Managing Optical Networks in the Optical Domain

Networking 2002

Pisa, Italy

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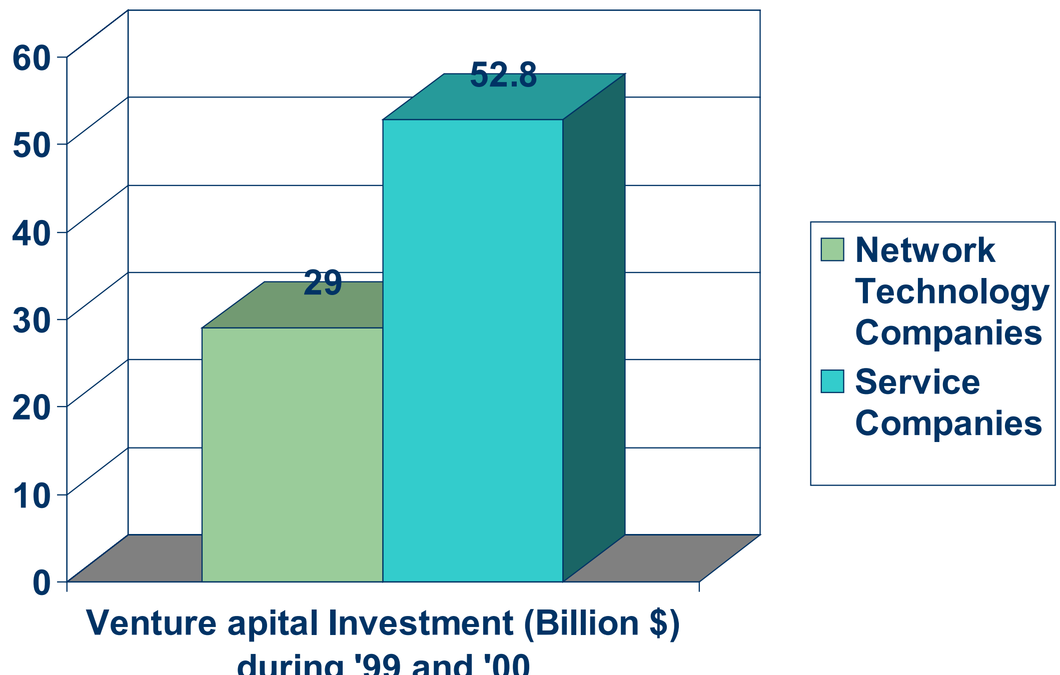
OVERVIEW

- Carrier networks are changing through an ***evolutionary***, not a ***revolutionary***, migration process
- Effects of this migration on bandwidth provisioning and network control processes
- Provisioning protocols and net management structures being developed

THE DREAM OF 2000

- In 1999 to 2001 the trade press had us believing

all optical networking would soon revolutionize the data communications world of all the PTTs, CLECs, RBOCs, etc.



• PricewaterhouseCoopers in Partnership with VentureOne Survey (2002).

NETWORK TECHNOLOGY COMPANIES

- By early 2001, over ***300*** companies focused on optical (photonic) equipment development

- General networking product stalwarts engaged in product development or company acquisition, collectively producing:

Optical Cross-Connect

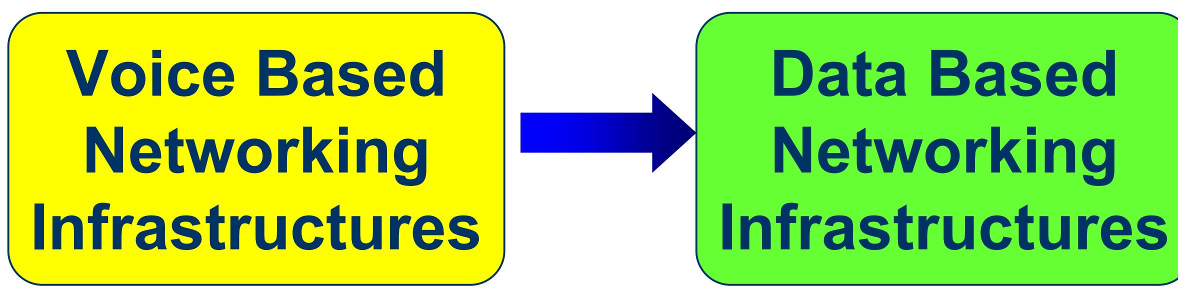
Optical Switch

Optical Add Drop Multiplexer

Management Software

SERVICE COMPANIES

- ”Emerging" ***IXCs and CLECs*** were focused on the delivery of next generation optically driven services
- Revolutionizing networking in the shift from voice based to data based networking



THE RATIONALE FOR THE "OPTICAL " ENTHUSIASM

- Significantly more data carrying bandwidth
- Optically based service provider revenue generating service opportunities
- Simplified network infrastructures greatly reducing service provider Capex and Opex costs

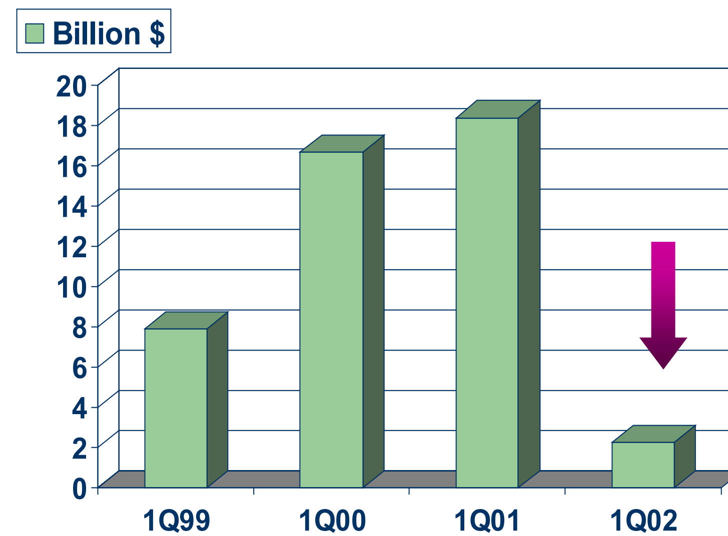
THE BASIC PREMISE OF THE OPTICAL REVOLUTION

- By doing everything optically, not electronically, networks became much cheaper to install and operate, while providing infinitely more power

  – with promises like these, the optical revolution could not be stopped….

OR, SO MANY THOUGHT

- **Beginning Q1 of 2001**
  - the economy slowed
  - infrastructure capital became unavailable
  - carriers began to fail
  - non-essential optical infrastructure spending ceased
  - the optical revolution slowed

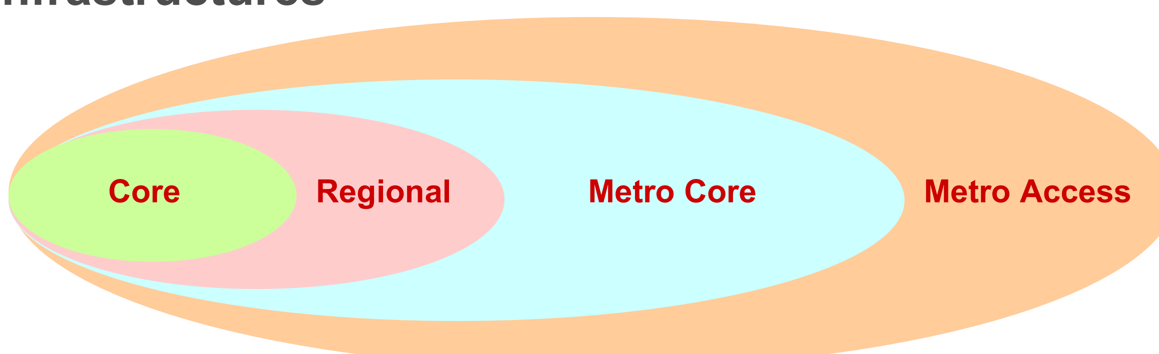


Commitments to Venture Capital Funds
http://www.lightreading.com

- **Optical equipment providers shifted from thoughts of rapid growth to thoughts of *survival***

OBJECTIVE FACTORS

- Technological barriers were more difficult to overcome than originally thought
- Component costs proved higher than anticipated
- More time was needed for
  - further the development of tunable lasers and all optical wavelength converters, etc.
  - refine the distinguishable cost differentiators in equipment, switching speed, amplifier needs, protocols, etc.
  - develop a uniform management of optical network infrastructures



ON THE UPSIDE

- During the ***photonic nuclear winter***
  - companies that can survive will become stronger, with refined products and certain competition eliminated
  - needs of the optical market segments will continue to evolve
  - product solutions for each market segment will become clearer
  - highly integrated optical components and modules will reduce product cost and increase product functionality

TECHNOLOGY CONTINUES TO MOVE FORWARD

- **Amplifiers** eliminating the costly electronic regeneration
  - for optical transmission up to 600km without "electronic" retrofit
- **Optical switching and mux equipment**
  - for easier "path" provisioning, monitoring, and restoration of optical data
- **Optical switching with MEMS**
  - leading candidate for small to very large (1024 x 1024) port optical switches.
- **DWDM** migrating from four or five channels (wavelengths) to 160 channels and more
  - from 2.5Gb/s to 10Gb/s per wavelength to 40Gb/s wavelength

THE NEW EXPECTATIONS

- **During 2002, we have come to believe that:**
- **the *revolution* of 2002 that called for rapid replacement of electronically oriented networks by all optical networks, with**
- **the retention of electronics only at points of user ingress and egress will not occur**
- **Instead, optical *evolution* will occur at a slower, more rational pace**

Revolution → **Evolution**

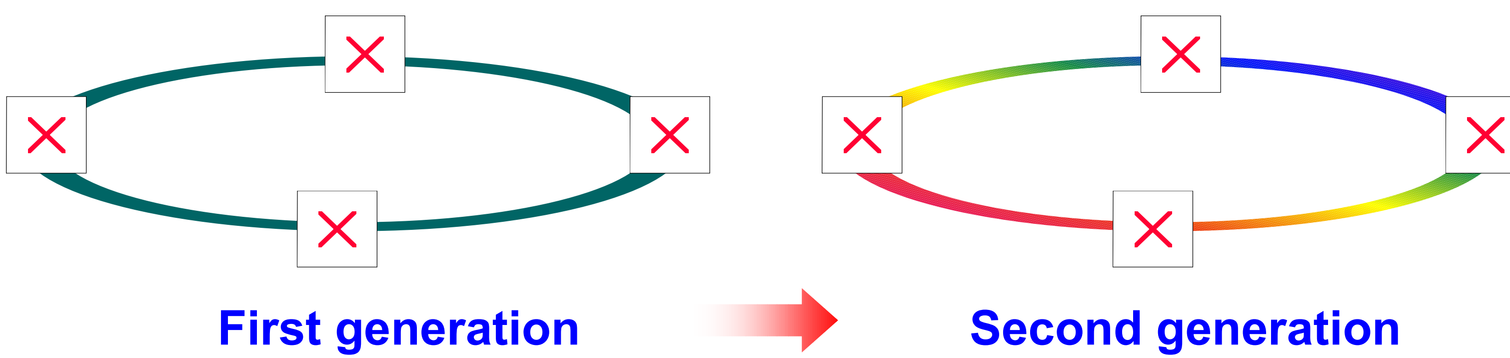
EVOLUTIONARY OUTLOOK IMPLIES

side-by-side existence of old and new will be much the norm

OPTICAL NETWORKING

old and new

- We are entering the third generation of carrier based networking:
  - **First generation** - based on SONET networks
    - with T1/E1, etc. "tributary" or "feeder" lines.
    - voice traffic oriented
  - **Second generation** - based on SONET networks
    - with DWDM point to point transmission systems
    - high speed routers and/or ATM switches in the network core
    - carrying data, and in some cases digitized voice



THIRD GENERATION - Technologies

- According to the evolution principle, based on
  - "old" SONET equipment
  - "new" SONET equipment
  - LAN and ATM switches and routers
  - Optical add/drop multiplexers,
  - Optical switches (fiber and wavelength)
  - All optical long haul transmission systems (where needed)

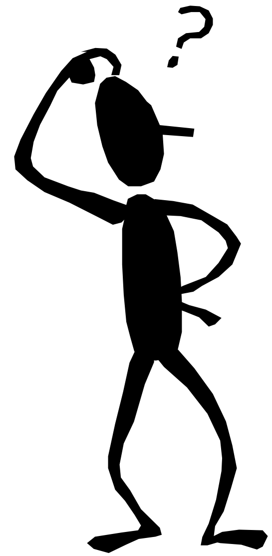
- Data transmission oriented

THIRD GENERATION - A Management Challenge

- Subscriber access may well be optically based, with SONET or Ethernet as the core access technology
- May well contain equipment from at least two, if not three, of these network generations
- Correspondingly, network operation must be based on ***"industry" standards*** that use management systems that bind together three generations of equipment into a seamless whole

THE CURRENT NETWORK MANAGEMENT SITUATION

- SONET Equipment
- IP Router
- LAN Switch
- ATM Switch
- DWDM Equipment
- TDM Equipment



Management

These technologies are *incompatible* in network management terms

TDM AND MANAGEMENT

- TDM equipment is managed by TL1 - a vendor independent protocol
- TL1 dates from a 1984 Bellcore design

  based on a command line interface designed to
  - transmit commands to machines and receive messages from machines
  - control network elements (elements, e.g., blades, within a platform)
  - convey alarm and fault information
- Although TL1 was applied to SONET, it never gained widespread use beyond TDM equipment

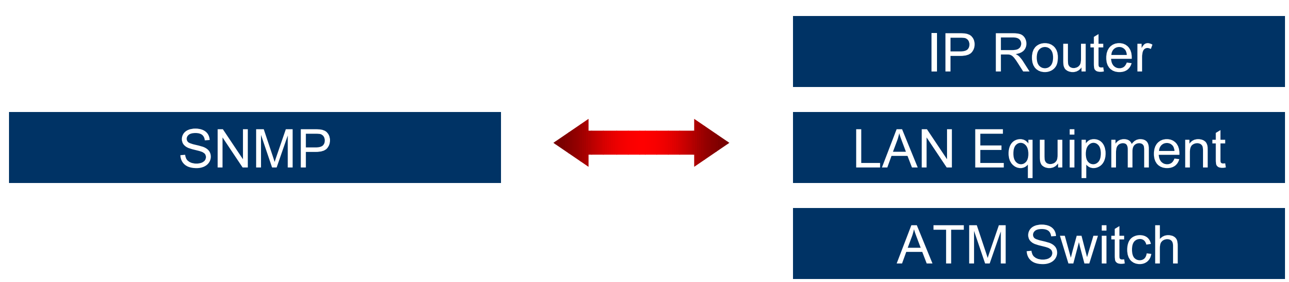
SONET AND MANAGEMENT

SONET equipment principally managed by an ISO developed (ITU adapted) protocol - the Common Management Information Protocol (CMIP) designed to be

- a machine-to-machine, intended to be vendor neutral
- since 1988 CMIP has found use for SONET equipment management
- has also appeared, together with SNMP in some ATM (switch) platforms
- CMIP never gained traction beyond SONET, and has not, for example, been used in the management of LAN networks

LAN AND MANAGEMENT

- LAN equipment, including routers, switches, and most ATM switches, use the Simple Network Management Protocol (SNMP)
  - SNMP was developed by the IETF



COMBINED (?) MANAGEMENT

- CMIP and SNMP are basically incompatible in operation
  - CMIP uses a ***connection oriented*** (Telco and ATM oriented) model of operation where
    - the networking platform or the management client must initiate execution of a handshake sequence to establish contact prior to the exchange information and commands
  - SMNP uses a (LAN oriented) ***connection-less*** model where
    - no connection oriented sequence prior to the exchange of commands and messages is needed

THE SPIRIT OF DISCORD

- ***SONET and LAN equipment differences are fundamental, beyond management suites, thus affecting (making more complex or restricting the effectiveness of)***
  - **third generation networks operation**
  - **next generation equipment "integration" into network *management systems***

WHY THE DIFFERENCES

- SONET
  - Designed to carry digitized voice in frames
- LAN
  - Designed to carry data packets

- Ways of carrying data packets in SONET streams were invented more recently
- New LAN protocols collectively known as supporting Voice over IP (VoIP) have been invented to carry digitized voice over LANs as data packets are coming into widespread use only gradually

STRUCTURES

- SONET
  - Synchronous
  - Hierarchical

OC3 → OC12 → OC48 → OC192 → OC768

- LAN
  - Asynchronous
  - Nonhierarchical

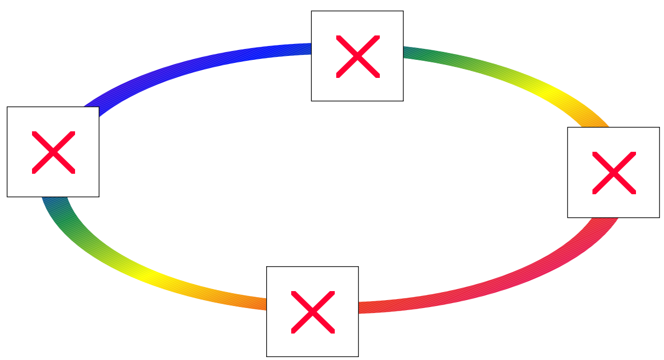
10M → 100M → 1G → 10G

RELIABILITY VS. AVAILABLITY

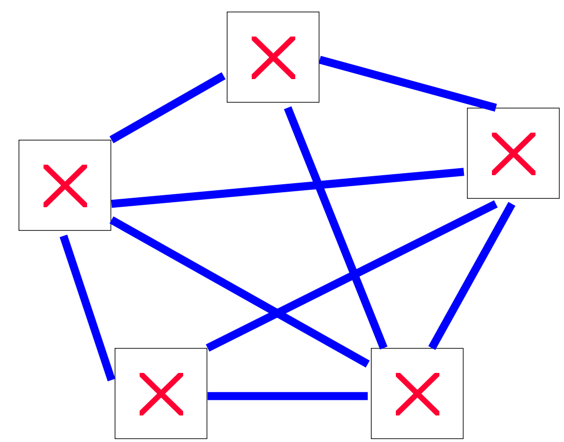
- SONET operates under the ***reliability principle*** of protection used to restore failed service
  - SONET reserves secondary path resources (e.g., fiber links) to take over in the case of primary resource failures
  - The "switch-over" to secondary resources (restoration of service) is guaranteed to occur in under 50 milliseconds
- LANs operate under the ***service availability principle***
  - LAN availability allows SNMP traps to signal failures, with routing algorithms
  - like OSPF used to determine new "paths" (routes) for packets to reach
  - destinations via new routes
  - no "availability" restoration time is guaranteed

TOPOLOGIES

- The SONET network topology is inherently one of interconnected rings
  - with a ring made up of SONET mux and cross-connect platforms connected by point-to-point physical links
- LAN networks are generically mesh topologies
  - some of which may also be collapsed to point to point or hub structures



SONET

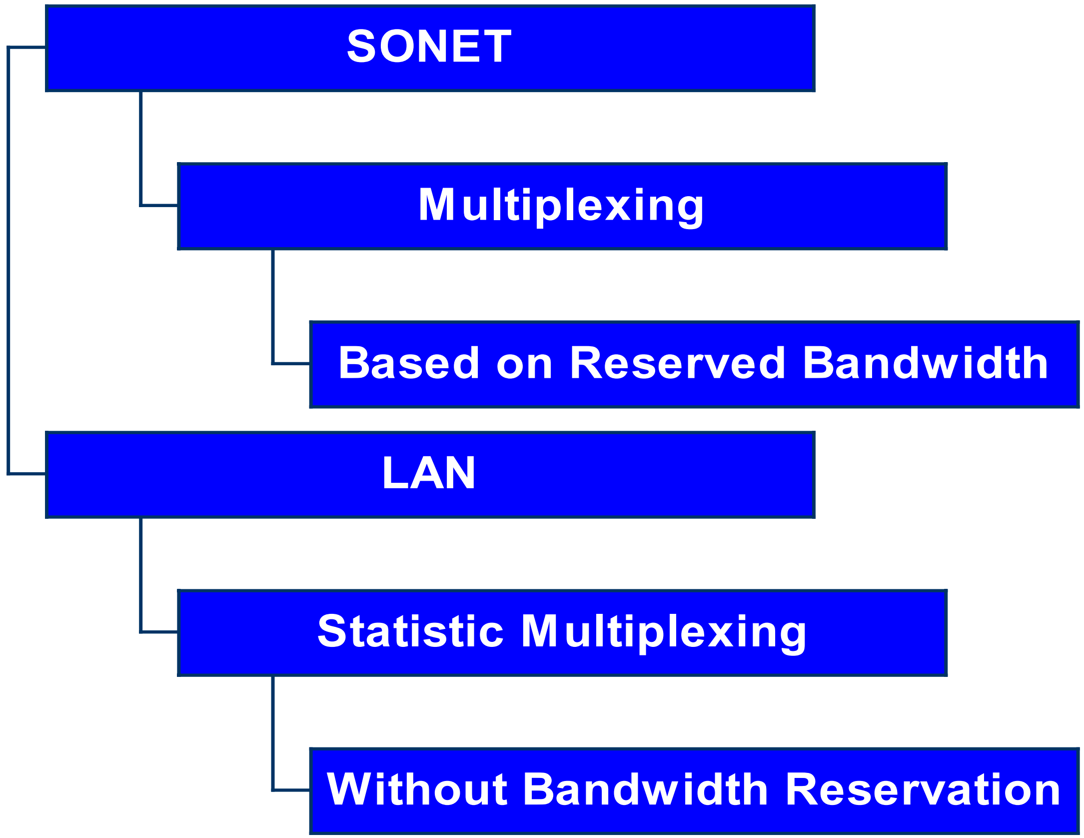


LAN

QOS

- SONET
  - Connection Oriented, Guarantee QoS
    - Asynchronous timing
      Hierarchical framing
      Restoration
      Data correction
- LAN
  - Packet Oriented, Initially Best Effort
  - Recent QoS technology
    - IntServ
      DiffServ
      Class of Service
      MPLS

BANDWIDTH UTILIZATION PRINCIPLES



- As a consequence, a SONET frame will always find bandwidth available for its carriage, while a LAN packet may have to wait to receive bandwidth for its carriage

BANDWIDTH PROVISIONING AND UTILIZATION IN THE HYBRID WORLD

- Clearly these differences and deficiencies must be improved upon, or overcome, as

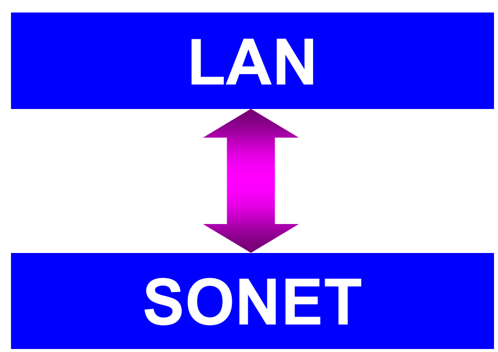
  everything demands the efficient and reliable end to end carriage of data (IP) packets

- Clearly, the ***evolutionary model*** imposes a carriage that likely begins and ends on Ethernet, with intervening passage through pure optical and SONET network segments

- There is need to ***quickly and easily provision*** the carriage capability, and efficiently use the network resources along the provisioned route

WHERE DOES THIS LEAVE US IN TERMS OF BW PROVISIONING AND UTILIZATION?

- In carrying LAN originated data, over existing voice developed SONET infrastructure developed, exhibiting
  - limited flexibility
  - inefficiencies of bandwidth utilization
  - slow and difficult, extensively manual, provisioning of "circuits" (realized from expensive platforms)



We Get…

Packet Service rate	*SONET frame level Required*	*% bandwidth utilization**
10 Mb/s Ethernet	51Mb/s level-1 frame	20%
100Mb/s Ethernet	155Mb/s level-3frame	42%
1000Mb/s Ethernet	2448Mb/s level-48 frame	42%

Adapted from "Delivering Ethernet over SONET using Virtual Concatenation", by Nilam Ruparelia, in CommsDesign.com.

- **For all cases shown, we assume the unused bandwidth to be wasted**

ALL THAT INTEREST…

- Third generation management protocols being developed by no less than
  - the Internet Engineering Task Force (IETF)
  - the International Telecommunications Union (ITU)
  - the American National Standards Institute (ANSI)
  - the Institute of Electrical and Electronic Engineers (IEEE)
  - the Optical Inter-networking Forum (OIF)

WITH SOME RESULTS…

- The protocols being developed by these bodies include:
  - the Generic Framing Procedure (GRP), or the Virtual concatenation protocol, a grooming standard for the more efficient carriage of Ethernet (or any other) packet stream over SONET
  - the Optical Transport Network (OTN) architecture standard (successor to SONET) integrates DWDM and its associated management architectures into the architecture
  - the Generalized Multi-Protocol Label Switching (GMPLS) integrates the provisioning of TDM, SONET, optical and LAN integrated end-to-end network infrastructures

GENERIC FRAMING PROCEDURE (GRP)

- The *purpose of GRP* is to create variable sized frames, sized to better fit the packet or data it is intended to carry
- GRP uses *virtual concatenation* to improve efficiency in the carriage of packets over SONET
- GRP addresses one aspect of *grooming -* the intelligent optimization of bandwidth throughout a network
- Recall that SONET carries data in frames, which come in a variety of fixed sizes, and which collectively define the SONET frame (and speed) hierarchy.

GRP AND DATA TRANSPORT

- By allowing the ***fragmentation*** of SONET data streams for insertion into several frames, while providing through ***concatenation*** for the combination of lower level frames to form higher-level frames

Packet Service rate	*VC SONET framing*	*% bandwidth utilization*
10 Mb/s Ethernet	6 VT1.5 frames	95%
100Mb/s Ethernet	2 level-1 frames	97%
1000Mb/s Ethernet	7 level-3 frames	91%

Adapted from "Delivering Ethernet over SONET using Virtual Concatenation", by Nilam Ruparelia, in CommsDesign.com.

Comment:Virtual concatenation would be associated with "new" (or upgraded) SONET equipment deployed where packet streams can enter of exit a ring

OPTICAL TRANSPORT NETWORK (OTN)

- ***OTN***, a development of the ITU and ANSI, is intended to address the shortcomings of SONET.
- Clearly OTN represents an ***extension or revision*** of the networking model that SONET is built around. It represents thinking that comes from the telco community.
- The OTN architecture places ***three optical sub-layers*** beneath the SONET/ATM layer. The three sub-layers provide for:
  - "end to end" networking over a single wavelength
  - networking of a multi-wavelength (DWDM) signal
  - the transmission of wavelengths on a fiber span

  These three elements being the three sub-layers named directly above.

OTN AND DATA TRANSPORT

- *Architecture of OTN* follows that of SONET with the hierarchy of optical channels, optical multiplex sections, and optical transmission sections paralleling the SONET hierarchy of section, line, and path
- Connections between two end points at any level of the hierarchy can be established as *trails*
- (As with SONET) each layer contains "overhead" information for the management of that layer
- The OTN optical channel, much like the SONET path, transports an optical bit stream between the two end points
- Unlike SONET, OTN is asynchronously timed like LANs.

GENERALIZED MULTI-PROTOCOL LABEL SWITCHING (GMPLS)

- **Different, yet unifying, management models are also being produced by the LAN community, in particular**
- **It has been noted that extensions to a LAN protocol called *Multi-Protocol Label Switching* (MPLS) can be applied to the pursuit of a unified management scheme**
- **These MPLS extensions are now known as**

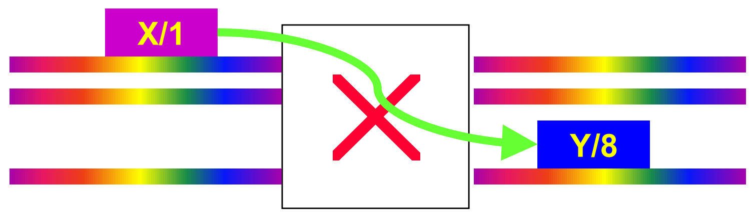
  Generalized MPLS protocol (GMPLS)

GMPLS COMPONENTS

- GMPLS uses:
  - OSFF-TE protocol to provide
    - topology and resource information
    - TE for Traffic Engineering
  - RSVP-TE and CR-LDP protocols
    - LDP, Label Distribution Protocol
    - CR, Constraint based Routing
    - for signaling of provisioning requests and routing

GMPLS PRINCIPLE

- By allowing packet switching devices to look only at a layer two "label", and not an IP and/or packet headers, in determining forwarding decisions, MPLS simplifies packet forwarding



Label/Input Port	Label/Output Port
X/1	Y/8
⋮	⋮

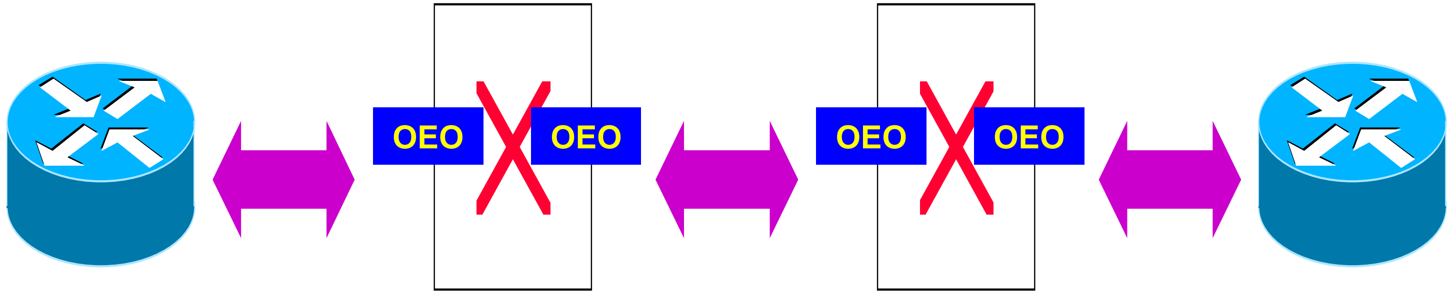
GMPLS OPPORTUNITY

- GMPLS <u>**separates the switching criteria from packet contents**</u> (except for the label)
  - Any mapping of packets to labels can be used in the forwarding process
    - e.g. time-slots, wavelengths, fibers (physical ports)
  - Yields separation is between the **control plane** and the **data plane**
  - With this separation, GMPLS can be extended to the control of SONET, optical, and TDM devices

- With GMPLS, an <u>***end-to-end path***</u> of appropriate resources can be established through <u>***a number of sub-networks***</u>, of different and varying technologies

CURRENT SITUATION – BW MANAGEMENT

- WDM systems are capable of providing over 1 Tbps of bandwidth over a single fiber link
- Each channel capable of delivering dozens of Gbps
- While existing systems implement WDM point-to-point, with OEO conversion at each switching point
- Emerging systems will be capable of all optical switching



CURRENT SITUATION - LACK OF GRANULARITIES

- The limits of optical technology have, until now, locked carriers into offering fiber capacity in 2.5 or 10Gbps increments
- In addition, until now customers could not buy bandwidth to fill temporary or seasonal needs without being saddled with excess unused capacity during periods when it is not needed

CUSTOMERS vs. CARRIERS

- Backbone customers require flexibility, but

  Customers are forced to buy inflexible service packages that don't match what they need or want
  - they defer buying more capacity until the need is urgent
  - buy bandwidth in whatever beefy chunks the backbone carrier can offer based on the constraints of its optical technology, not in the increments nor for the times customers necessarily want

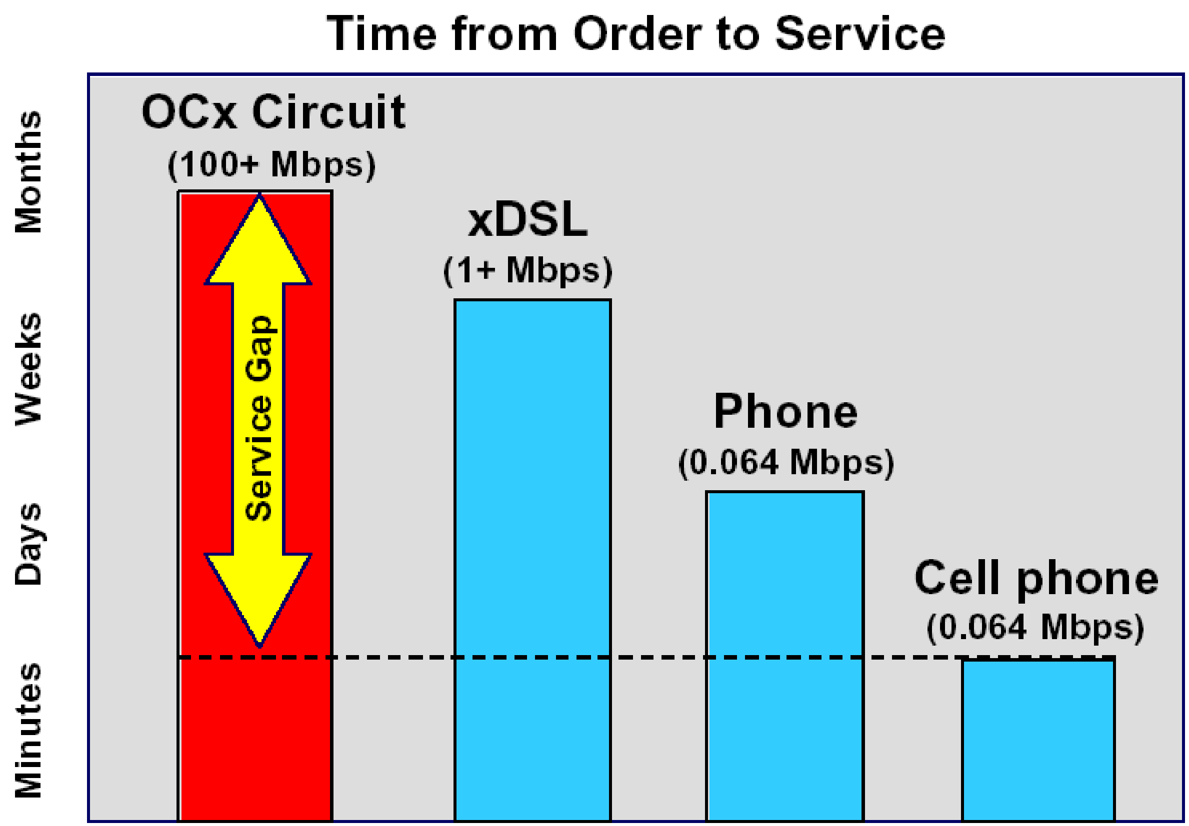
CURRENT SITUATION - LACK OF FLEXIBILITY

- Customers must endure long waits before their orders are fulfilled

  - requested BW cannot be provisioned effectively

  - delayed provisioning exacts a hefty toll in lost carrier revenues and eroded customer goodwill

AVERAGE PROVISIONING TIME

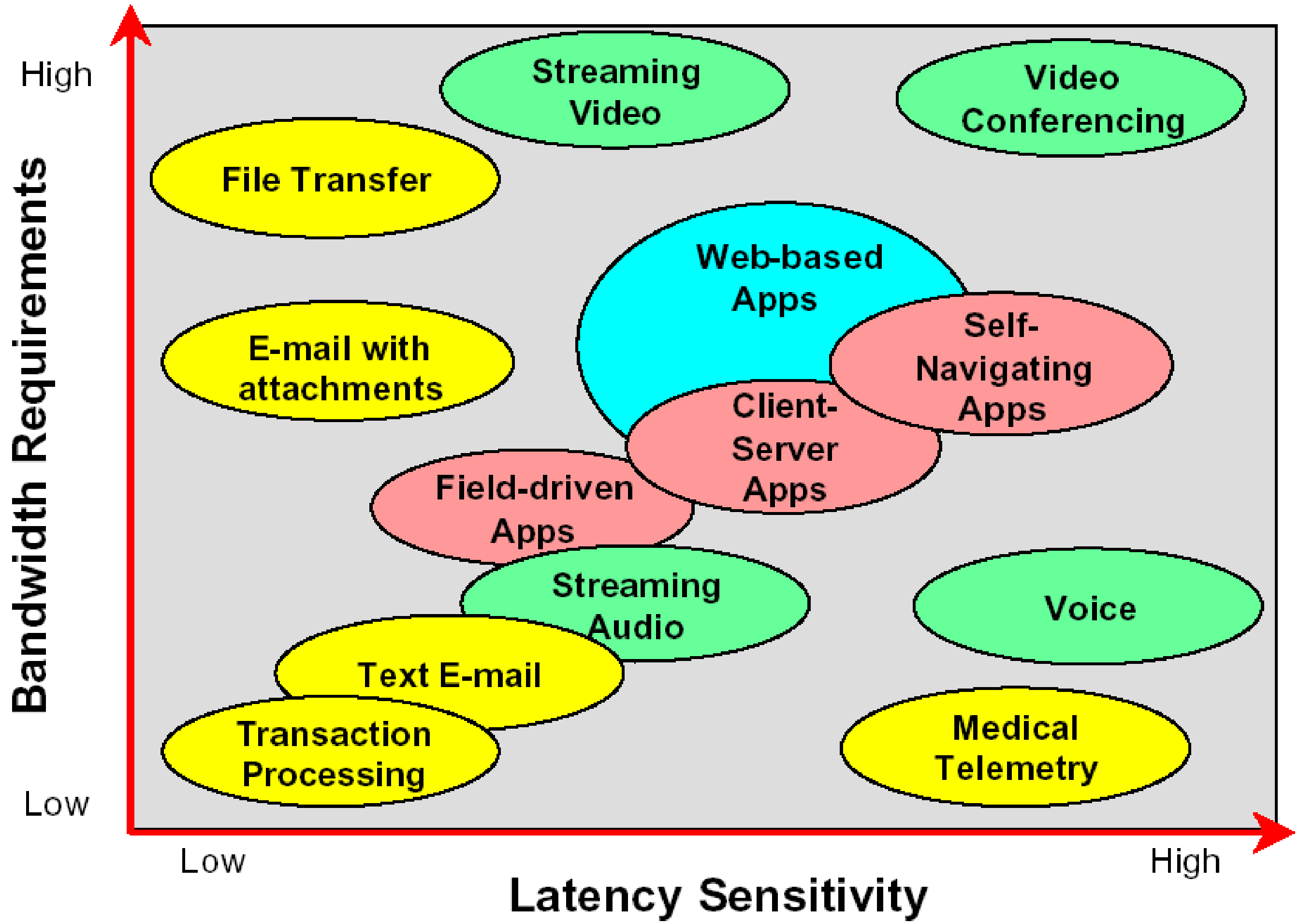


- From “The need for flexible Bandwidth in the Internet Backbone” by Peter Sevcik and Rebecca Wetzel, May 2001

CURRENT SITUATION - LACK OF DYNAMICITY

- **New Wide Range of Applications**
  - ever increasing number and variety of new applications which customers are running over backbone networks
  - each application requires different network bandwidth and network performance characteristics

NETWORK REQUIREMENTS BY APPLICATION



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OLD NETWORKING MODELS

- In recent memory

....when applications were few in number, applications were routinely paired with networks that had the attributes they needed to perform well

– E.g., there was the public switched telephone network for plain old telephone service, and there were satellite networks for TV

NEW - OPTICAL - NETWORKING MODELS

- These days, with new applications emerging daily, it is infeasible to build separate networks for different applications

- This means that ***single networks*** must support ***many applications*** with diverse and often competing requirements, to deliver services reflecting diverse business priorities, and to accommodate transient bandwidth needs,

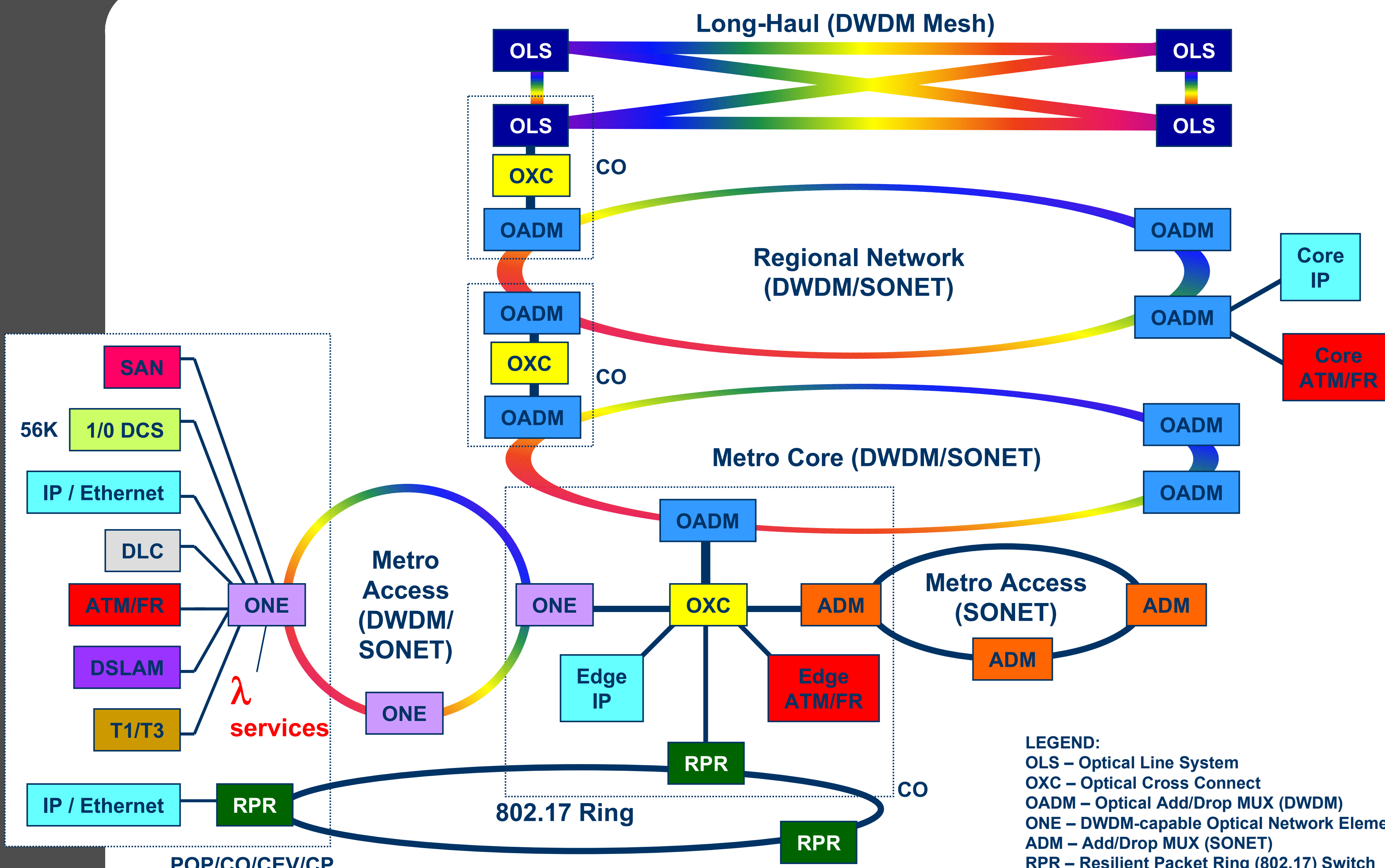
In the optical domain described above

MANAGEMENT IN THE OPTICAL DOMAIN

- Optical devices place new requirements on network management systems
- Switching functions must be performed and optical performance must be monitored
  - An optical switch cannot interrogate the contents of a packet or frame header in the optical domain, as an electronic switch can in the electronic domain
  - It is therefore, optical (bit stream) signals that an optical device switches, and not packet or frame streams
- Network management, therefore, must determine the switching patterns of optical switches
  - Occasionally, network management must also select settings for the secondary optical devices associated with an optical switch

OPTICAL TRANSPORT NETWORKS

DWDM MAKING INROADS INTO METRO CORE AND ACCESS



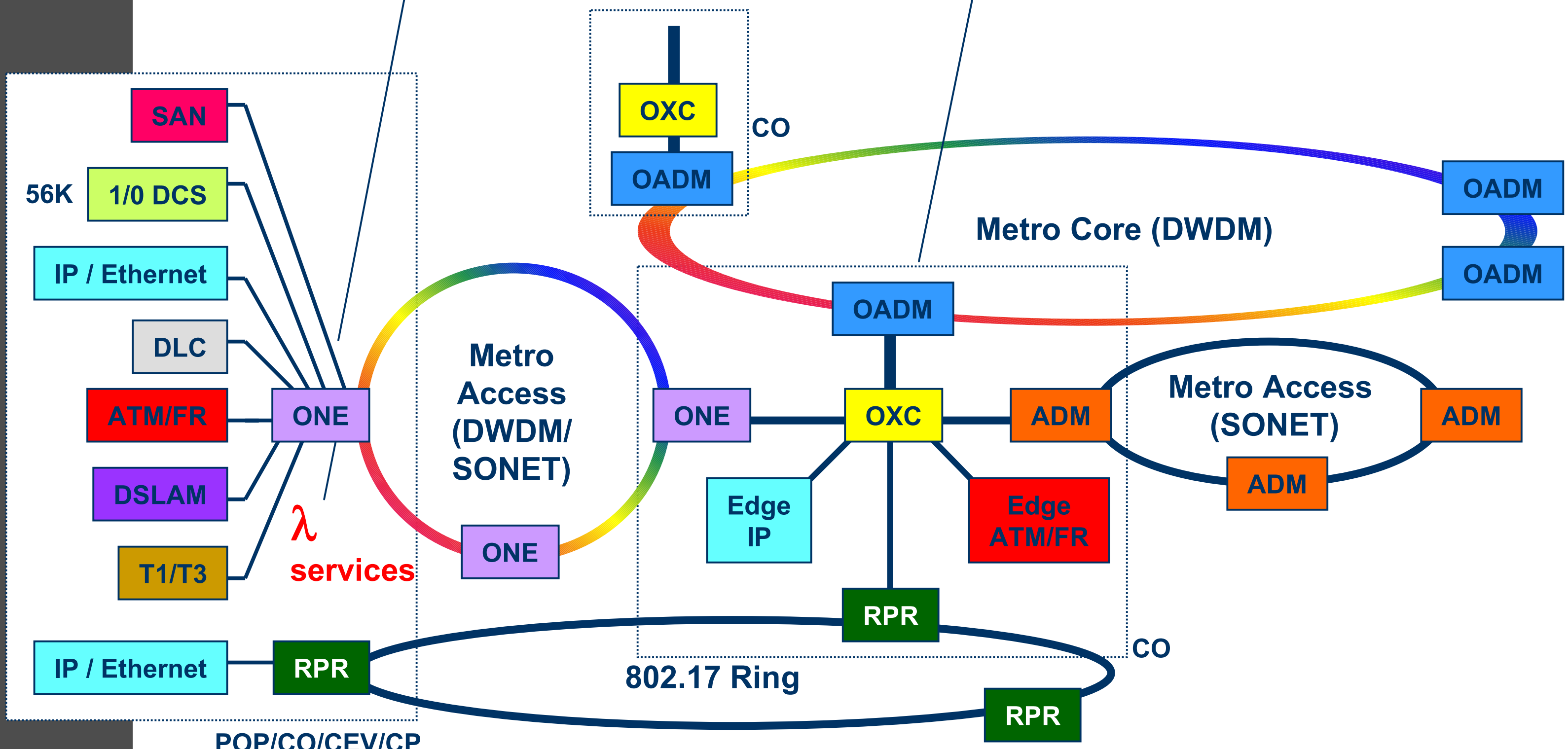
LEGEND:
OLS – Optical Line System
OXC – Optical Cross Connect
OADM – Optical Add/Drop MUX (DWDM)
ONE – DWDM-capable Optical Network Element
ADM – Add/Drop MUX (SONET)
RPR – Resilient Packet Ring (802.17) Switch
DLC – Digital Loop Carrier

NEED FOR BANDWIDTH PROVISIONING

METRO CORE AND METRO ACCESS NETWORKS

At the Metro Access:
- Multiple Service Types
- Variable BW Needs
- Emerging Applications
- Customer SLAs

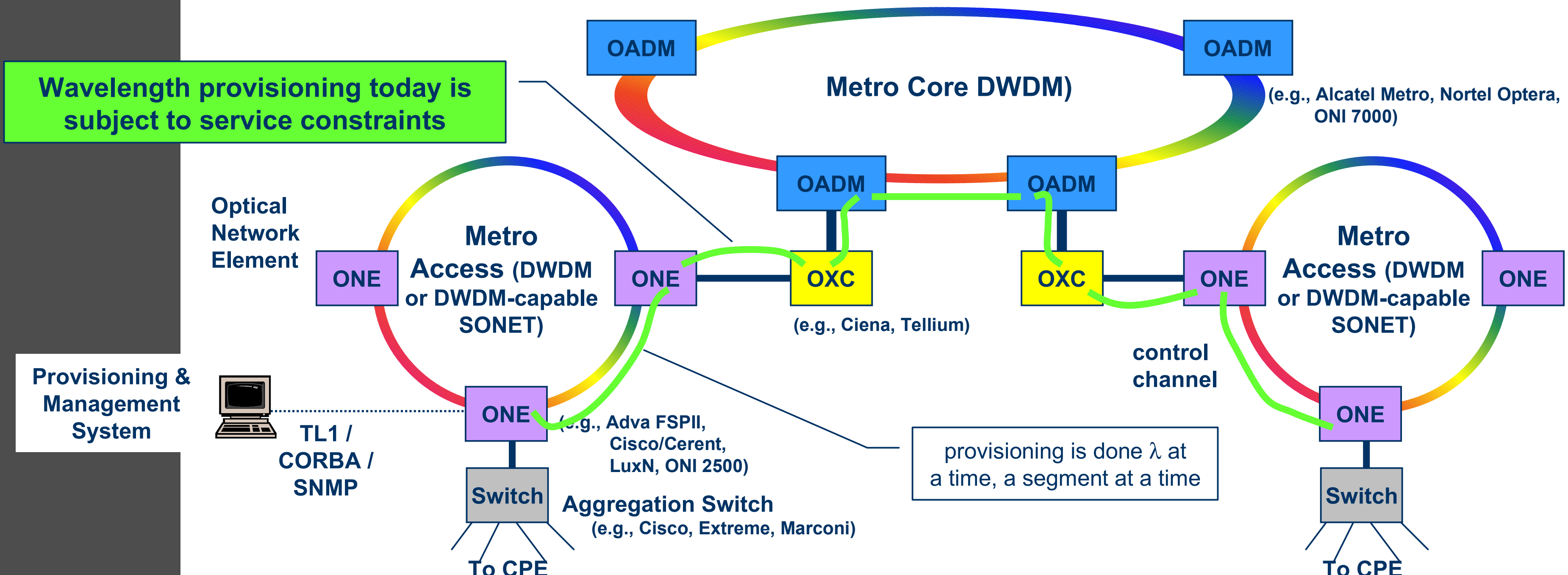
At the Metro Core:
- High Levels of Aggregation
- Need for Wavelength Efficiency
- Multiple Transport Technologies
- Inter-Carrier SLA Guarantees



WAVELENGTH PROVISIONING TODAY

SUBJECT TO CONSTRAINTS THAT LIMIT SERVICE FULFILLMENT

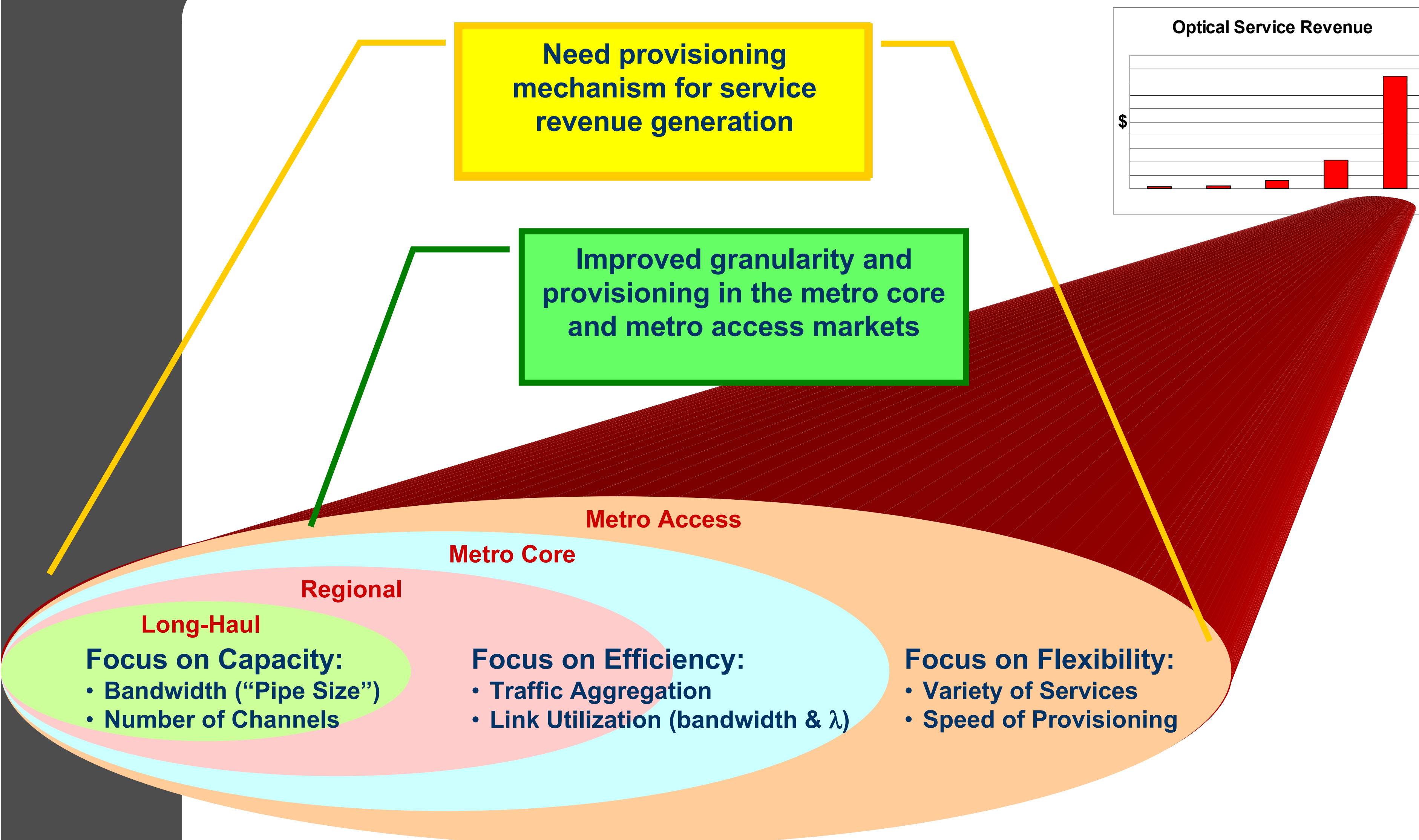
- Inability to deal with multivendor environments
- Incompatible vendor-specific provisioning that take hours or days
  - Segment-by-segment provisioning that require high levels of operator intervention
  - No support for bandwidth-on-demand network-wide customer provisioning
- Prevalence of wavelength collisions (fallout) and stranded BW



"PROVISIONING FOR MAXIMUM BENEFIT"

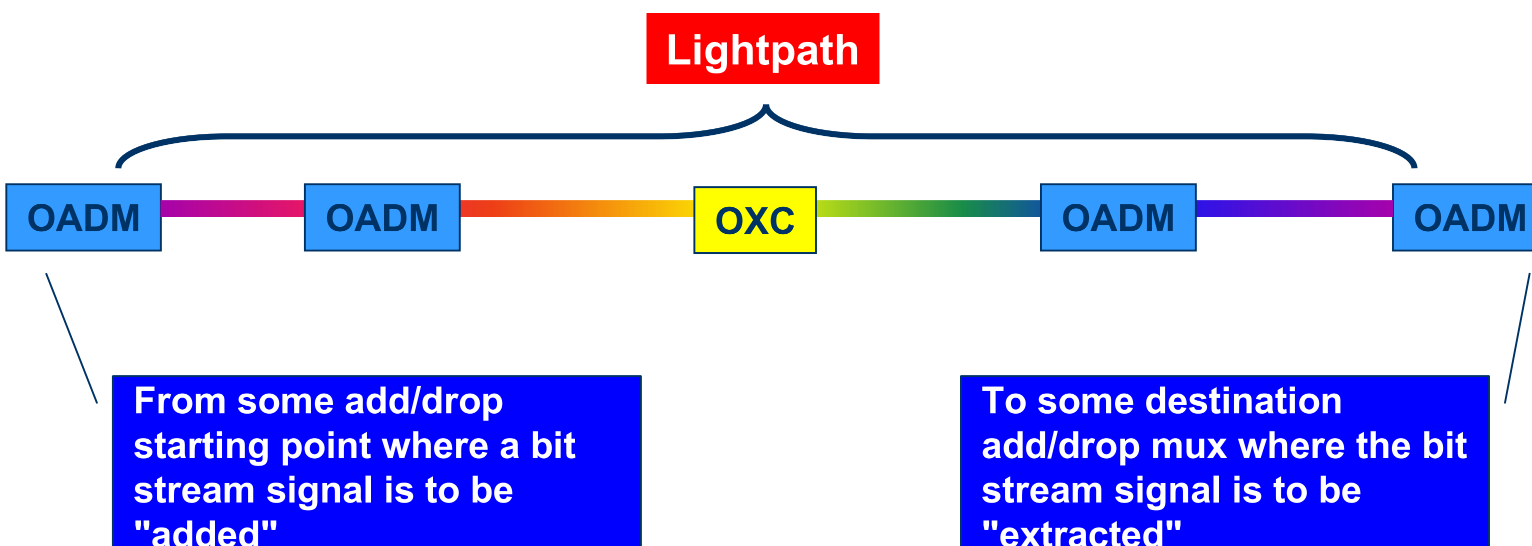
Higher Revenues	**Increases wavelength service revenue:** ● More revenues per wavelength due to: ✓More intelligent wavelength assignment for better efficiency ● New services including: ✓On-demand, real-time customer provisioning ✓Additional revenues through SLA managed services
Lower Network Capital Equipment Costs	**Reduces wavelength service delivery costs:** ● Less wavelengths needed per service/customer ● Universal provisioning platform for all network equipment
Lower Network Operations Costs	**Reduces costs required to manage network:** ● Better knowledge of resource availability network-wide ● Lower service / maintenance times due to automatic self-provisioning

NETWORK APPLICATION:



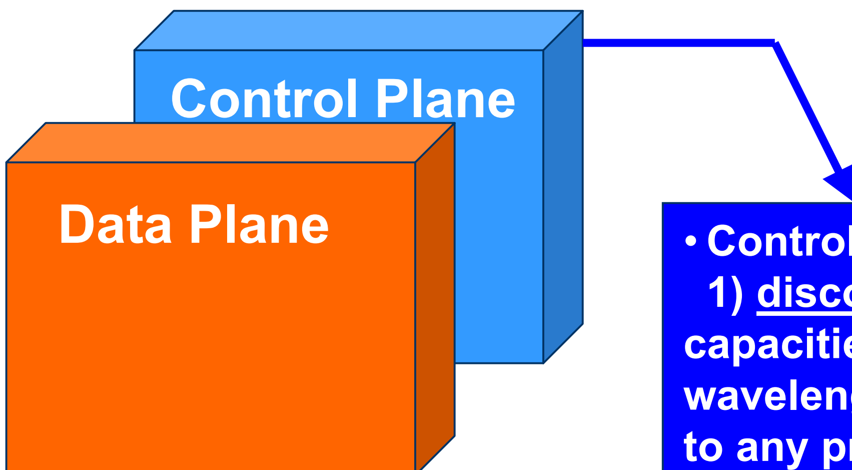
IN AN ALL-OPTICAL SUB-NETWORK

- Net management software imposes on a collection of switches:
  - Finding a fiber or wavelength path
    - In other publications, we and others have referred to these paths as ***lightpaths*** in order to distinguish these from LAN routed or SONET frame “paths”
  - Routing the traffic over the lightpath



NEXT GENERATION NETWORK MANAGEMENT GOALS

- **With our migration to optical and integrated networks, time, trial, and trouble, has taught us that we want networks in which the management is over a separate *control plane***



• Control Software Must:
1) discover what resources (links, link capacities, switches and switch ports, wavelengths, etc.) are available and useful to any provisioning request,
2) construct i.e., identify or compute the proper data stream path, observing any desirable constraints, and
3) manage path setup, path maintenance including restoration in the face of failure, and path termination.

POTENTIAL NEEDS/BENEFITS

- It is the automatic execution of the discover, construct, and manage tasks by the "control plane" of the network management hardware and software that (among other things):
  - allows for the introduction of new services, including those wherein the subscriber ultimately only pays for resources used,
  - reduces provisioning time from days to weeks, to minutes or milliseconds,
  - allows carriers to more fully use available network resources,
  - eliminates the detrimental effects of lost inventory (network resources),
  - allows fine tuning of network growth plans, as the control plane (almost as a byproduct of its essential tasks) monitors and reports the utilization of resources

PROTOCOLS FOR DYNAMIC BANDWIDTH MANAGEMENT IN OPTICAL DOMAIN

- In these all-optical networks, ***new protocols are needed to provision resources for lightpaths***.
  - When a connection request arrives to the network, a connection management protocol must
    - find a route and a wavelength for the lightpath,
    - provision the appropriate network resources for the lightpath.
  - As traffic becomes more **dynamic**, and as the rate of connection requests increases, automated provisioning methods will be required

PROTOCOLS FOR DYNAMIC LIGHTPATHS ESTABLISHMENTS AND MANAGEMENT

- **In order to establish lightpaths in a wavelength-routed network, algorithms and protocols must be developed to select routes and assign wavelengths to lightpath, as well as reserve network resources**

- **In the dynamic lightpath connections environment**

the *objective* of a lightpath management protocol is *to minimize the probability that a new connection request will be blocked*

RWA

- The problem of finding a route for a lightpath and assigning a wavelength to the lightpath is referred to as the ***routing and wavelength assignment problem*** (***RWA***)
  - the ***objective*** of the RWA problem is to route lightpaths and assign wavelengths in a manner which minimizes the amount of network resources that are consumed, while ensuring that no two lightpaths share the same wavelength on the same fiber link
  - in the absence of wavelength conversion, a lightpath must occupy the same wavelength on each link in its route known as the ***wavelength-continuity constraint***
- The optimal formulation of the RWA problem is known to be NP-complete; therefore, heuristic solutions are often employed.

EXISTING SOLUTIONS

- Since the first work on lightpath definition [1]
- a large number of lightpath establishment algorithms have been proposed, as surveyed in [2], [3] :

  - 1. I. Chlamtac, A. Ganz and, G. Karmi, "Purely Optical Networks for Terabit Communication," IEEE INFOCOM, 1989.
  - 2. H. Zang, J.P. Jue, and B. Mukherjee, "A Review of Routing and Wavelength Assignment Approaches for Wavelength-Routed Optical WDM Networks," SPIE/Kluwer Optical Networks Magazine, vol. 1, no. 1, pp. 47-60, Jan. 2000.
  - 3. G. Xiao, J. Jue and I. Chlamtac, "Lightpath Establishment in WDM Metropolitan Area Networks", SPIE/Kluwer Optical Networks Magazine, special issue on Metropolitan Area Networks, 2003.

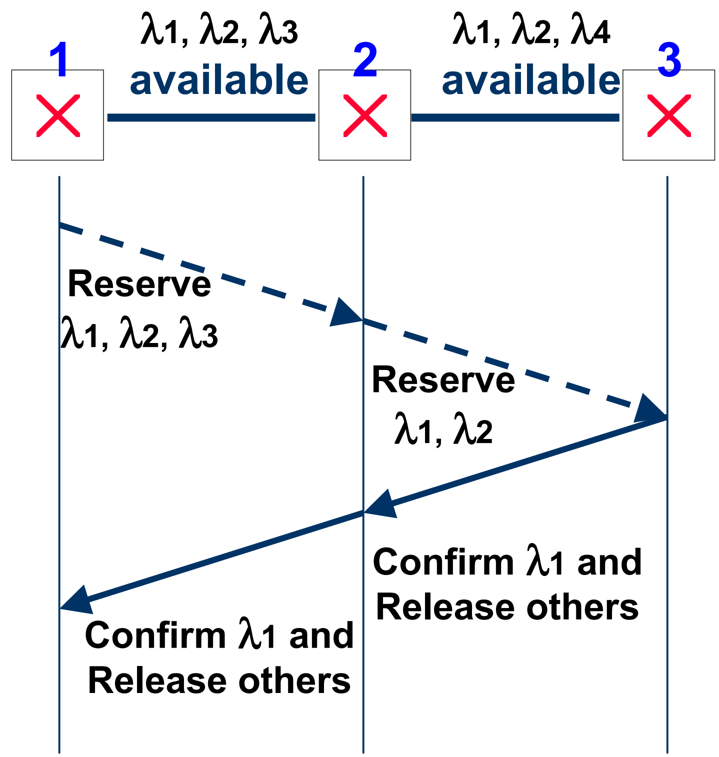
SIGNALING SCHEMES

- For a dynamic RWA execution leading to lightpath establishment
  - A provisioning protocol is required which based on information about current network conditions can select and reserve resources needed along the path
  - A signaling protocol is needed to collect and distribute the information for proper provisioning to occur

SIGNALING SCHEMES (CONTINUED)

- Existing provisioning approaches have typically been classified as:
  - *In Source-initiated reservation* (SIR) policies
    - wavelength resources are reserved as control message traverses the network along the forward path to the destination
  - *In Destination-initiated reservation* (DIR) policies
    - wavelength resources are reserved by a control message heading back towards the source node

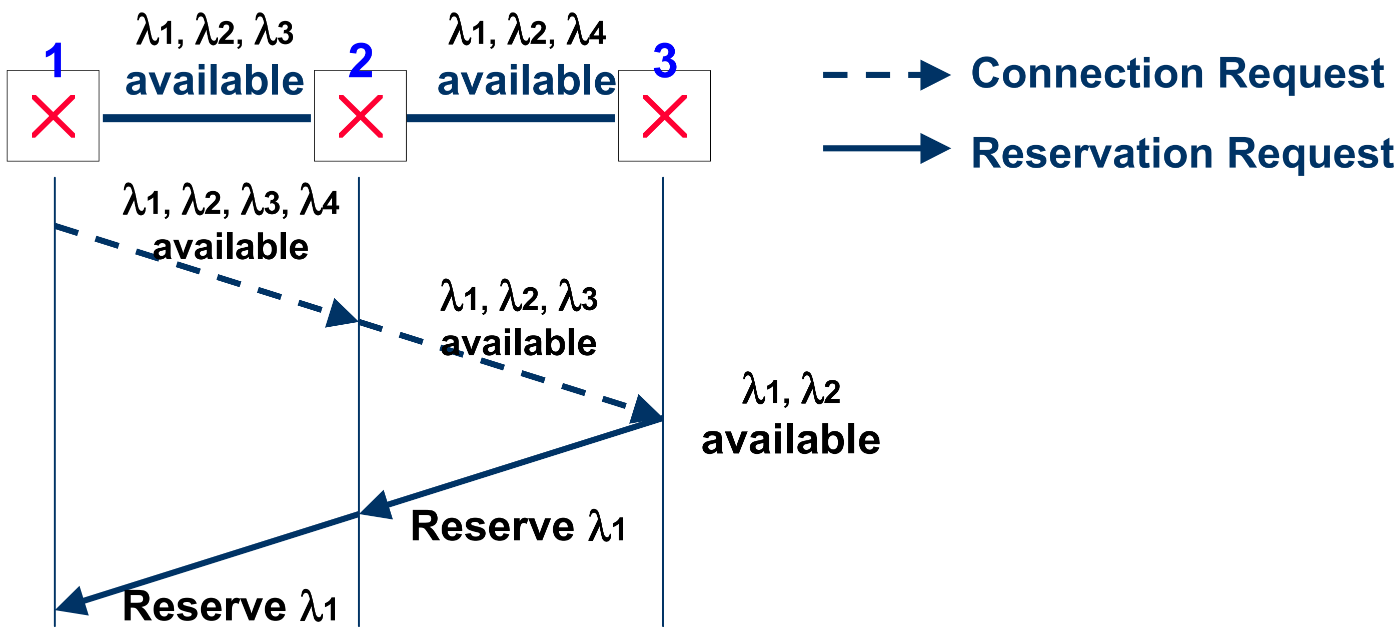
EXAMPLE OF SIR



DESTINATION-INITIATED RESERVATION

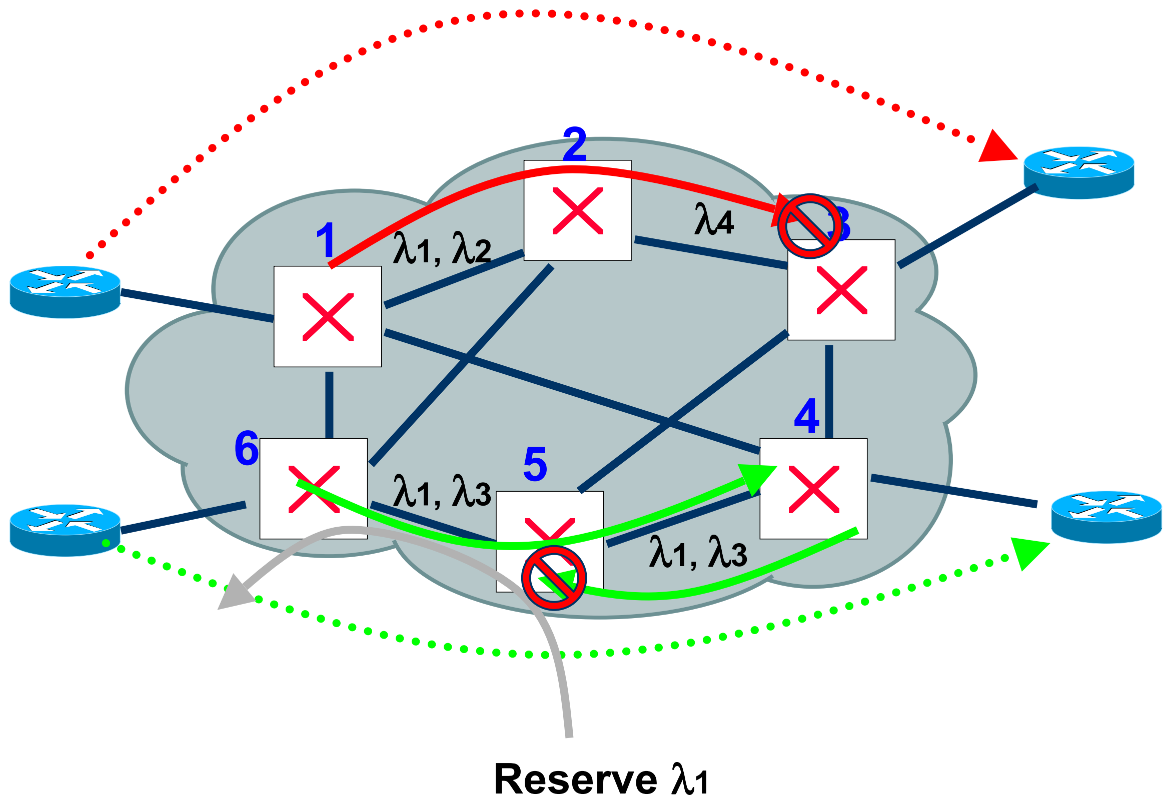
- In Destination-initiated reservation (DIR) reservations are initiated by the destination node, and executed in the backward direction
- PROBE message is sent from the source to the destination along the path
  - A set of wavelengths in the PROBE message may either be a single wavelength or multiple wavelengths depending on the information is available at the source node
- The provisioning scheme in the emerging GMPLS standard is an example of DIR

EXAMPLE OF DIR



BLOCKING IN DIR

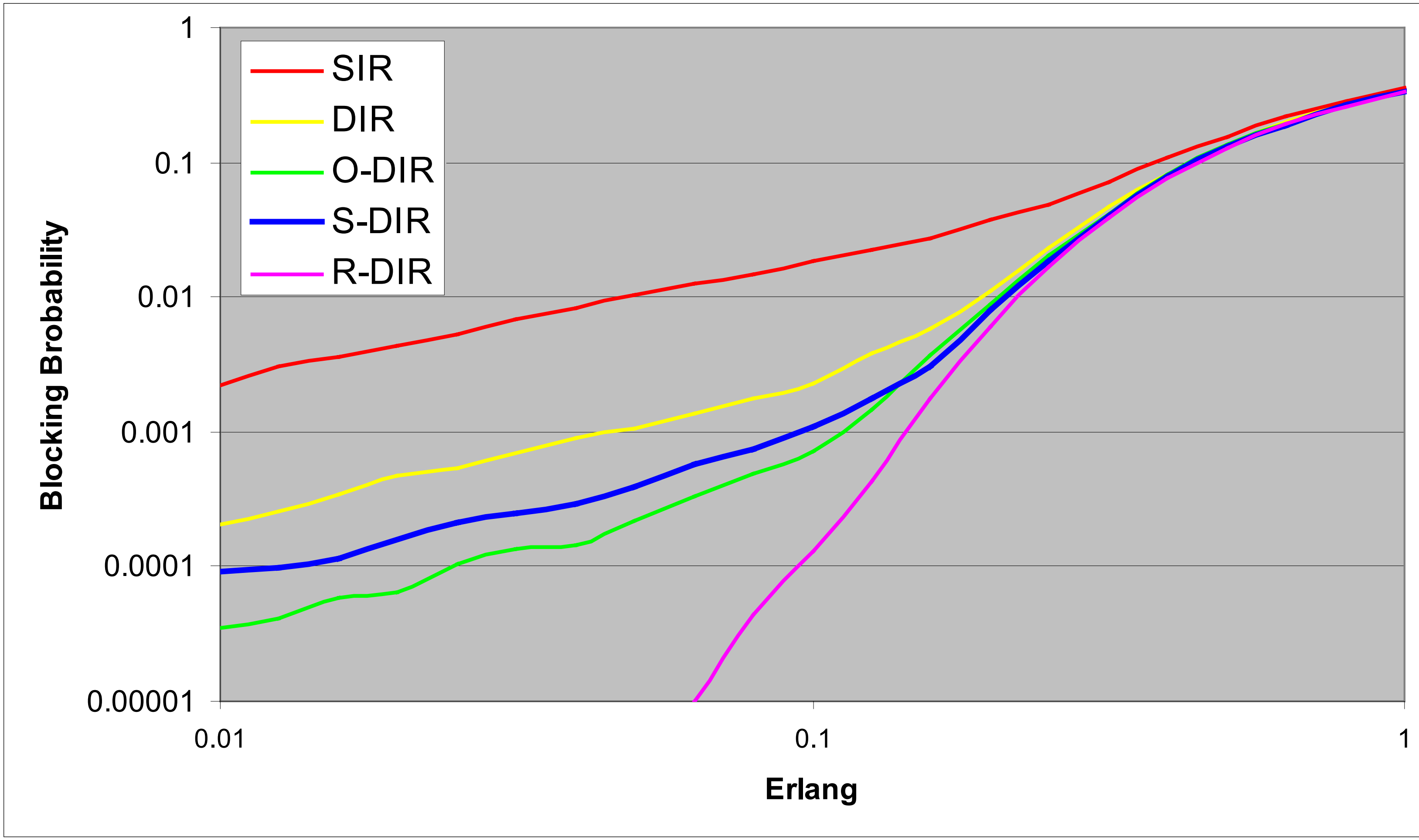
- Insufficient Resource
- Out-Dated Information



ENHANCED SCHEMES OF DIR

- O-DIR: Over-reservation
  – In the backward direction, reserve more than one wavelength
- S-DIR: Segmentation
  – Reservation can begin at any intermediate node
- R-DIR: Retry
  – Source node tries to reset up connection blocked in backward direction

PERFORMANCE COMPARISON



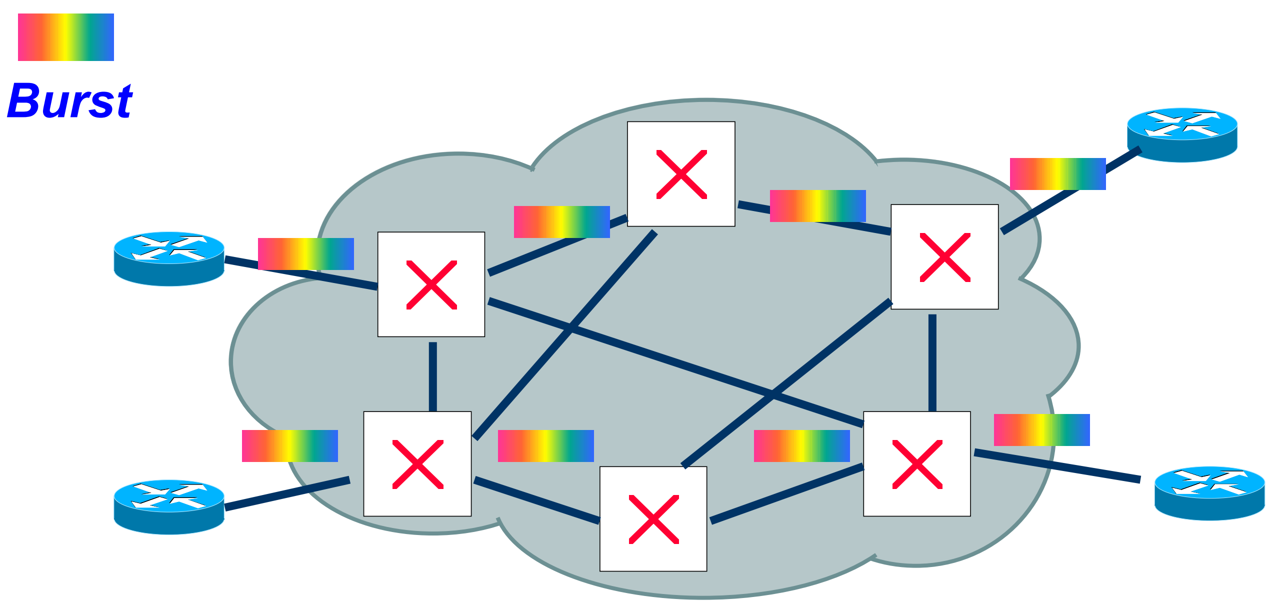
PERFORMANCE COMPARISON

- Observations:
  - If setup time is not critical, R-DIR will achieve best performance in terms of blocking probability
  - If setup time is critical, O-DIR will outperform others when traffic is light
- Note: Different schemes can be combined with each
  - S-DIR has better performance than O-DIR under heavy traffic

CAN GMPLS SURVIVE PAST THE OPTICAL WINTER?

Some claim that,

- In long term, in particular second half of this decade GMPLS can become the signaling cornerstone of on demand, optical bandwidth provisioning, ultimately
- Evolving into an effective optical burst switching mechanism



Optical Burst Switching Network

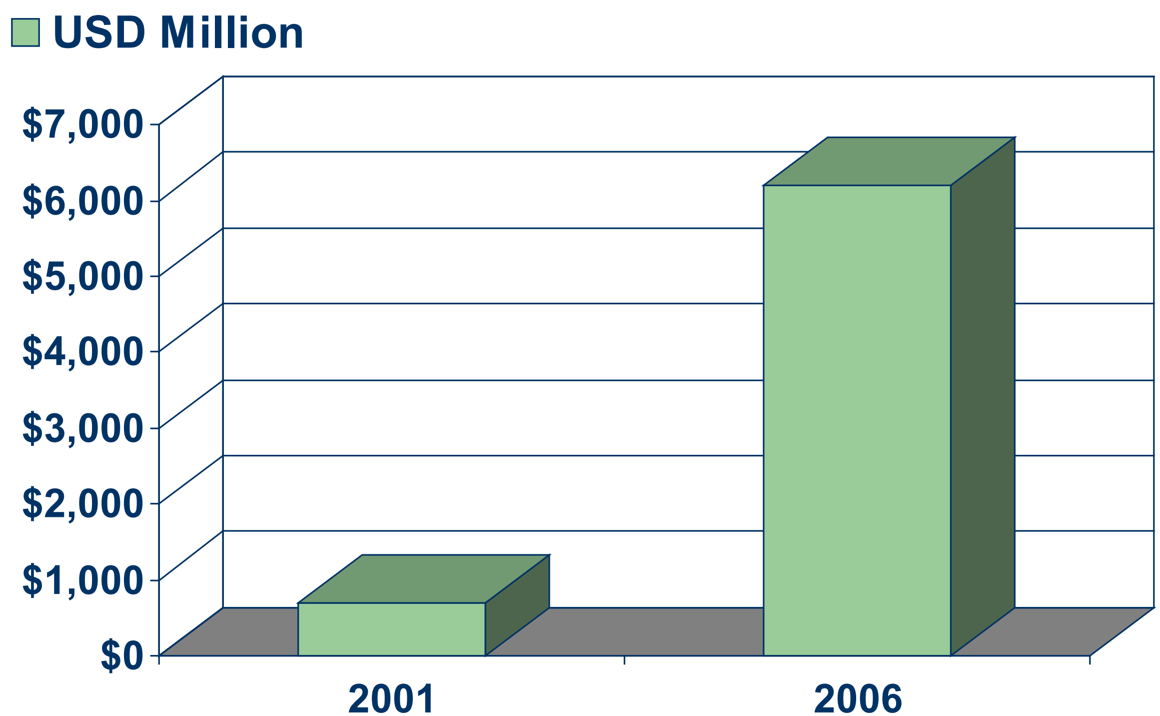
BUT, SHORTER TERM PROSPECTS?

- Over the first half of this decade GMPLS is expected to become the mainstay for wavelength services
- "Advancement in DWDM and optical switch technologies and an ever-growing need for cost-effective bandwidth transmission are fueling interest in the wavelength services market"
  - from *Pioneer Consulting LLC* (Boston, MA)
- "The growing use of wavelength services would appear to be inevitable given the need for a more cost-effective use of bandwidth, technological advances in DWDM and optical switching technologies, and a growing list of applications that stand to benefit from the leasing of lambdas,"
  - Paul Kellett, senior optical markets analyst

REVENUE POTENTIAL

- In the short term, wavelength services will remain a primarily long-haul service offering
- as DWDM further penetrates the metro segment, the opportunity for wavelength services will increase in the metro as well.
- "*Gigabit Ethernet* and *SAN* [Storage Area Networking] services will stimulate demand for leasing bandwidth" (Source: Jason Marcheck, senior market analyst, 2002)
  - *Metro wavelength services* revenues are expected to grow from $183 million in 2001 to more than $2.9 billion by the end of 2006
  - *Global long-haul wavelength service* revenues are predicted to increase from $439 million in 2001 to more than $3.3 billion by 2006

GLOBAL W-SERVICES MARKET



- Expected to net $6.2 billion by 2006

WE EXPECT, AS PART OF: EMERGING OPTICAL NETWORK MANAGEMENT…

- Automated on-demand provisioning for providing DWDM network resources to be a key element for the success, if not the survival, of operators and providers
- It is believed that dynamic on-demand wavelength provisioning services will enable service providers to respond quickly and economically to customer demands.
- Provide the ability to dynamically allocate additional bandwidth by simply lighting up another wavelength when needed, and releasing the (stranded) wavelength when it is no longer needed
- Lead to significantly higher operational margins while, eventual

AND, IN CONCLUSION…

We view

An optical network bandwidth management suite which provides automated provisioning system for all-optical networks an opportunity to control the future world of DWDM networking,

And, therefore, not surprisingly, we believe that the question for most carriers is not whether to migrate to end to end all-optical networks, but when…