Optical Networking: Recent Developments, Issues, and Trends

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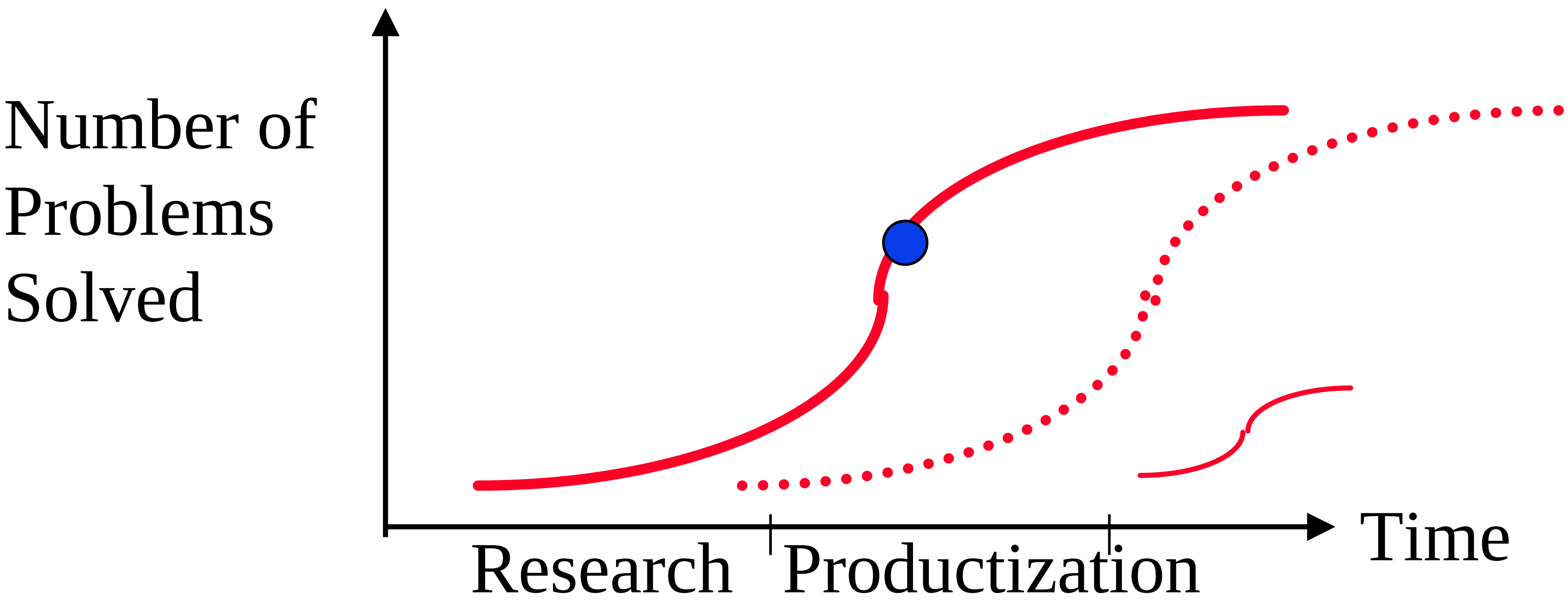
These slides are available on-line at:

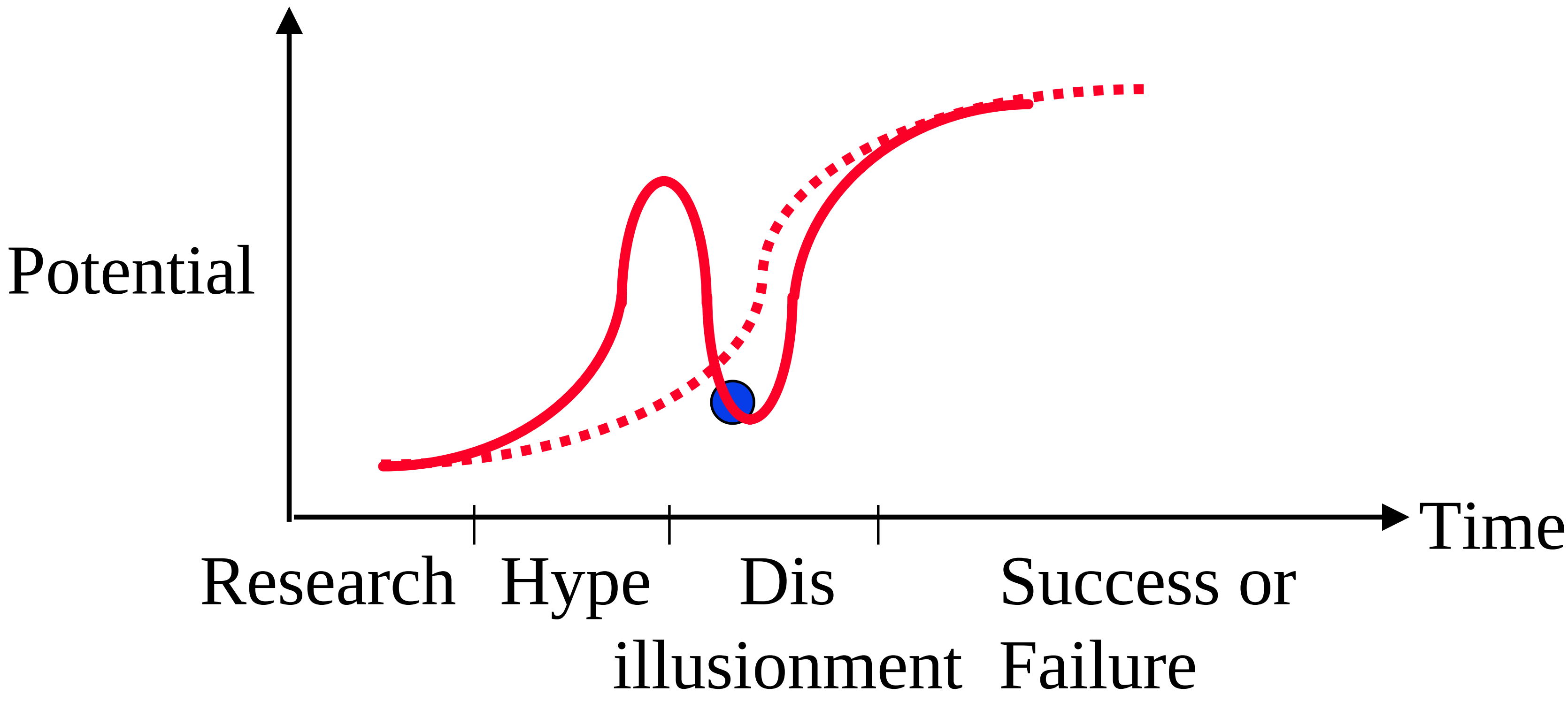
http://www.cis.ohio-state.edu/~jain/talks/opt_wpr.htm

1. Trends in Networking
2. Core Network Issues: DWDM, OEO VS OOO
3. Metro Network Issues: Next Gen SONET vs Ethernet with RPR
4. Access Networks Issues: Passive optical networks
5. IP Control Plane: MPLS, GMPLS

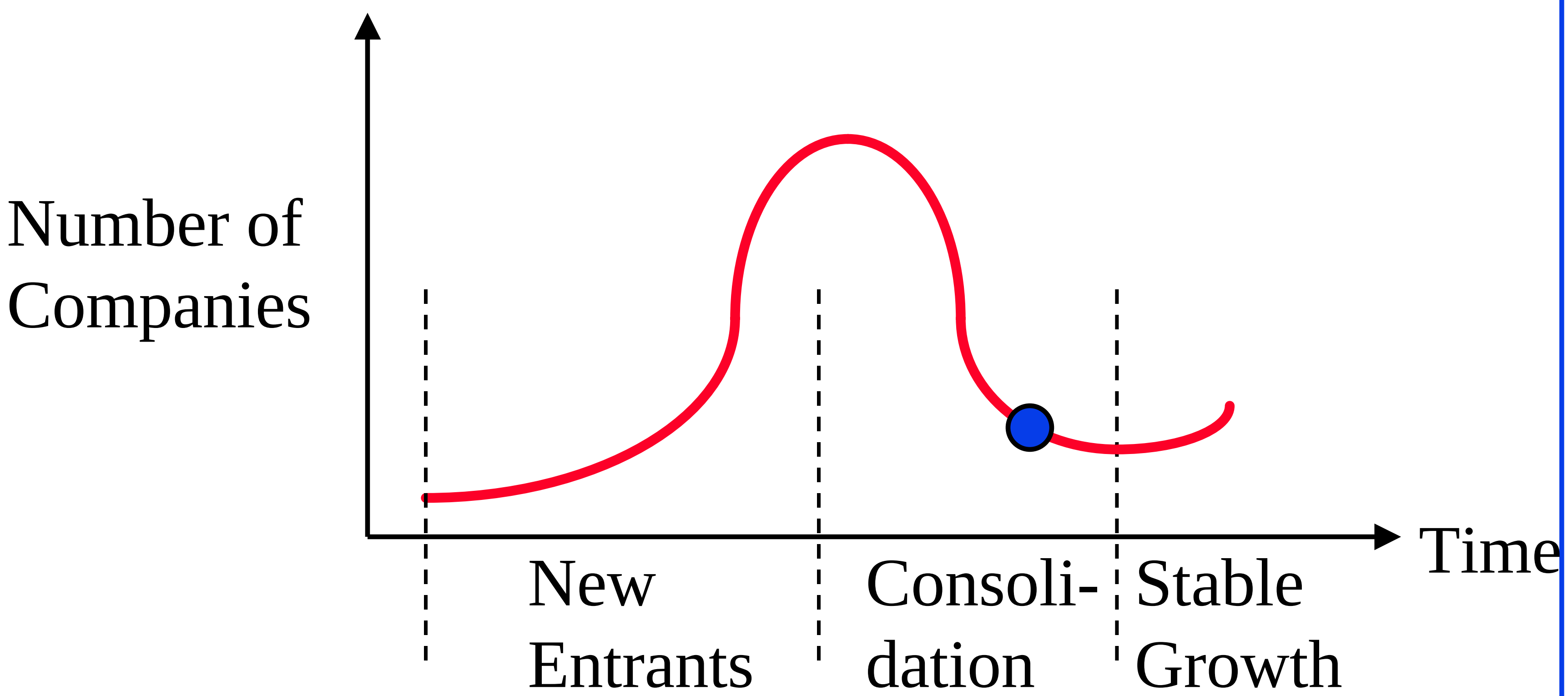
Life Cycles of Technologies



Hype Cycles of Technologies



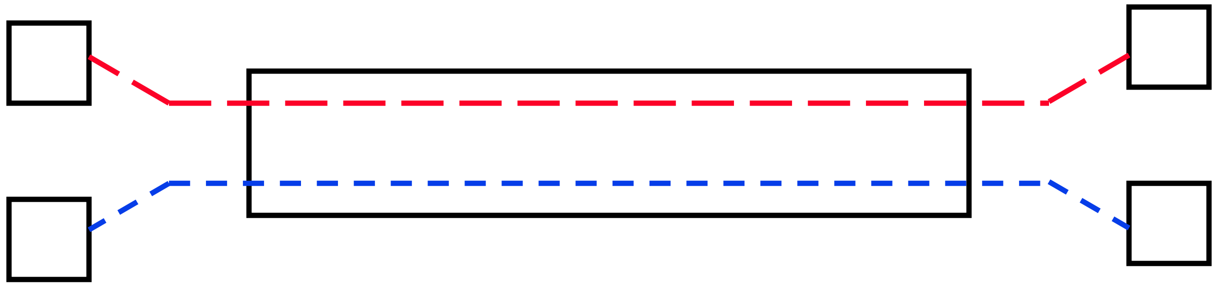
Industry Growth



Trend: Back to ILECs

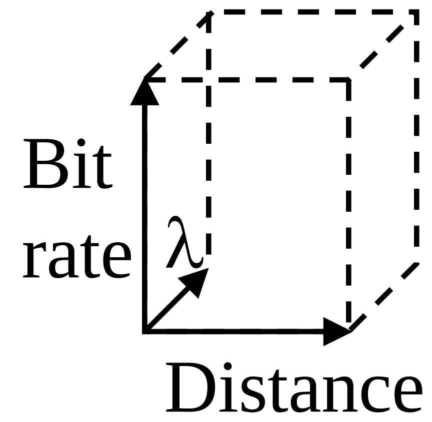
1. CLECs to ILECs
   ILEC: Slow, steady, predictable.
   CLEC: Aggressive, Need to build up fast
   New networks with newest technology
   No legacy issues
2. Back to Voice
   CLECs wanted to *start* with data
   ILECs want to *migrate* to data
   ⇒ Equipment that support voice circuits but allow packet based (hybrids) are more important than those that allow only packet based

Sparse and Dense WDM



- 10Mbps Ethernet (10Base-F) uses 850 nm
- 100 Mbps Ethernet (100Base-FX) + FDDI use 1310 nm
- Some telecommunication lines use 1550 nm
- WDM: 850nm + 1310nm or 1310nm + 1550nm
- Dense ⇒ Closely spaced ≈ 0.1 - 2 nm separation
- Coarse = 2 to 25 nm = 4 to 12 λ's
- Wide = Different Wavebands

Recent DWDM Records



- 32λ× 5 Gbps to 9300 km (1998)
- 16λ× 10 Gbps to 6000 km (NTT'96)
- 160λ× 20 Gbps (NEC'00)
- 128λ× 40 Gbps to 300 km (Alcatel'00)
- 64λ× 40 Gbps to 4000 km (Lucent'02)
- 19λ× 160 Gbps (NTT'99)
- 7λ× 200 Gbps (NTT'97)
- 1λ×1200 Gbps to 70 km using TDM (NTT'00)
- 1022 Wavelengths on one fiber (Lucent'99)

Potential: 58 THz = 50 Tbps on 10,000 λ's

Ref: IEEE J. on Selected Topics in Quantum Electronics, 11/2000.

Core Optical Networks

- Higher Speed: 10 Gbps to 40 Gbps
- Longer Distances: 600 km to 6000 km
- More Wavelengths: 16 λ's to 160 λ's
- All-optical Switching: OOO vs OEO Switching

Optical Transport Products

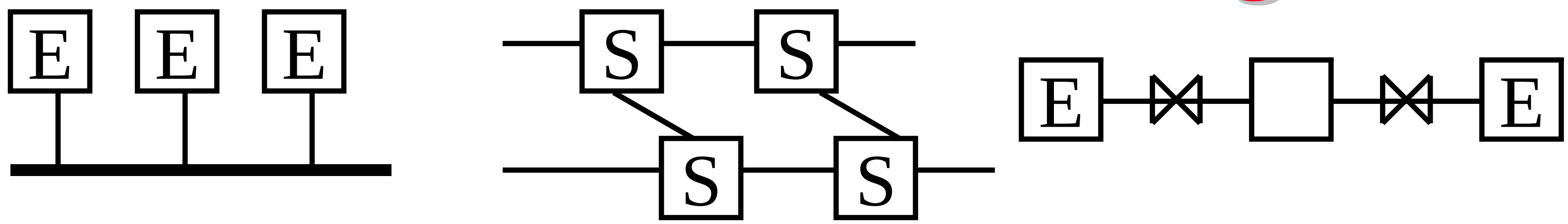
Product	λ's	Gb/s	km	Avail-ability
Siemens/Optisphere TransXpress	80	40	250	2001
	160	10	250	2001
Alcatel 1640 OADM	160	2.5	2300	2001
	80	10	330	2001
Corvis Optical Network Gateway	160	2.5	3200	2000
	40	10	3200	2000
Ciena Multiwave CoreStream	160	10	1600	2001
Nortel Optera LH4000	56	10	4000	2000
Optera LH 5000	104	40	1200	2002
Sycamore SN10000	160	10	800	2001
	40	10	4000	2001
Cisco ONS 15800	160	10	2000	2002

- Ref: "Ultra everything," Telephony, October 16, 2000

OEO vs OOO Switches

- OEO:
  - Requires knowing data rate and format, e.g., 10 Gbps SONET
  - Can multiplex lower rate signals
  - Cost/space/power increases linearly with data rate
- OOO:
  - Data rate and format independent
    $\Rightarrow$ Data rate easily upgraded
  - Sub-wavelength mux/demux difficult
  - Cost/space/power relatively independent of rate
  - Can switch multiple ckts per port (waveband)
  - Issues: Wavelength conversion, monitoring

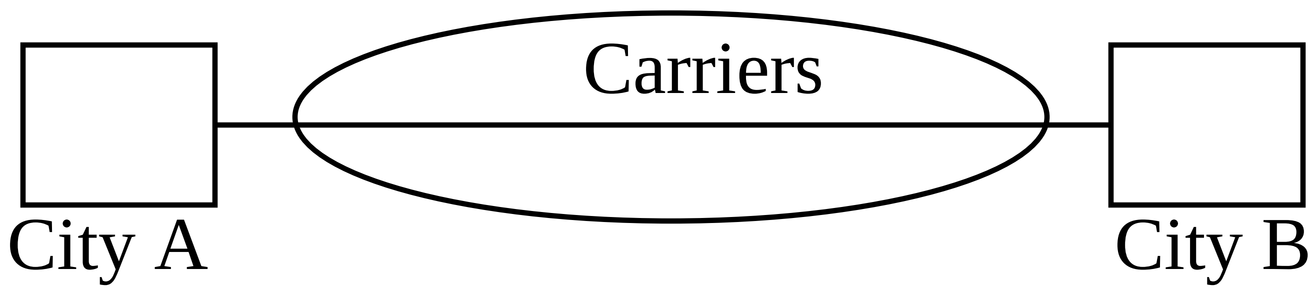
Trend: LAN - WAN Convergence



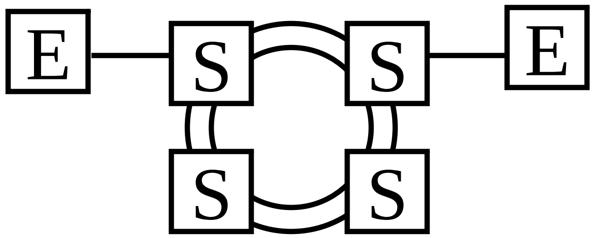
- Past: Shared media in LANs. Point to point in WANs.
- Future: No media sharing by multiple stations
  - Point-to-point links in LAN and WAN
  - No distance limitations due to MAC. Only Phy.
  - Datalink protocols limited to frame formats
- 10 GbE over 40 km without repeaters
- Ethernet End-to-end.
- Ethernet carrier access service:$1000/mo 100Mbps

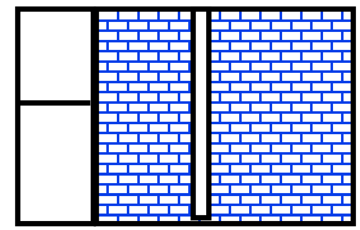
SONET

- Synchronous optical network
- Standard for digital optical transmission (bit pipe)
- Developed originally by Bellcore to allow mid-span meet between carriers: MCI and AT&T. Standardized by ANSI and then by ITU
  $\Rightarrow$ Synchronous Digital Hierarchy (SDH)
- You can lease a SONET connection from carriers



SONET Functions





- Protection: Allows redundant Line or paths
- Fast Restoration: 50ms using rings
- Sophisticated OAM&P
- Ideal for Voice: No queues. Guaranteed delay
- Fixed Payload Rates: 51M, 155M, 622M, 2.4G, 9.5G
  Rates do not match data rates of 10M, 100M, 1G, 10G
- Static rates not suitable for bursty traffic
- One Payload per Stream
- High Cost

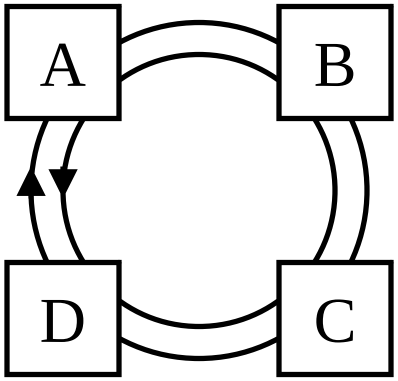
SONET vs Ethernet

Feature	SONET	Ethernet
Payload Rates	51M, 155M, 622M, 2.4G, 9.5G	10M, 100M, 1G, 10G
Payload Rate Granularity	Fixed	√Any
Bursty Payload	No	√Yes
Payload Count	One	√Multiple
Protection	√Ring	Mesh
OAM&P	√Yes	No
Synchronous Traffic	√Yes	No
Restoration	√50 ms	Minutes
Cost	High	√Low
Used in	Telecom	Enterprise

SONET vs Ethernet: Remedies

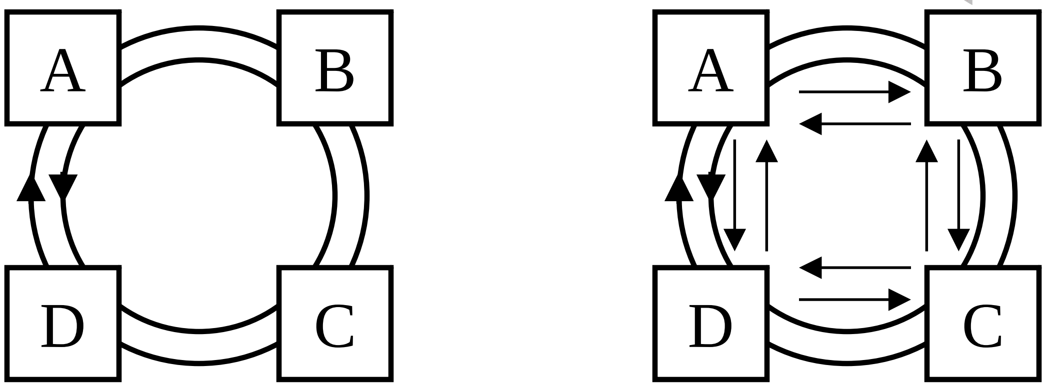
Feature	SONET	Ethernet	Remedy
Payload Rates	51M, 155M, 622M, 2.4G, 9.5G	10M, 100M, 1G, 10G	10GE at 9.5G
Payload Rate Granularity	Fixed	√Any	Virtual Concatenation
Bursty Payload	No	√Yes	Link Capacity Adjustment Scheme
Payload Count	One	√Multiple	Packet GFP
Protection	√Ring	Mesh	Resilient Packet Ring (RPR)
OAM&P	√Yes	No	In RPR
Synchronous Traffic	√Yes	No	MPLS + RPR
Restoration	√50 ms	Minutes	Rapid Spanning Tree
Cost	High	√Low	Converging
Used in	Telecom	Enterprise	

RPR: Key Features



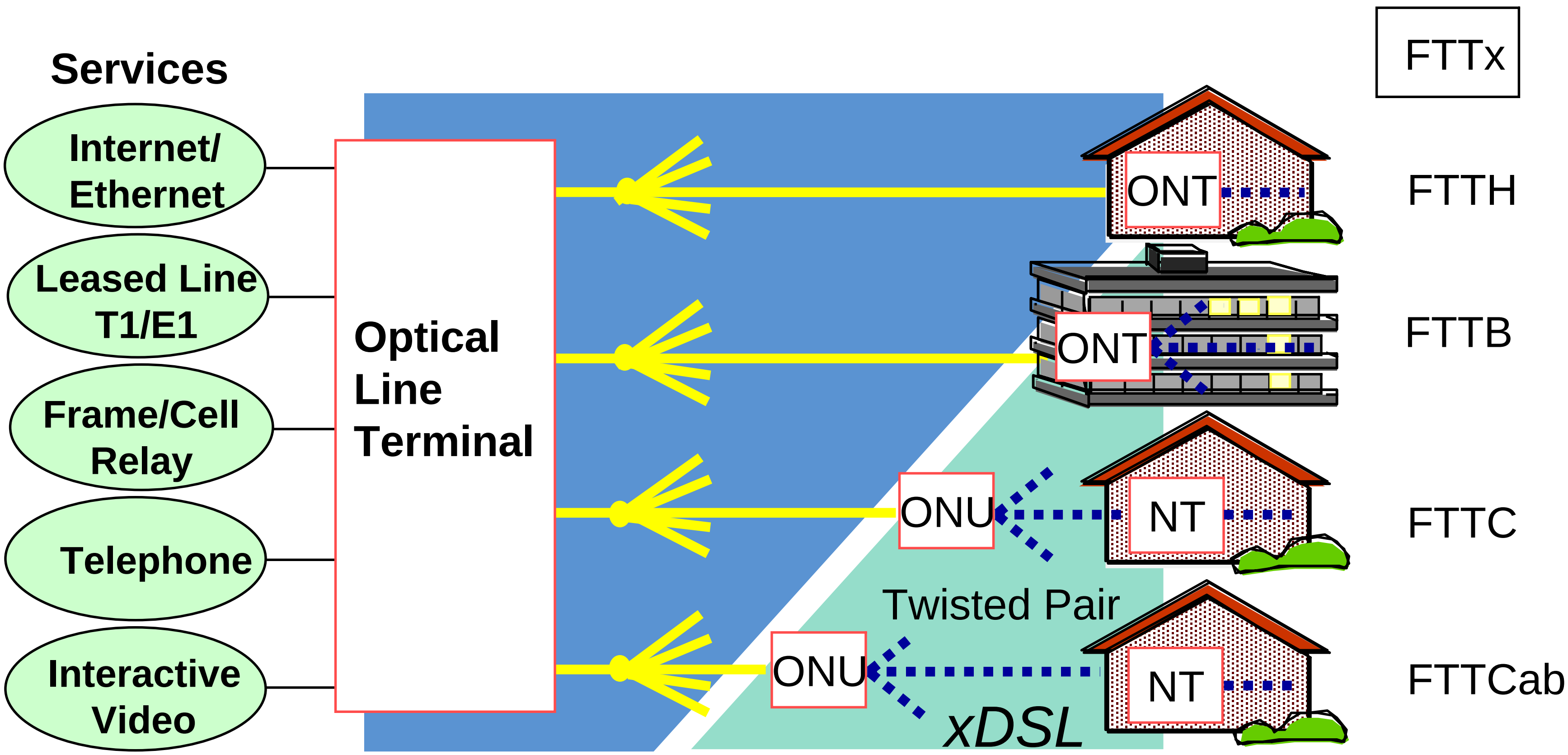
- Dual Ring topology
- Supports broadcast and multicast
- Packet based ⇒ Continuous bandwidth granularity
- Max 256 nodes per ring
- MAN distances: Several hundred kilometers.
- Gbps speeds: Up to 10 Gbps

RPR Features (Cont)



- Both rings are used (unlike SONET)
- Normal transmission on the shortest path
- Destination stripping ⇒ Spatial reuse
  Multicast packets are source stripped
- Several Classes of traffic: A0, A1, B-CIR, B-EIR, C
- Too many features and alternatives too soon

Access: Fiber To The X(FTTx)



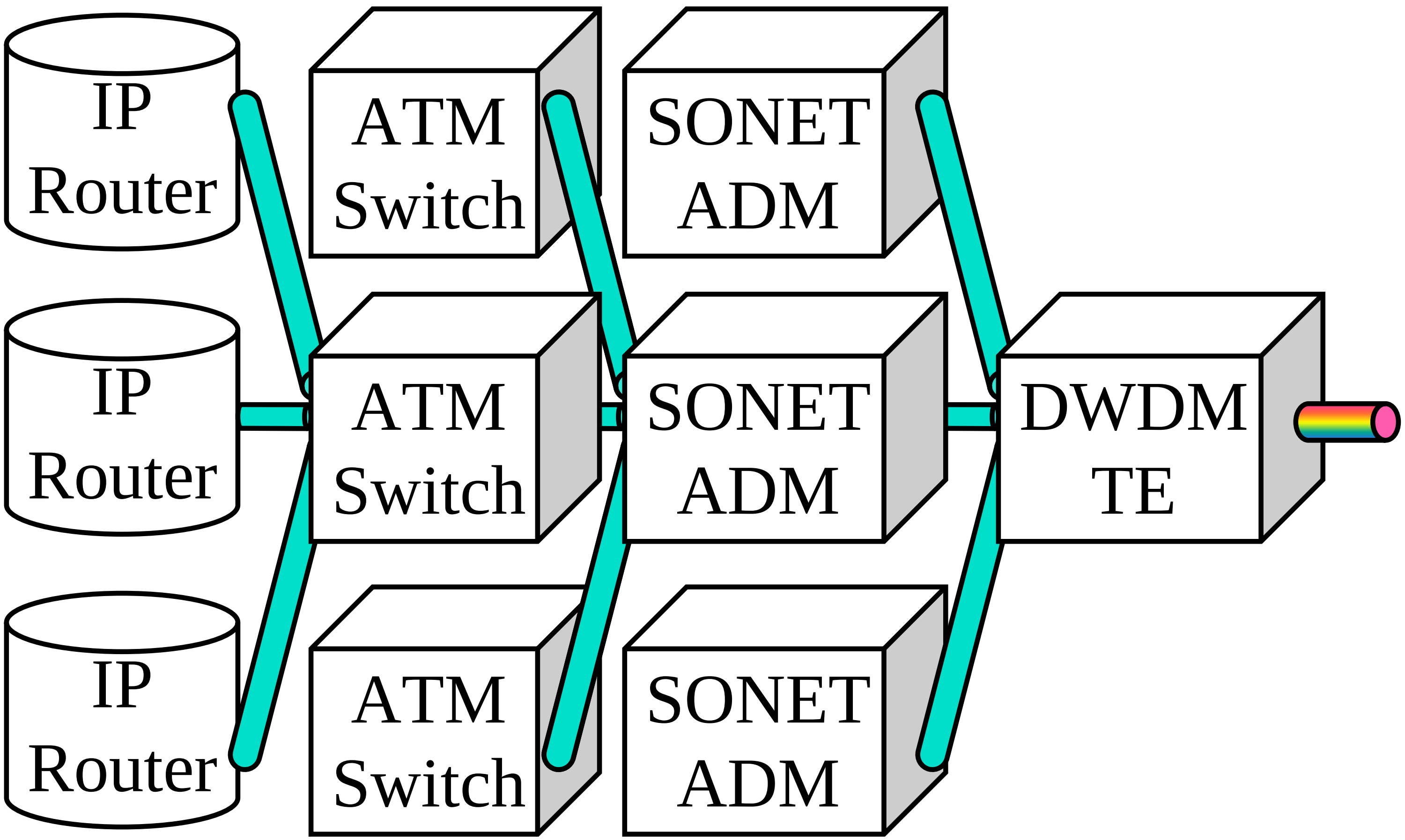
FTTH :Fiber To The Home
FTTB :Fiber To The Building
FTTC:Fiber To The Curb
FTTCab :Fiber To The Cabinet

Why PONs?

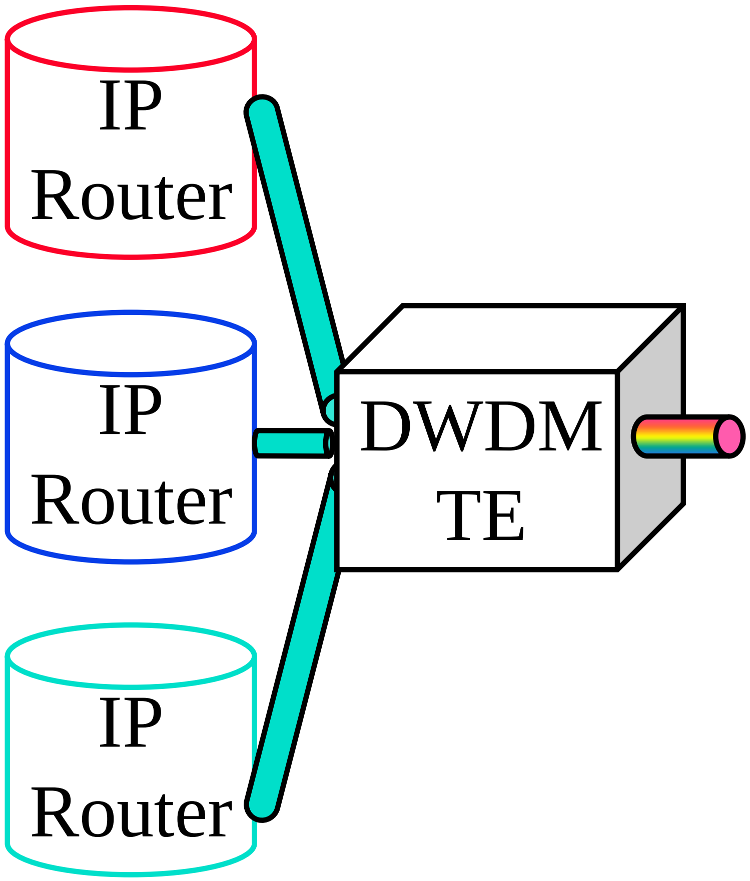
1. Passive ⇒ No active electronics or regenerators in distribution network ⇒ Very reliable. Easy to maintain. Reduced truck rolls. Shorter installation times. Reduced power expences.
   ⇒ Lower OpEx.
2. Single fiber for bi-directional communication
   ⇒ Reduced cabling and plant cost ⇒ Lower CapEx
3. A single fiber is shared among 16 to 64 customers
   ⇒ Relieves fiber congestion
4. Single CO equipment is shared among 16 to 64 customers
   2N fibers + 2N transceivers vs 1 fiber + (N+1) transceivers
   ⇒ Significantly lower CapEx.
5. Scalable ⇒ New customers can be added. Exisiting Customer bandwidth can be changed
6. Multi-service: Voice, T1/E1, SONET/SDH, ATM, Video, Ethernet. Most pt-pt networks are single service.

Useful if customers are clustered ⇒ Asia (Korea, China)

IP over DWDM (Past)

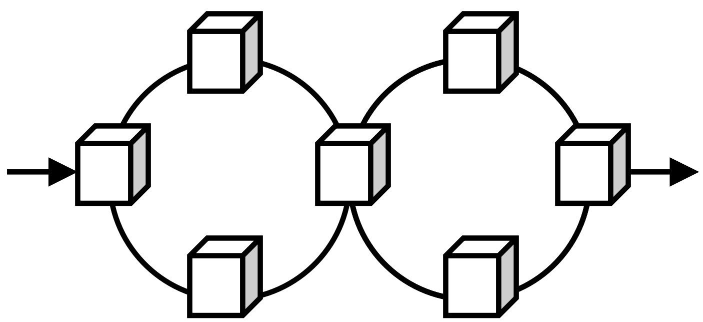


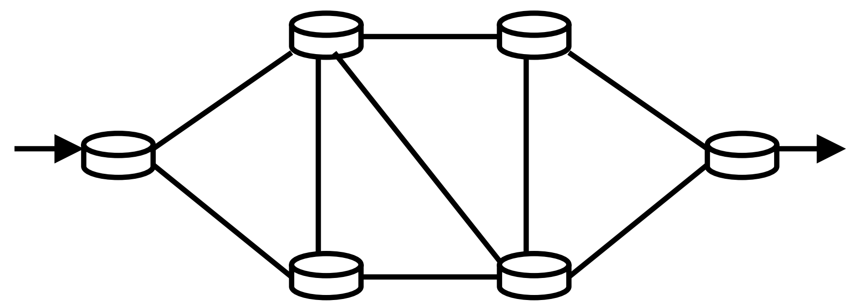
IP over DWDM (Future)



Telecom vs Data Networks

	Telecom Networks	Data Networks
Topology Discovery	Manual	Automatic
Path Determination	Manual	Automatic
Circuit Provisioning	Manual	No Circuits
Transport & Control Planes	Separate	Mixed
User and Provider Trust	No	Yes
Protection	Static using Rings	No Protection



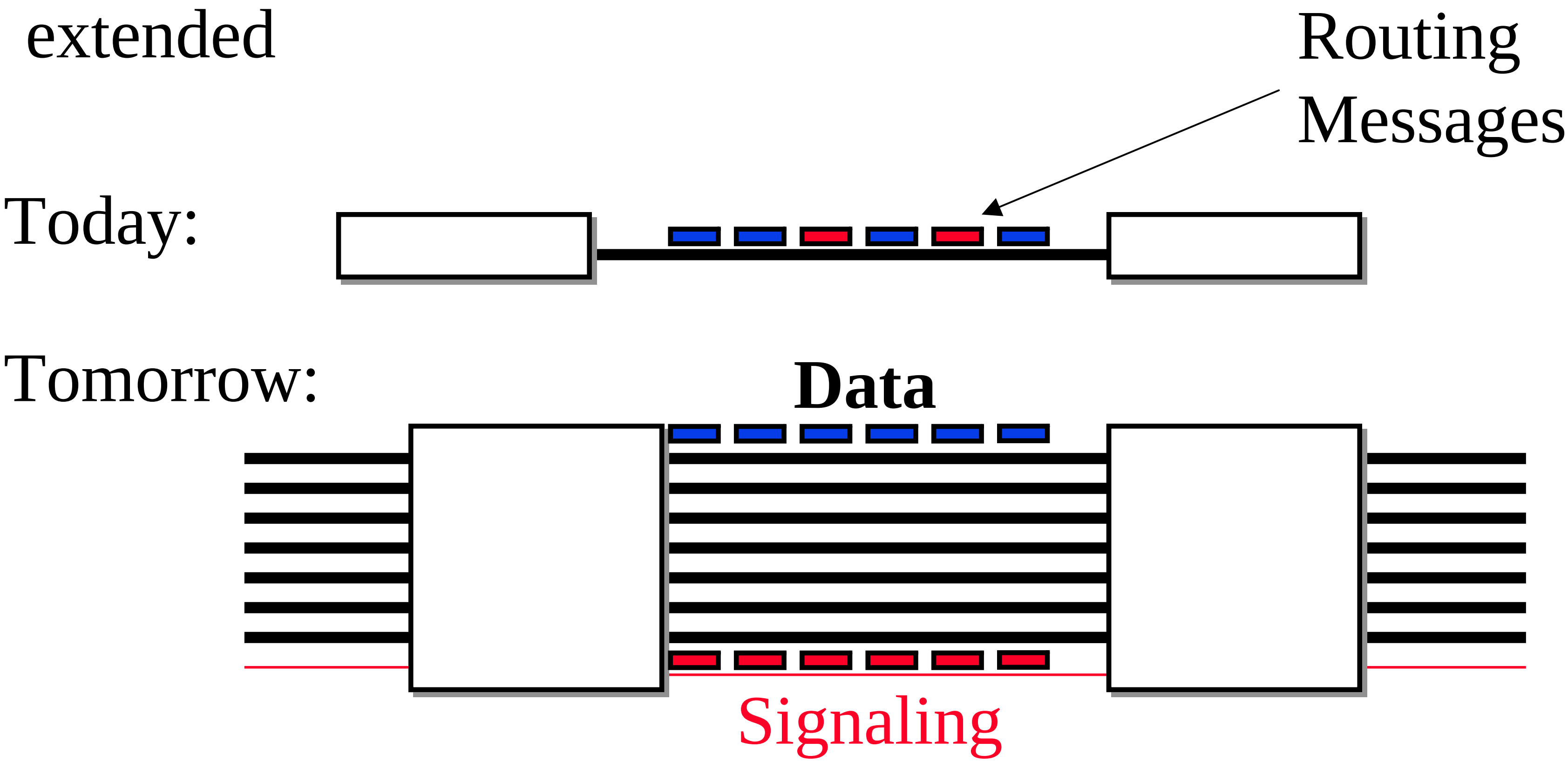


IP over DWDM Issues

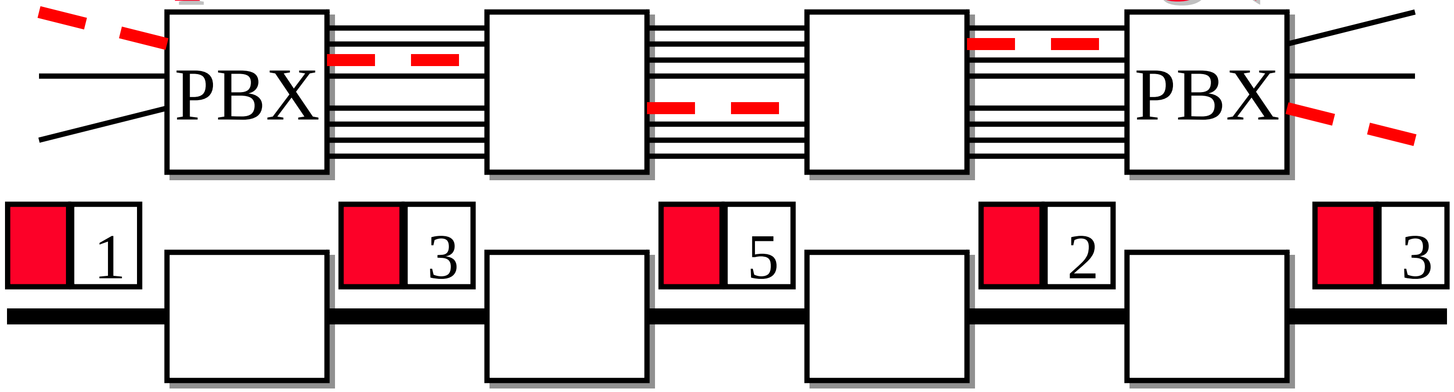
1. Data and Control plane separation
2. Circuits
3. Signaling
4. Addressing
5. Protection and Restoration

Control and Data Plane Separation

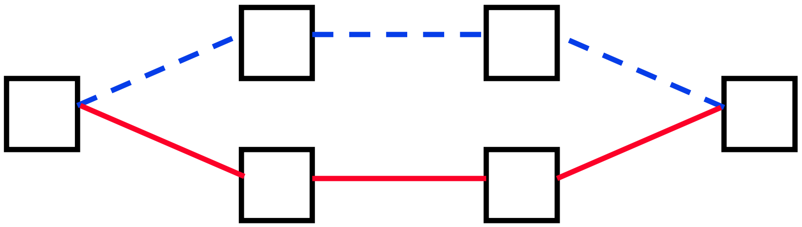
- Separate control and data channels
- IP routing protocols (OSPF and IS-IS) are being extended



Multiprotocol Label Switching (MPLS)

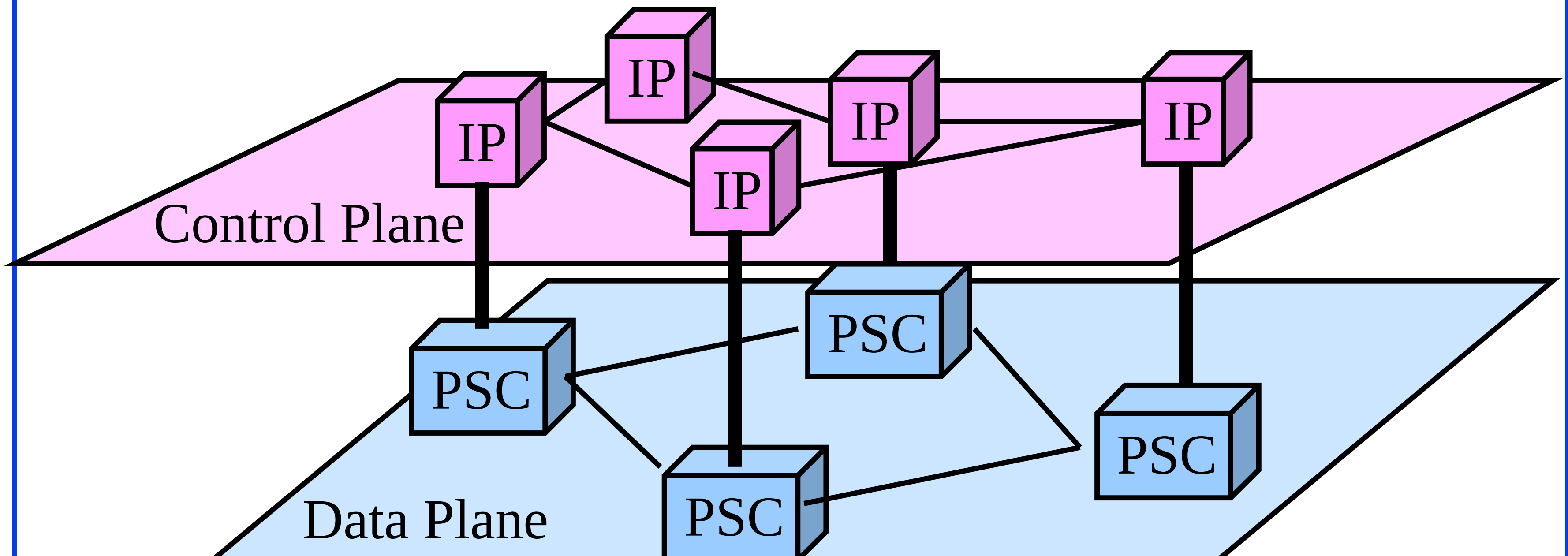


- Allows virtual circuits in IP Networks (May 1996)
- Each packet has a virtual circuit number called ‘label’
- Label determines the packet’s queuing and forwarding
- Circuits are called Label Switched Paths (LSPs)
- LSP’s have to be set up before use
- Allows traffic engineering



IP-Based Control Plane

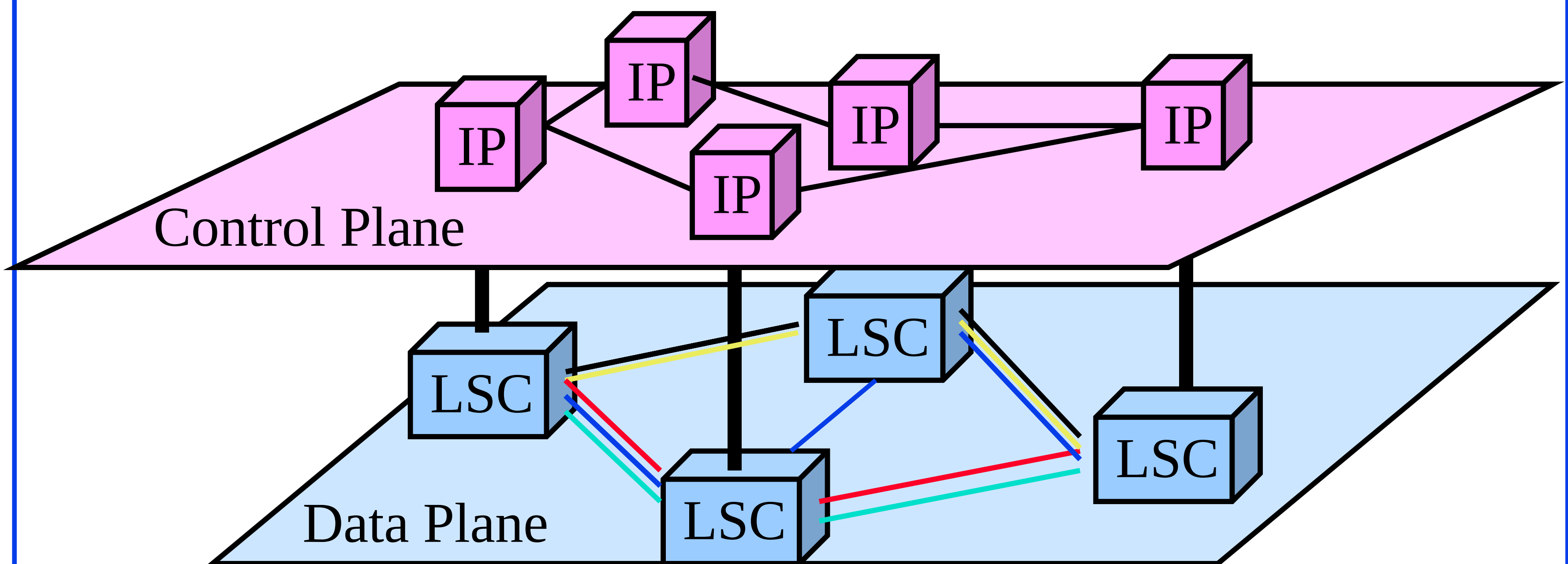
- Control is by IP packets (electronic).
  Data can be any kind of packets (IPX, ATM cells).
  ⇒ MPLS



PSC = Packet Switch Capable Nodes

MPλS

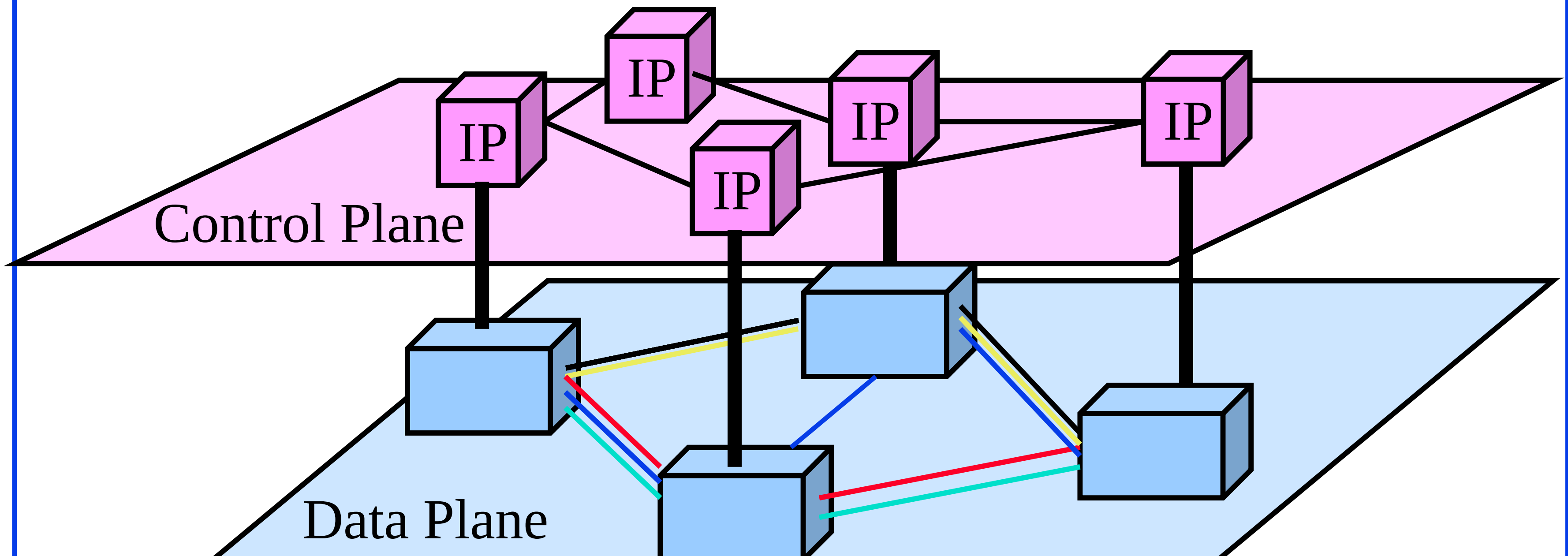
- Control is by IP packets (electronic).
  Data plane consists of wavelength circuits
  ⇒ Multiprotocol Lambda Switching (October 1999)



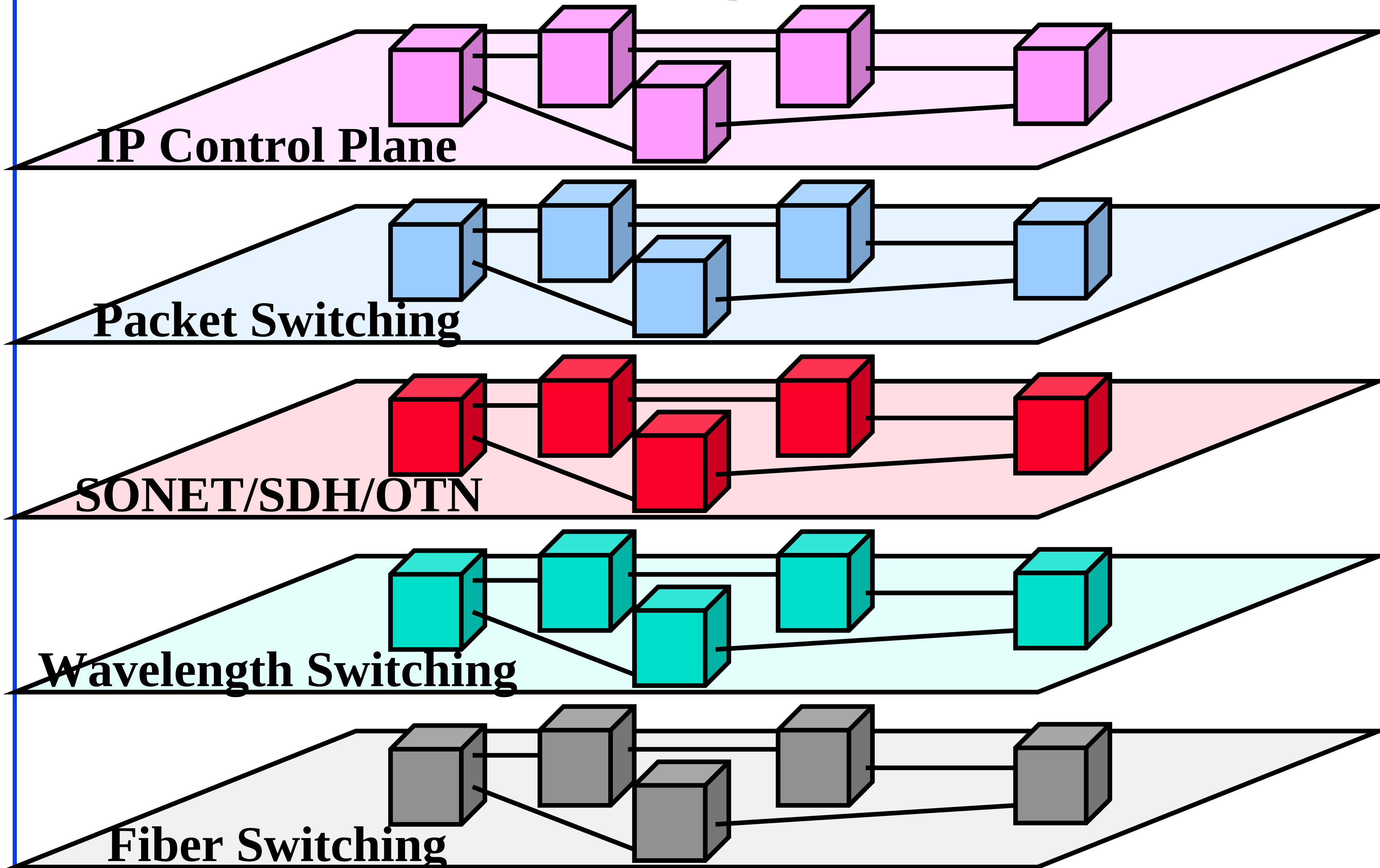
LSC = Lambda Switch Capable Nodes
= Optical Cross Connects = OXC

GMPLS

- Data Plane = Wavelengths, Fibers, SONET Frames, Packets (October 2000)
- Two separate routes: Data route and control route

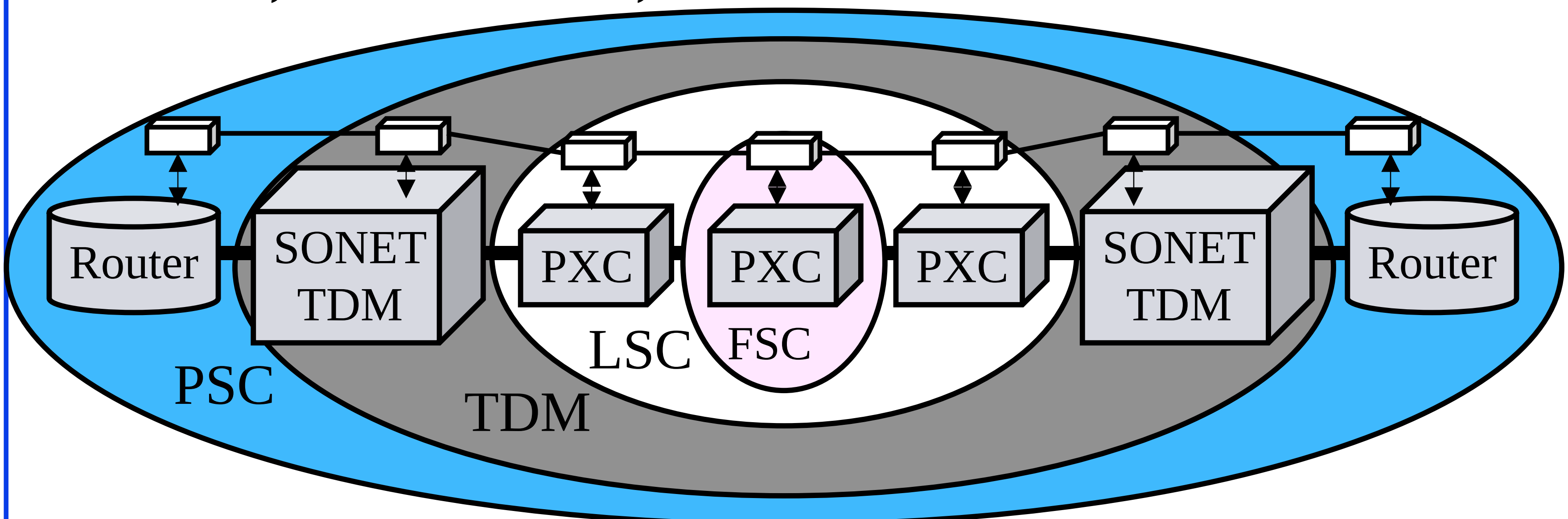


GMPLS: Layered View



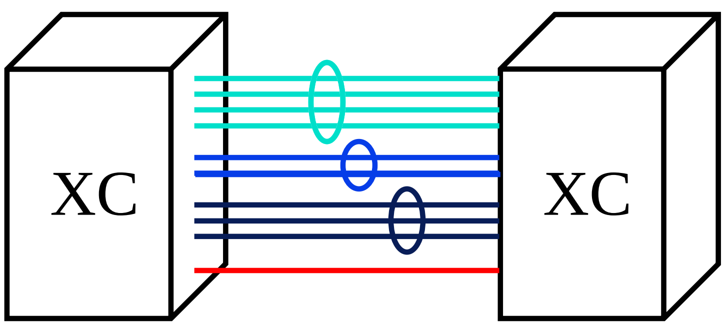
GMPLS: Hierarchical View

- Packets over SONET over Wavelengths over Fibers
- Packet switching regions, TDM regions, Wavelength switching regions, fiber switching regions
- Allows data plane connections between SONET ADMs, PXCs. FSCs, in addition to routers



MPLS vs GMPLS

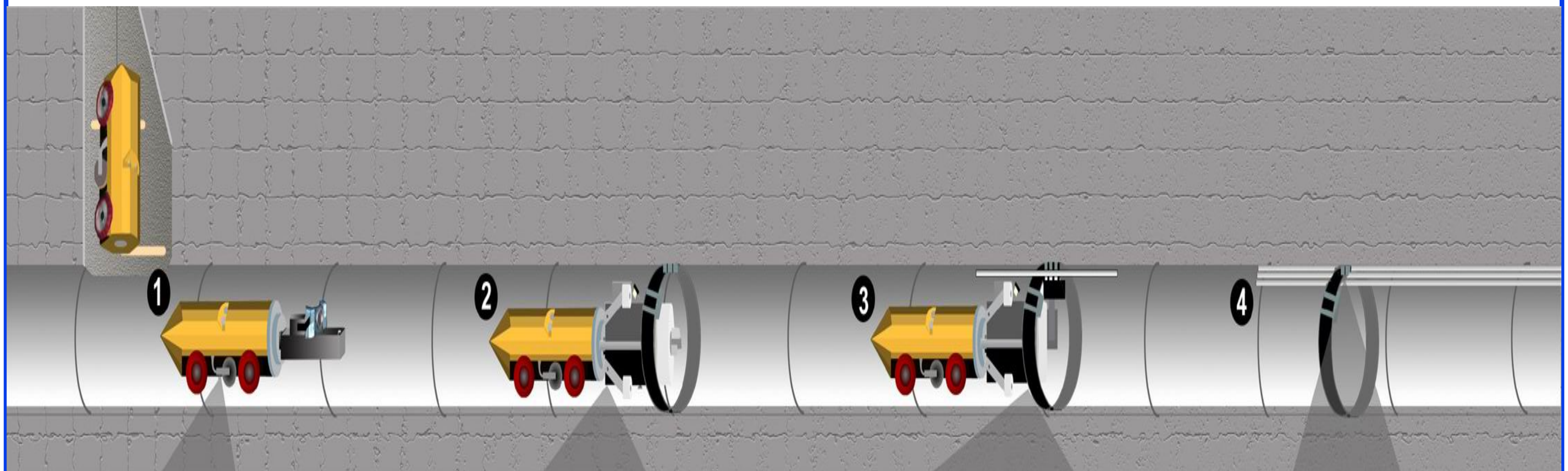
Issue	MPLS	GMPLS
Data & Control Plane	Same channel	Separate
Types of Nodes and labels	Packet Switching	PSC, TDM, LSC, FSC, …
Bandwidth	Continuous	Discrete: OC-n, λ's, ..
# of Parallel Links	Small	100-1000's
Port IP Address	One per port	Unnumbered
Fault Detection	In-band	Out-of-band or In-Band



Fiber Access Thru Sewer Tubes (FAST)

- Right of ways is difficult in dense urban areas
- Sewer Network: Completely connected system of pipes connecting every home and office
- Municipal Governments find it easier and more profitable to let you use sewer than dig street
- Installed in Zurich, Omaha, Albuquerque, Indianapolis, Vienna, Ft Worth, Scottsdale, ...
- Corrosion resistant inner ducts containing up to 216 fibers are mounted within sewer pipe using a robot called Sewer Access Module (SAM)
- Ref: http://www.citynettelecom.com, NFOEC 2001, pp. 331

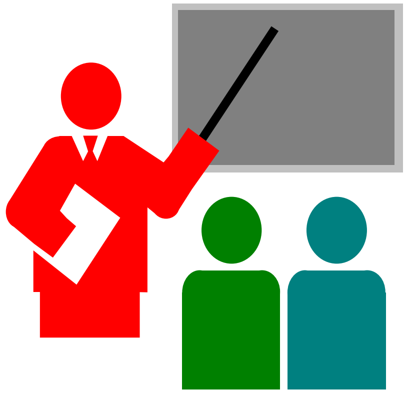
FAST Installation



1. Robots map the pipe
2. Install rings
3. Install ducts
4. Thread fibers

Fast Restoration: Broken sewer pipes replaced with minimal disruption

Summary



1. ILEC vs CLECs ⇒ Evolution vs Revolution
2. Core market is stagnant
   ⇒ No OOO Switching and Long Haul Transport
3. Metro Ethernet ⇒ Ethernet Service vs Transport
   ⇒ Next-Gen SONET vs Ethernet with RPR
4. PONs provide a scalable, upgradeable, cost effective solution.

Summary (Cont)

5. High speed routers
   $\Rightarrow$ IP directly over DWDM
6. Separation of control and data plane
   $\Rightarrow$ IP-Based control plane
7. Transport Plane = Packets $\Rightarrow$ MPLS
   Transport Plane = Wavelengths
   $\Rightarrow$ MPλS
   Transport Plane = λ, SONET, Packets
   $\Rightarrow$ GMPLS
8. UNI allows users to setup paths on demand

References

- Detailed references in http://www.cis.ohio-state.edu/~jain/refs/opt_refs.htm
- Recommended books on optical networking, http://www.cis.ohio-state.edu/~jain/refs/opt_book.htm
- Optical Networking and DWDM, http://www.cis.ohio-state.edu/~jain/cis788-99/dwdm/index.html
- IP over Optical: A summary of issues, (internet draft) http://www.cis.ohio-state.edu/~jain/ietf/issues.html
- Lightreading, http://www.lightreading.com