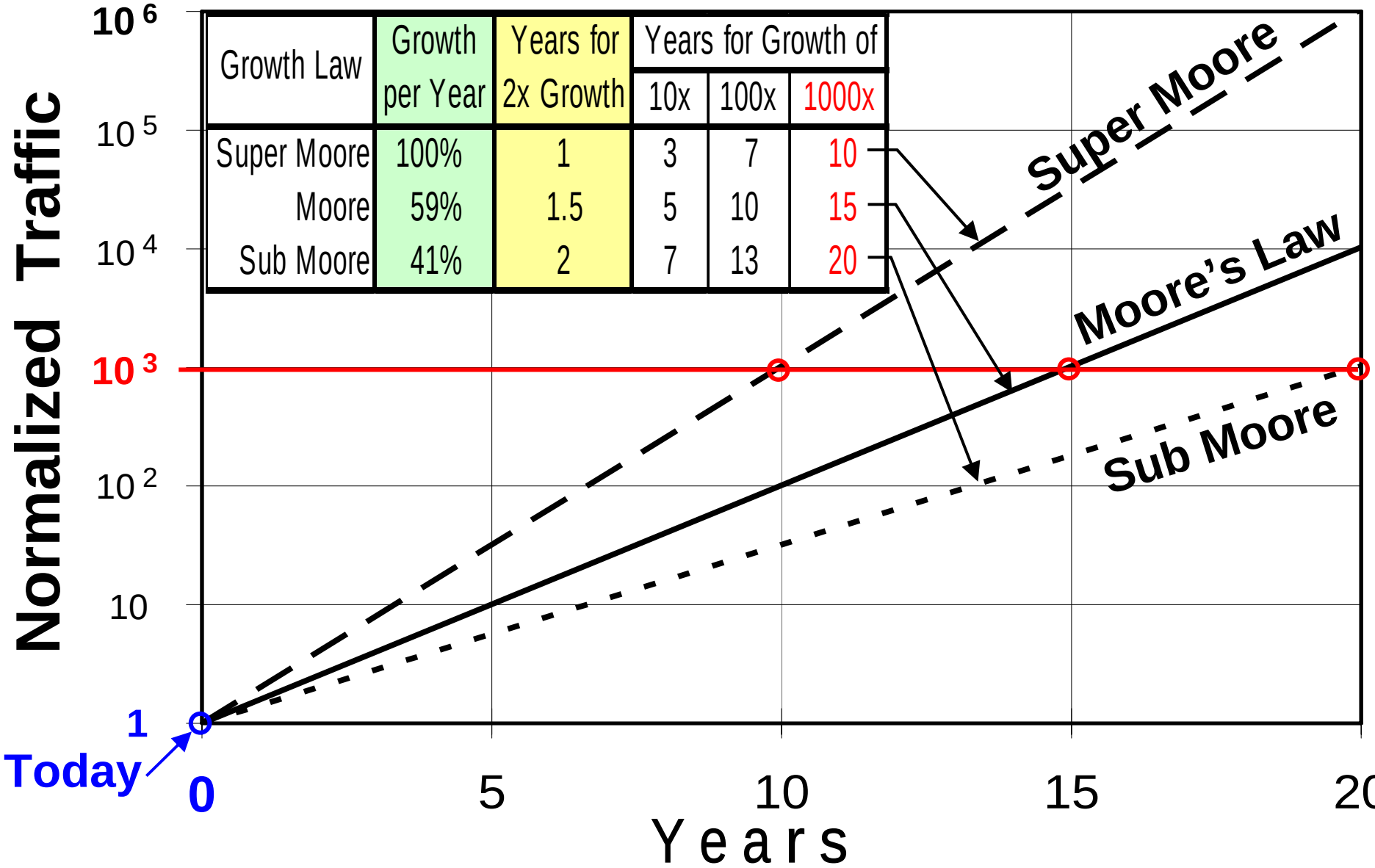

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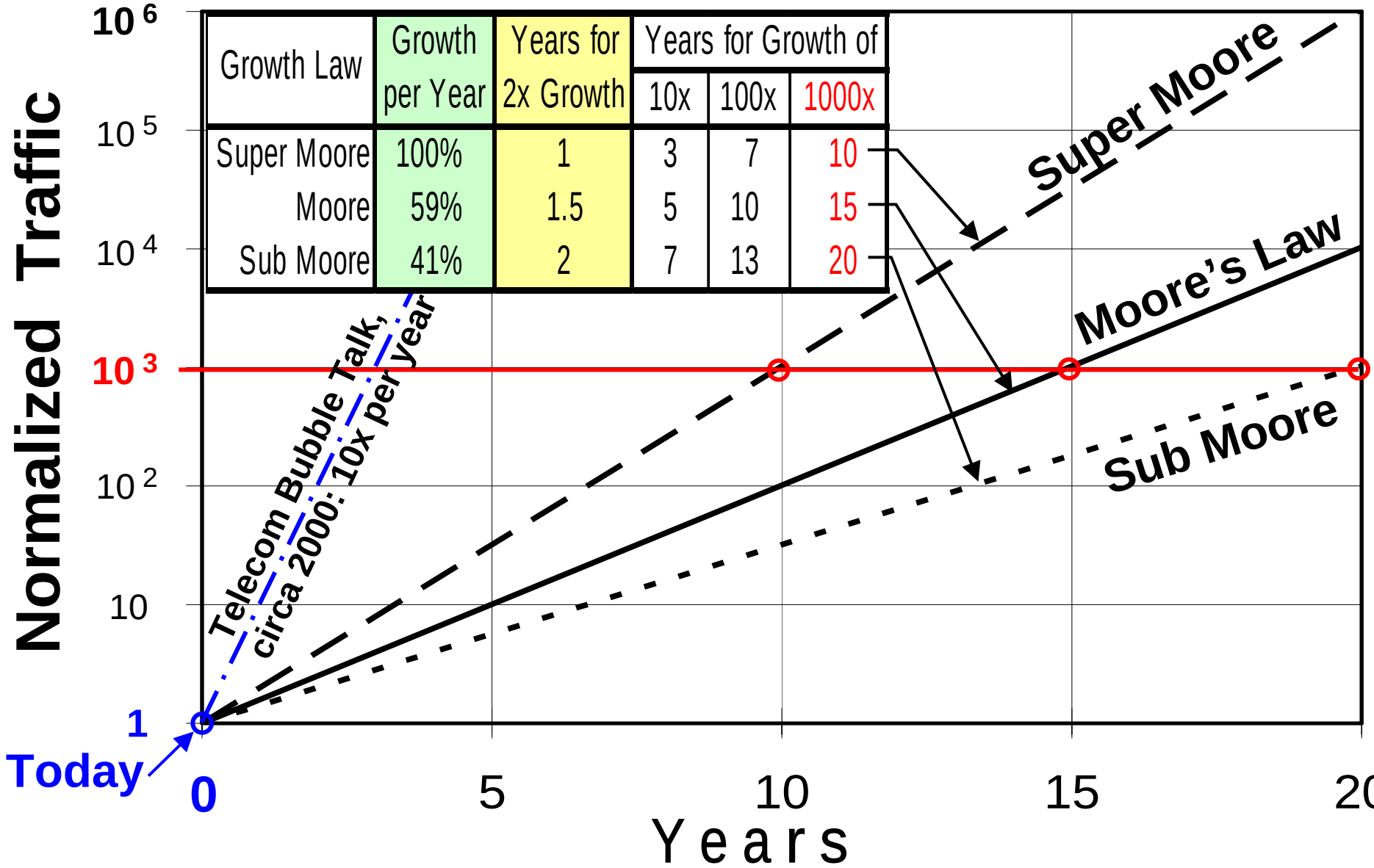

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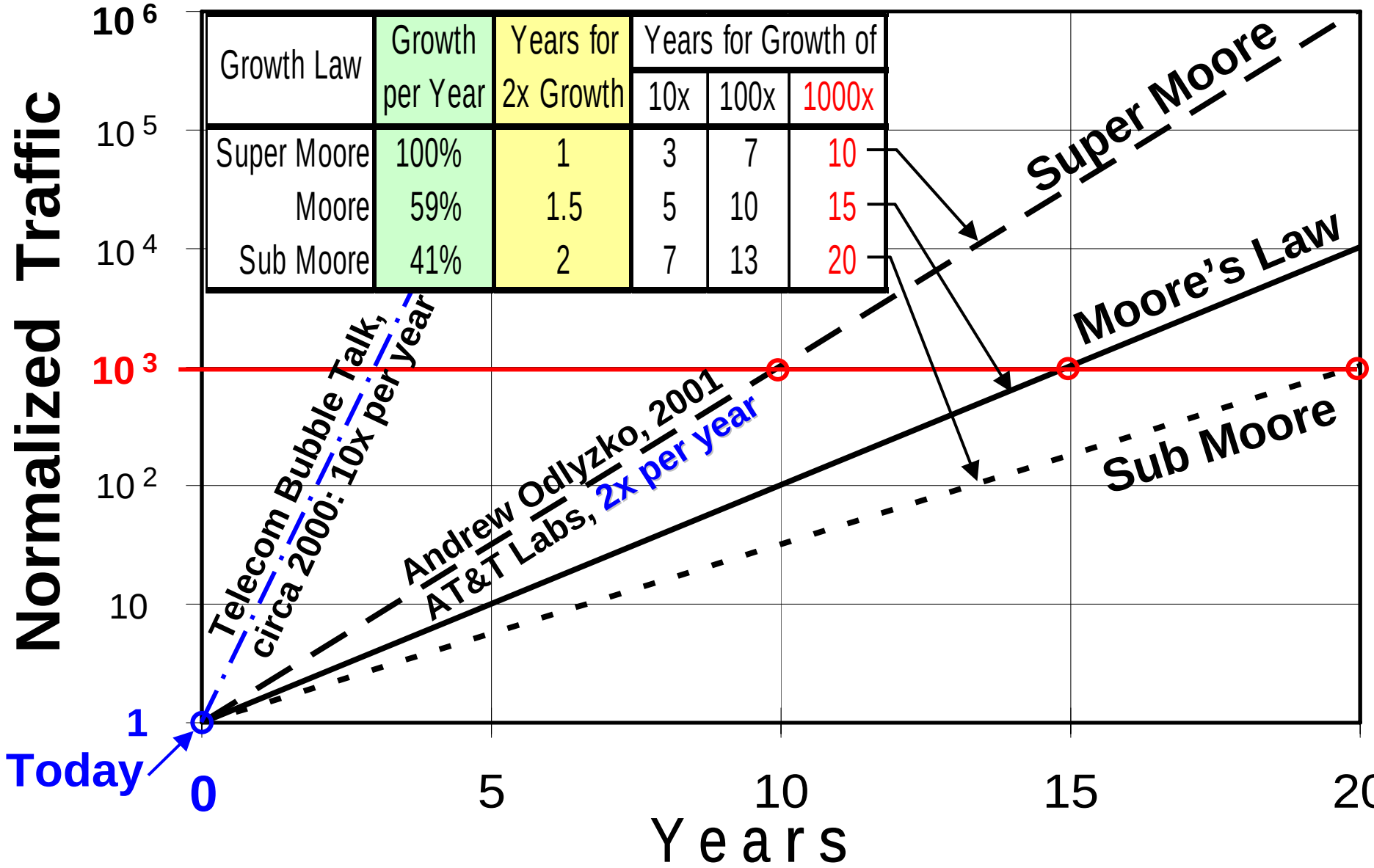

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Watson and Gilder

Wall Street Journal, Feb. 22, 2008, p. A15

Unleashing the 'Exaflood'

- "… Cisco's newest video-conferencing system requires 15 megabits per second in each direction. A one-hour conference call could thus produce 13.5 gigabytes, which is more than a high-definition movie. Just 75 of these Cisco conference calls would equal the entire Internet traffic of the year 1990…."

- "…Netflix, which is gradually moving from the post office to the Net, last year shipped 1.8 million DVDs every day. If converted to high definition, Netflix would have mailed 5.8 exabytes of motion pictures, or almost half the size of the entire U.S. Internet of 2007 ...."

- "… we estimate that, by 2015, U.S. IP traffic will reach an annual total of 1,000 exabytes, or one million million billion bytes. The U.S. Internet will thus be 50 times larger [than today] …"

Internet Traffic Growth Estimates (2007)

Current (mid-2007) annual Internet traffic growth rates	
U.S.	50-60%
World	50-60%

Year-end 2006 monthly Internet traffic estimate	
U.S.	450-800 PB (PetaByte = 10^{15} bytes)
World	2000-3000 PB (PetaByte = 10^{15} bytes)

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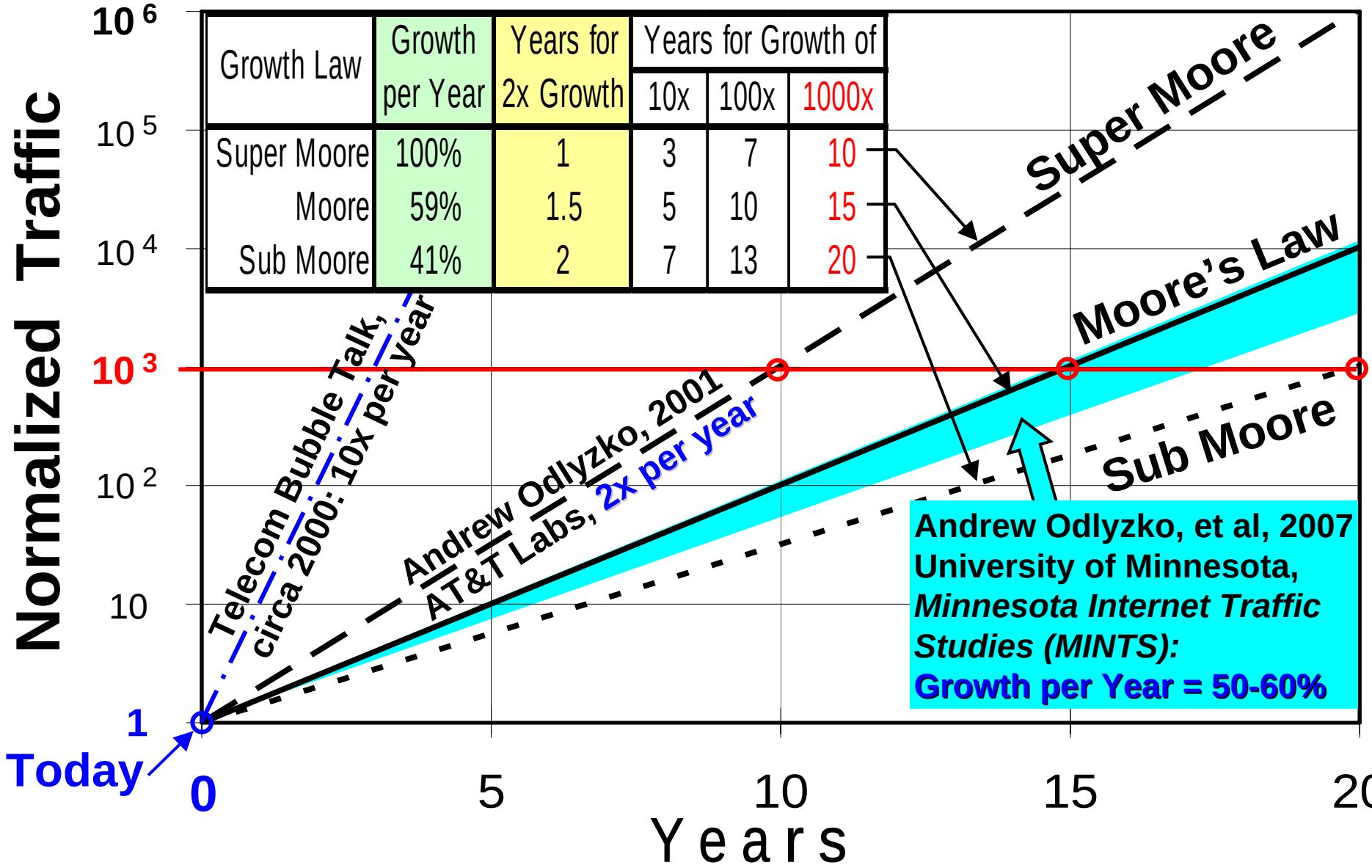

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What are the bottlenecks that will be encountered on the way to achieving 1000x Growth of the Internet (in 10-20 years)?

- Maximum Capacity of the Optical Fiber
- Ultimate Size of the IP Router (Size, Power, Cost)
- Size of the Core Optical Switch <u>will not be a bottleneck</u>
  - But OEO Core Switches (SONET/SDH, OTN or Ethernet) can be a bottleneck

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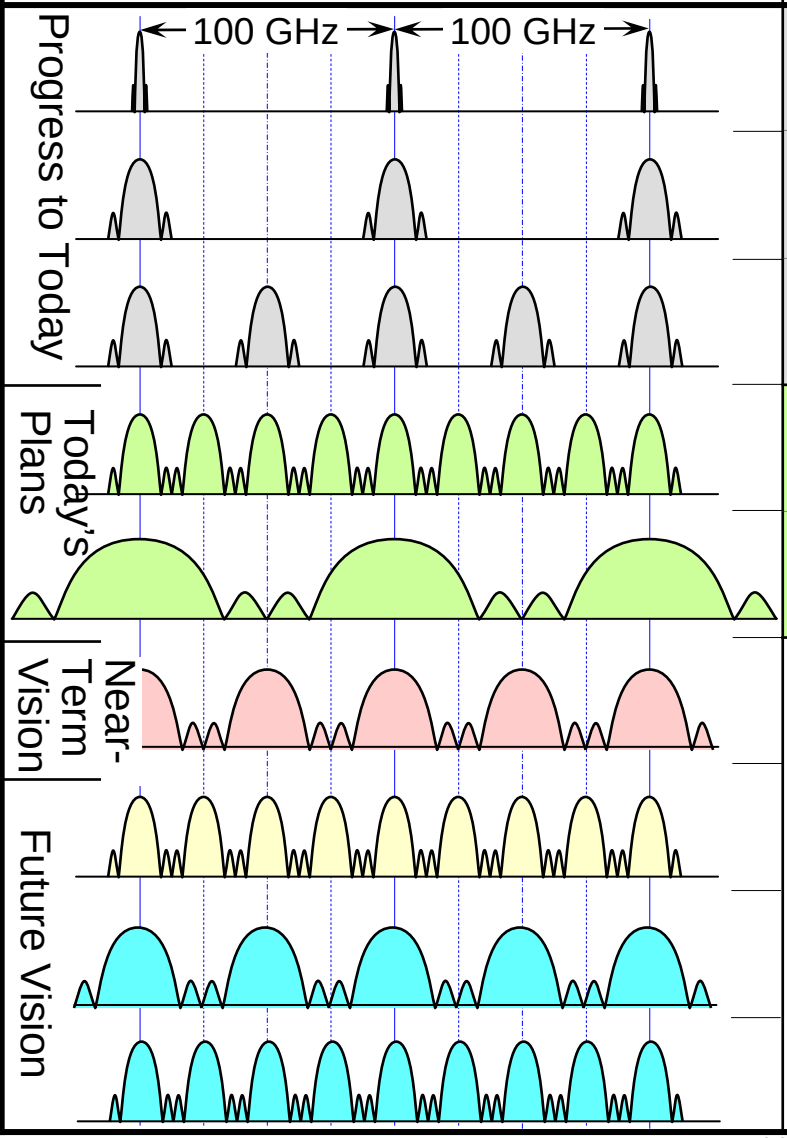
High-Spectral-Efficiency (SE) Fiber Transmission

Strategic Technology Office



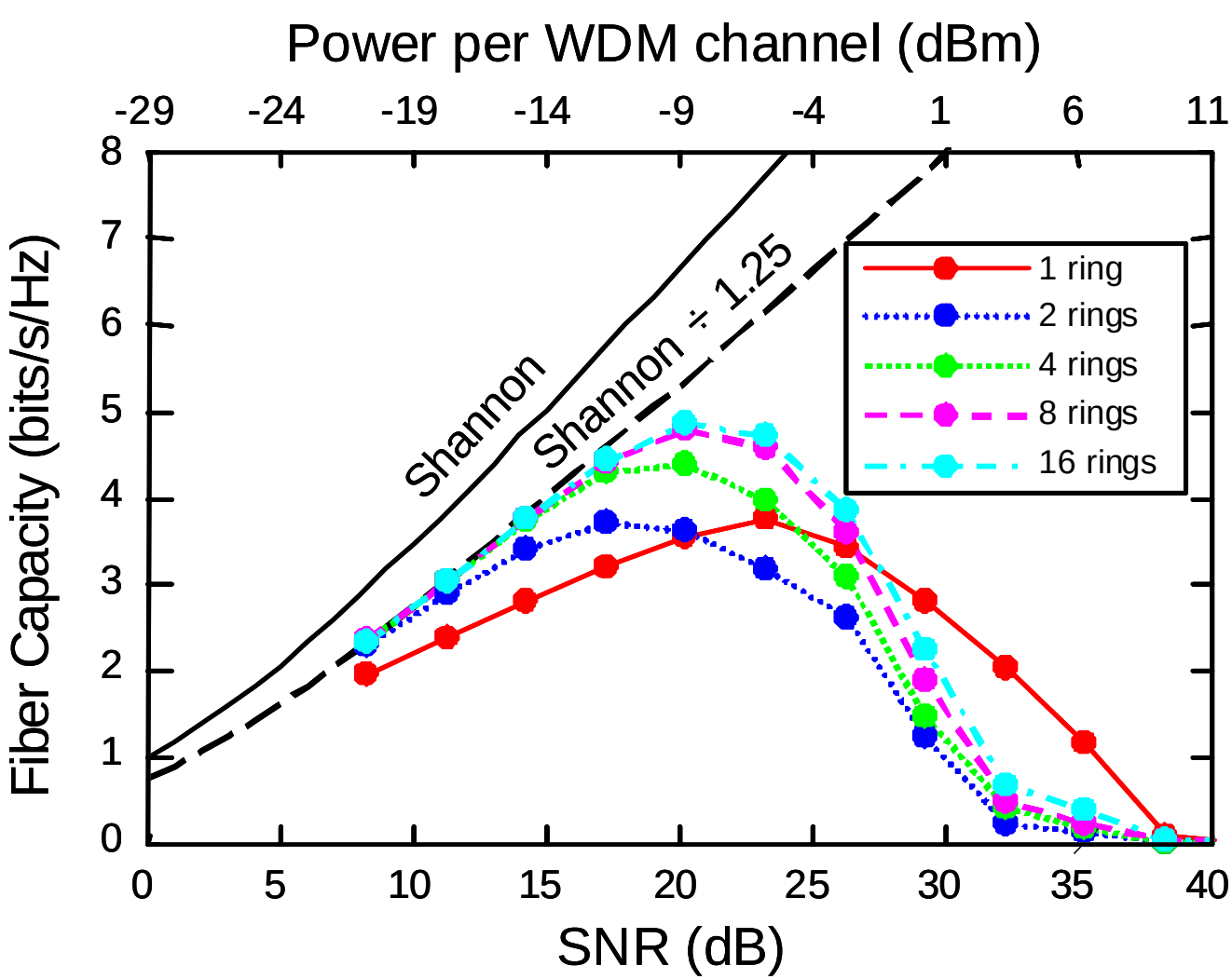
Optical Spectrum	Mod Fmt	Gb/s per λ	Δλ GHz	SE b/s/Hz	Num λ's C-Band	Tb/s in C-Band	Tb/s in C,L-Band
Progress to Today	Binary OOK	2.5	100	0.025	40	0.25	0.5
		10	100	0.1	40	0.4	0.8
		10	50	0.2	80	0.8	1.6
Today's Plans	Binary OOK	10	25	0.4	160	1.6	3.2
		40	100	0.4	40	1.6	3.2
Near-Term Vision	Advanced Modulation	40	50	0.8	80	3.2	6.4
Future Vision		40	25	1.6	160	6.4	12.8
		100	50	2.0	80	8.0	16.0
		100	25	4.0	160	16.0	32.0

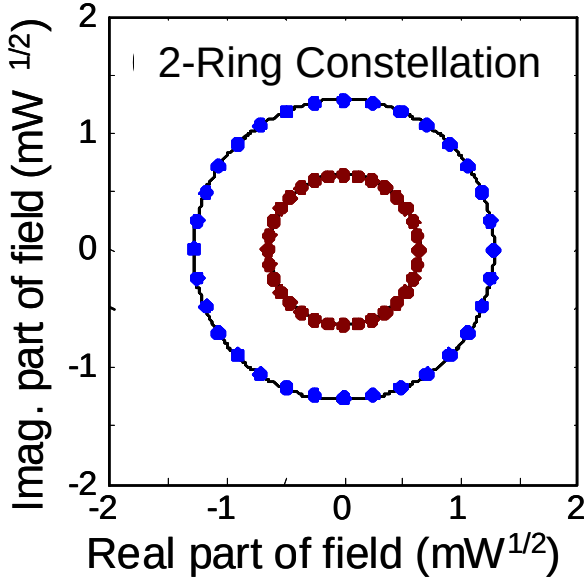
Capacity of Fiber-Optic Comm. Systems

Essiambre, et al, Alcatel-Lucent, Bell Labs

Abstract: "… analysis reveals that a **5 bits/s/Hz** capacity in a single polarization for transmission **over 2000 km** is possible using advanced technologies."

OFC, 08, OTuE1 2:00 pm





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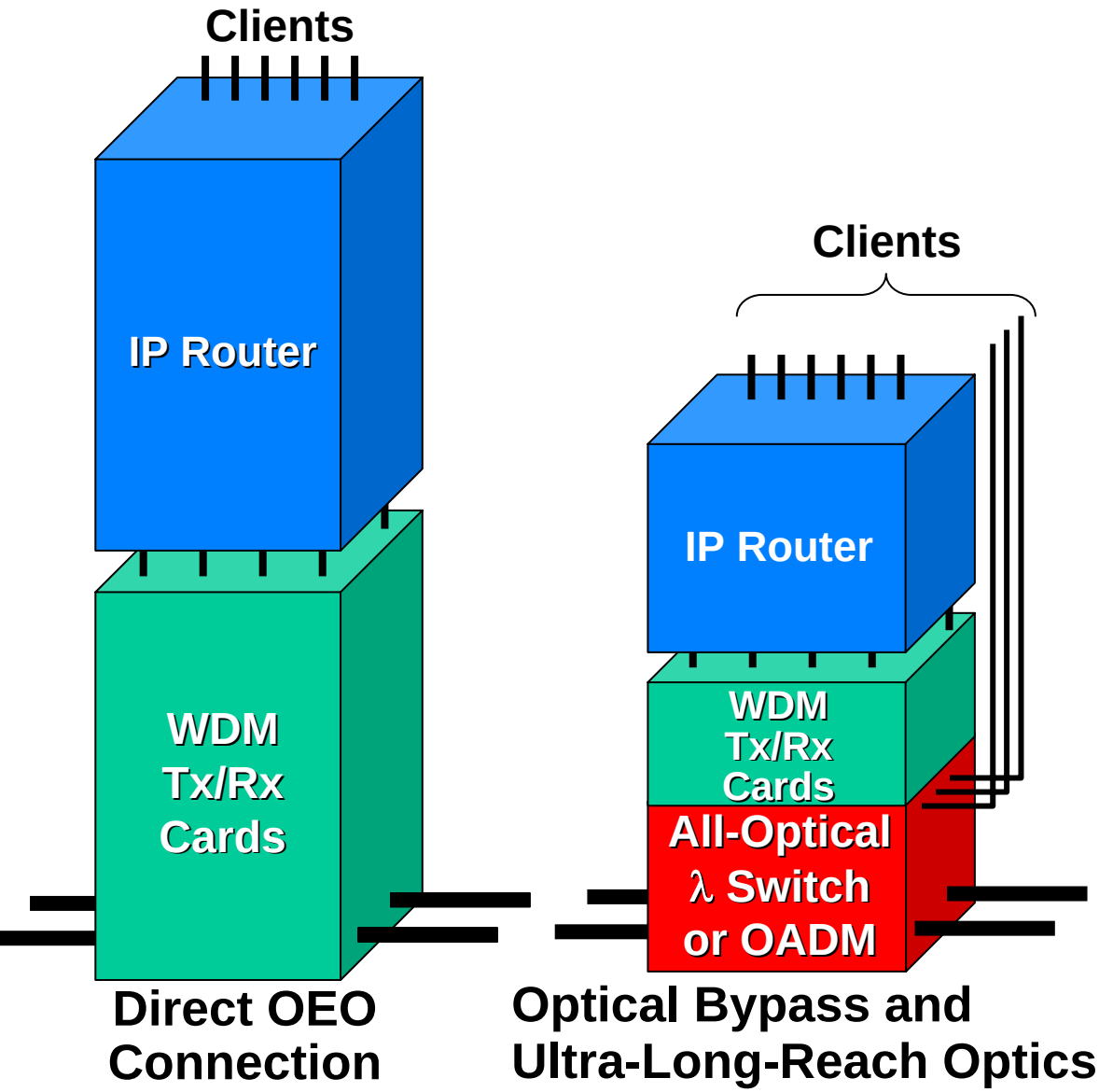
Current State of IP/WDM Network Node Architecture



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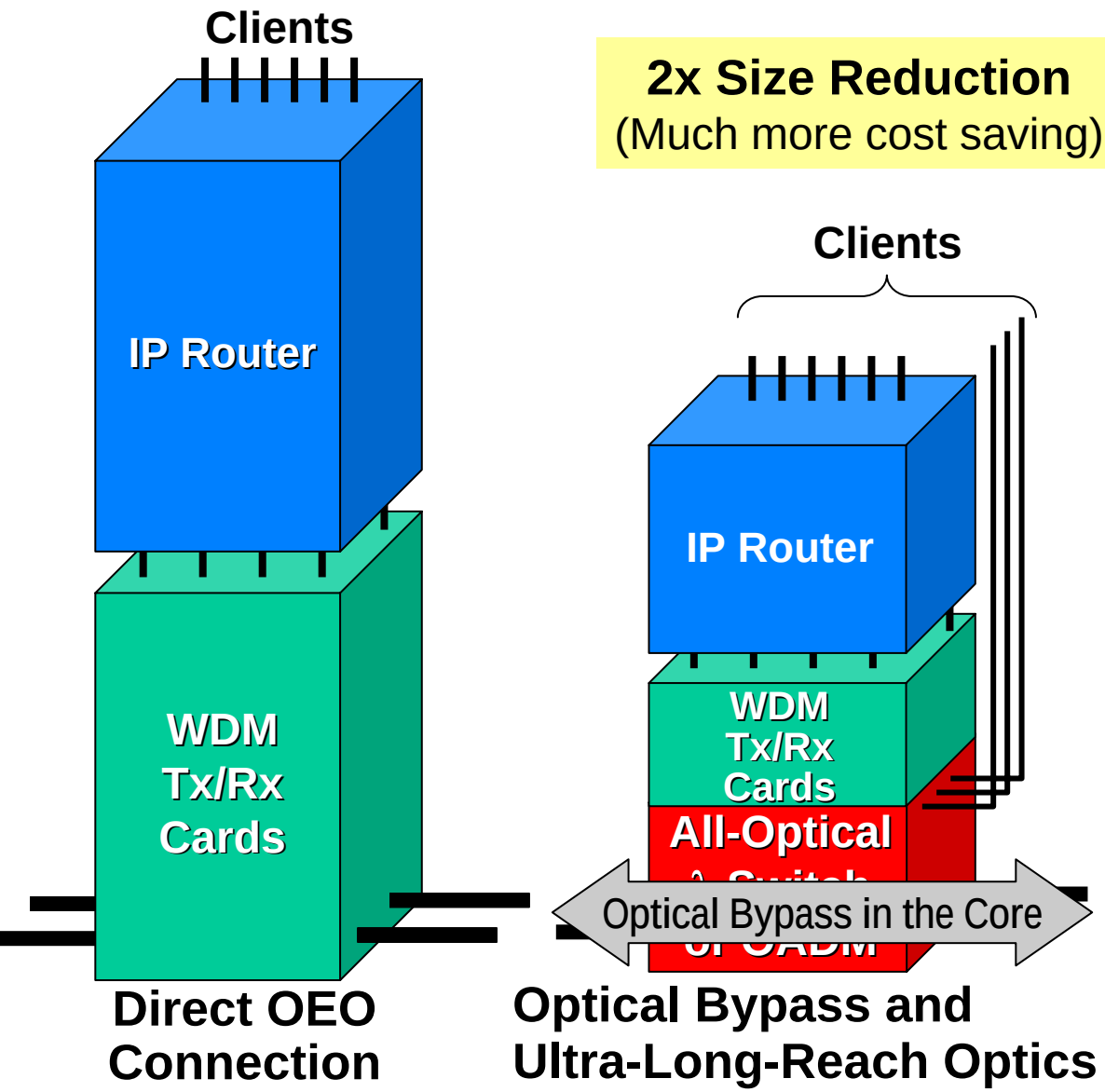
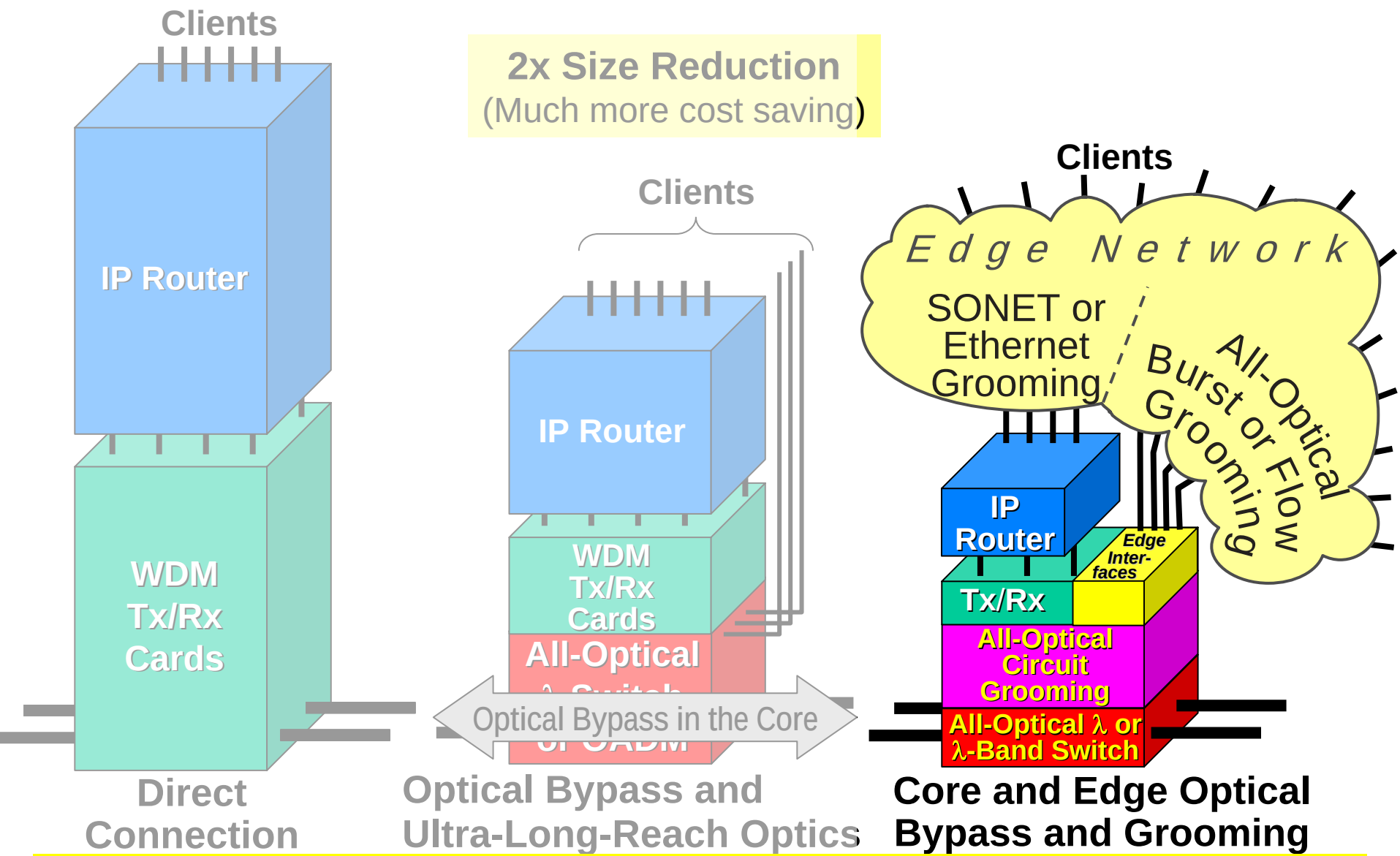


Possible Evolution of IP/WDM Network Node Architecture



From: Saleh and Simmons, "Evolution Toward the Next-Generation Core Optical Network", *JLT, Sept 2006*

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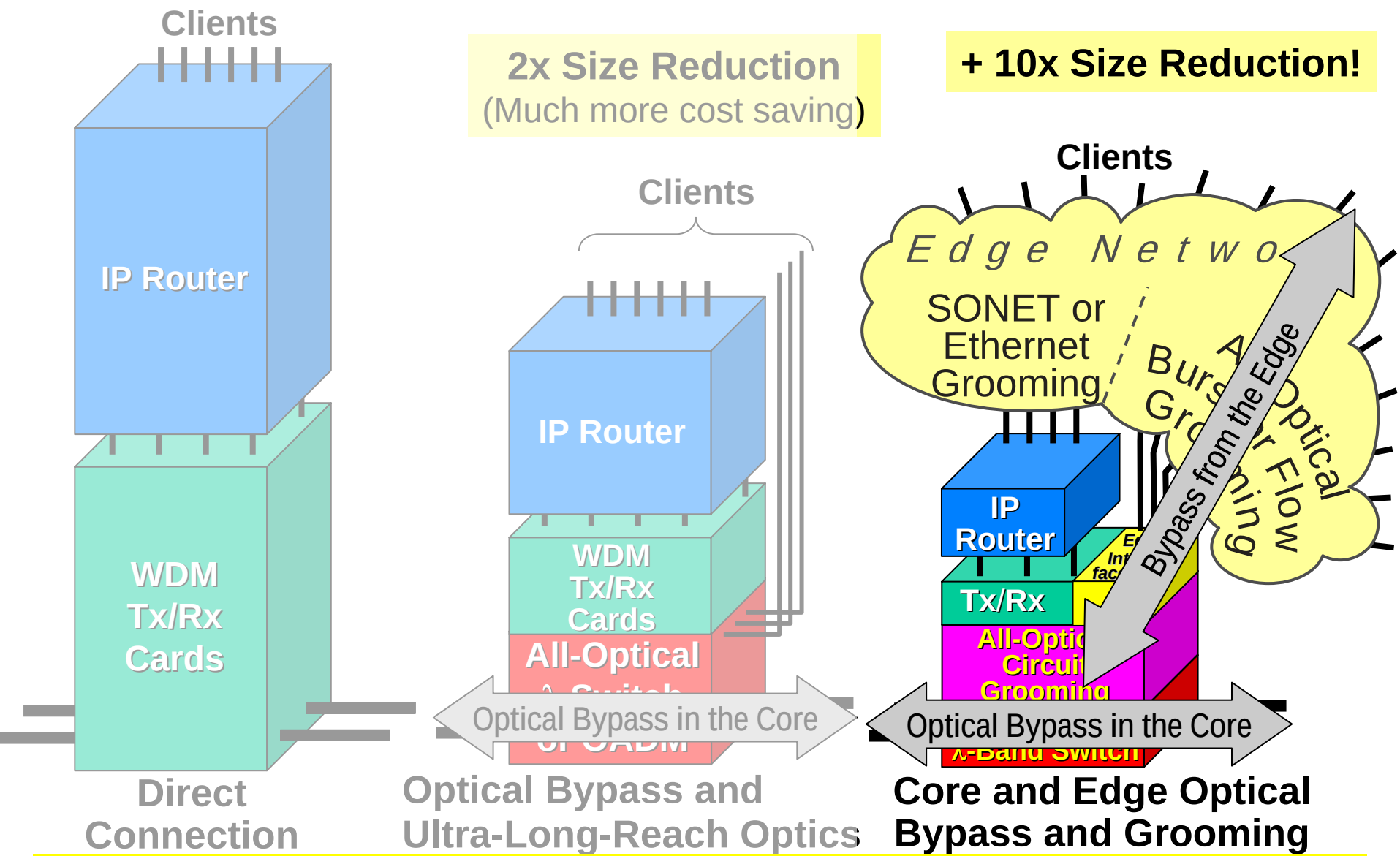

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We still do not have a factor of a 1000!

- Other known techniques to enhance scalability
  - Multicasting / Caching / Unicasting (e.g., for IPTV)
  - Improving efficiency of packing IP packets in wavelength (through improved MPLS and other Layer-2 grooming techniques
- Can Dynamic Optical Networking Help Us Further ?
  - We have initial estimates
  - But this subject is still under active investigations, even here at OFC 2008 !
  - It is also the subject of the just-launched DARPA CORONET Program

Reconfigurable Optical Networks: Is it Worth?

Roshani, et al, Univ. of Texas at Dallas

OFC, 08, OTuA2 2:30 pm

Abstract: "*A fundamental question to address is what levels of traffic fluctuations may **justify** the deployment of **reconfigurable optical networks**. Based on a flow model, this study provides a preliminary answer for **IP/MPLS over WDM** networks.*"

Conclusion:

"From a pure network utilization perspective, reconfigurable optical networks appear to provide ***tangible*** advantages when the levels of traffic fluctuations exceed some threshold value …"

Dictionary:

tan·gi·ble

Adj. 2. real or actual, rather than imaginary or visionary

Cost Study of Dynamically Transparent Networks

Ruffini, et al, *U. Dublin, and Alcatel-Lucent*

Strategic Technology Office

OFC, 08, OMG2 2:30 pm

Abstract: "*The network equipment **cost benefit** of **dynamic wavelength routing** is compared with point-to-point IP networks and static wavelength routing in a simple ring topology with **variable network traffic loading**.*"

Conclusion:

"This initial exploration has shown the potential for cost savings in spatially reconfigurable networks. The cost sensitivity analysis indicates that ***benefits persist*** …"

OFC Studies on Dynamic Optical Networking for Distributed and Grid Computing Applications

Technologies, Architecture and Services for the Next-Generation Core Optical Networks, **Saleh**, DARPA, USA

OFC, 07, Workshop on the Future of Optical Networking

Shows Orders of Magnitude Effective Enhancement of Network Capacity Through the Use of Dynamic Optical Networking for Distributed and Grid Computing Applications

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Distributed Computing over Optical Networks,
Guo, et al, *Shanghai Jiao Tong University and Shanghai Supercomputer Center,*

OFC, 08, OWF1 1:00 pm

Abstract: "*This paper overviews the opportunities and challenges of distributed computing over optical network. The Terabits Optical Network Integrated Computing Environment (TONICE) project and the Integrated Resources Management System (IRMS) are presented.*"

Performance Comparison of Optical Circuit and Burst Switching for Distributed Computing Applications,
Yu, et al, *U. at Buffalo (SUNY) and NEC Labs.*

OFC, 08, OWF4 2:00 pm

Abstract: "*Intertask communications in distributed computing applications are modeled using both the frequency of communications and the ratio of data transmission time over computing time to evaluate the performance of static OCS, dynamic OCS, and OBS.*"

Summary of Techniques for Scaling IP-over-Optical Networks

Technique for Scaling the IP-over-Optical Network	Fiber Capacity Bottleneck		Router Size Bottleneck
Optical Bypass at the Core	-		2 X
Optical Bypass from the Edge	-		10 X
Multicasting/Caching/ Unicasting	5 X		(Included above)
Scalable 250-Tb/s IP Routers	-		25 X
High-Spectral-Efficiency Modulation Formats	(4 b/s/Hz) 10 X	(2 b/s/Hz) 5 X	-
Use Multiple Fiber-Pairs per Link	(2 Pairs) 2 X	(4 Pairs) 4 X	-
Increased Efficiency of Packing IP Packets in Wavelength	2 X		-
Dynamic Optical Circuit Switching and Sub-Wavelength Grooming	5 X		2 X
Total Scaling Factor	1000 X		1000 X

The DARPA *CORONET* Program

- To enable the scalability of next-generation networks, DARPA just launched the ***CORONET*** Program
- Its full title is: "*Dynamic Multi-Terabit Core Optical Networks: Architecture, Protocols, Control and Management*"
- Its immediate purpose is to solve the first 10x problem, but also to get ideas for dealing with network robustness and further growth
- The Program has two phases:
  - **Phase 1** (18 Months) is for developing and testing (by simulations) architecture, protocols, and algorithms
  - **Phase 2** (24 Months) is for developing and testing a compatible network control and management software suitable for transition to commercial telecommunications and Government carriers
- The performing teams of CORONET will be announced very soon

Overview of the *CORONET* Target Network

- Global core optical network
- IP (with MPLS) over WDM architecture
- Network services
  - Predominantly IP services (with differentiated QoS)
  - Substantial amount of wavelength-services
- Scalable for up to 10x increase in aggregate network demand over today's state-of-the-art networks
- Highly dynamic network with very fast service set-up and tear-down
- Resilient to multiple concurrent network failures
- Simplified network operation and increased security

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Thank You!