# Optical Networking: Recent Developments, Issues, and Trends

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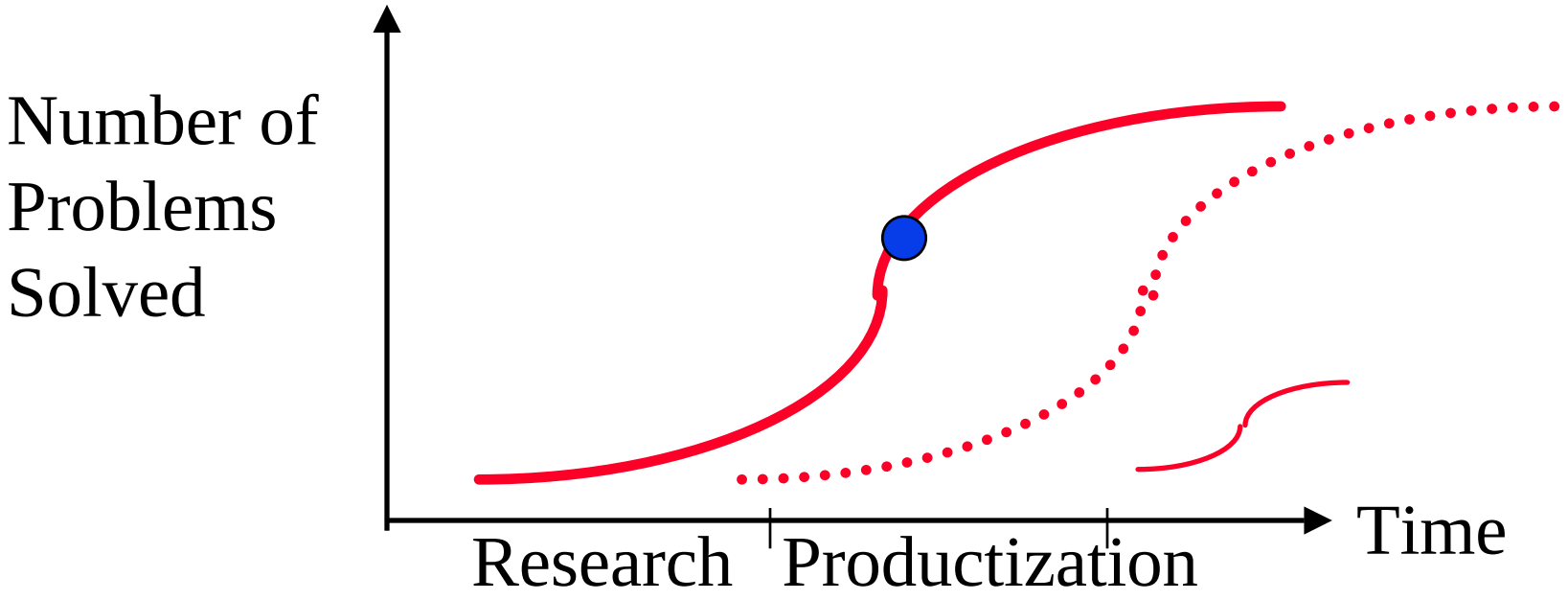
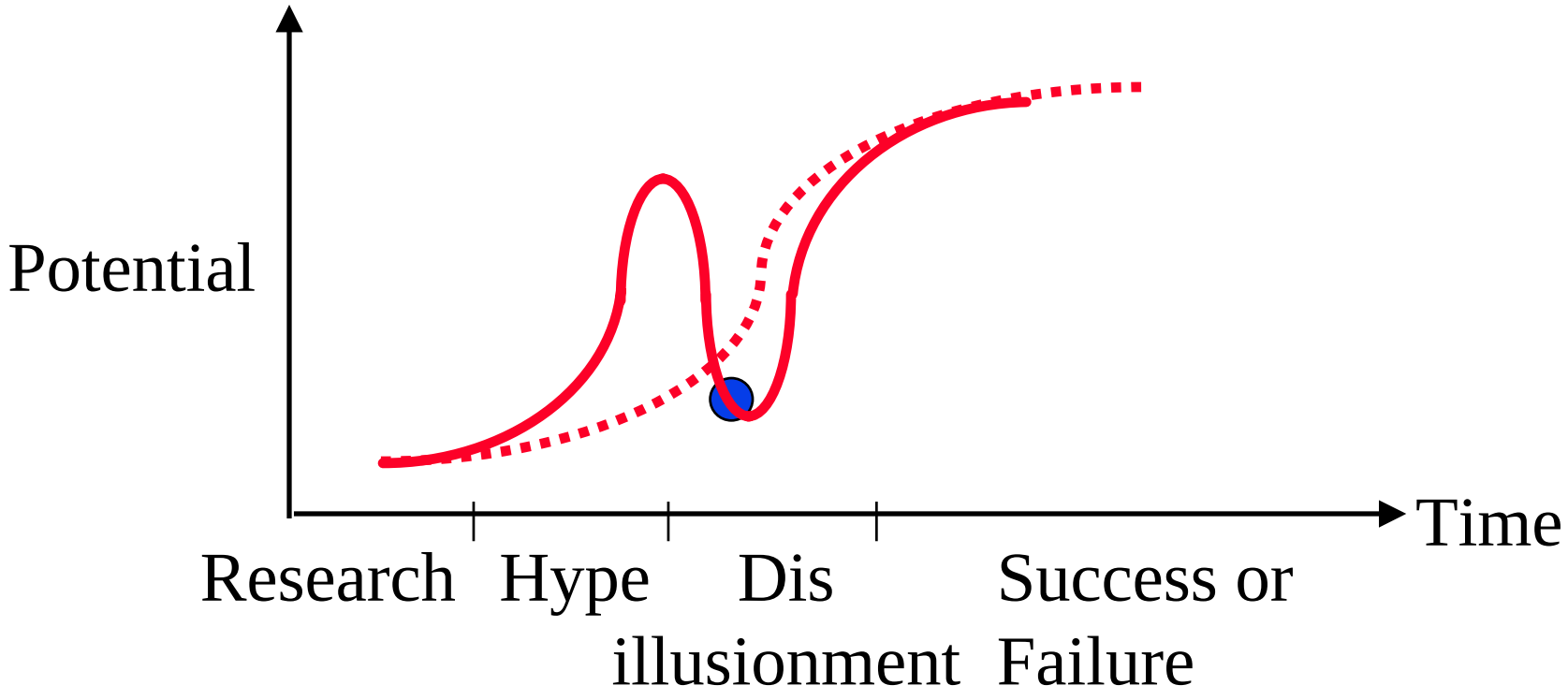
These slides are available on-line at:
http://www.cis.ohio-state.edu/~jain/talks/opt_wpr.htm


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

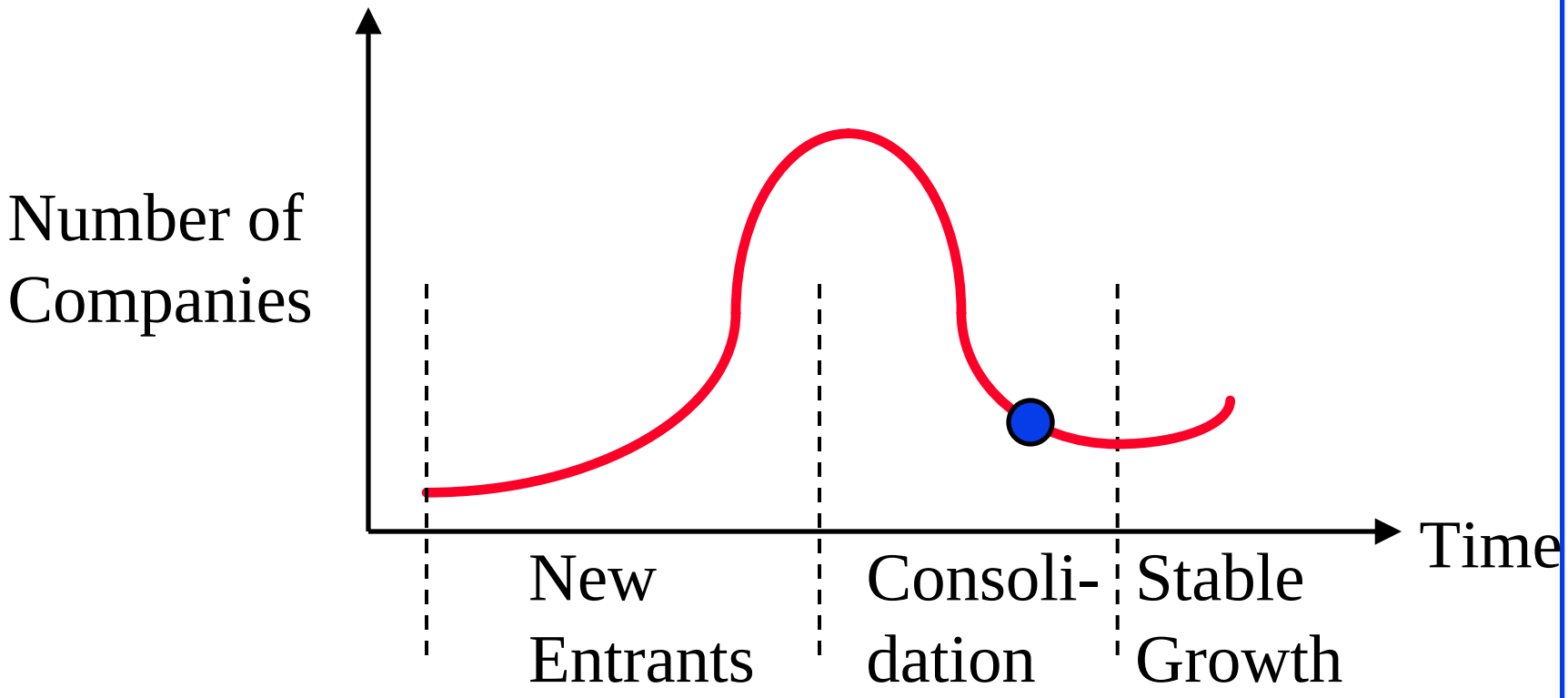
# Life Cycles of Technologies



# Hype Cycles of Technologies



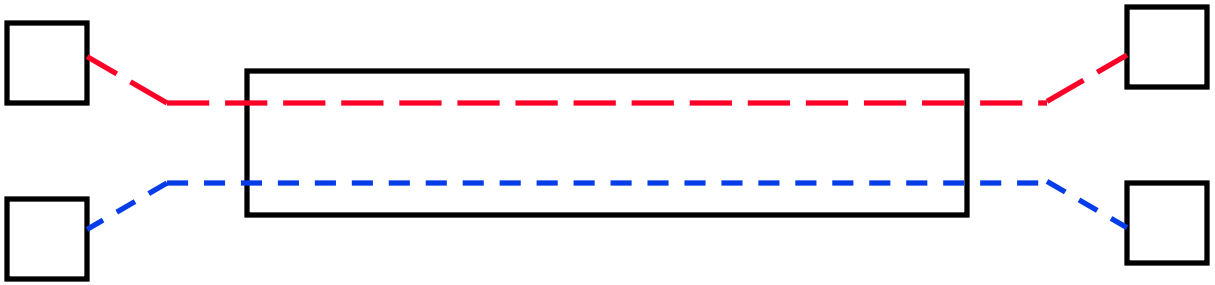
# Industry Growth



# Trend: Back to ILECs

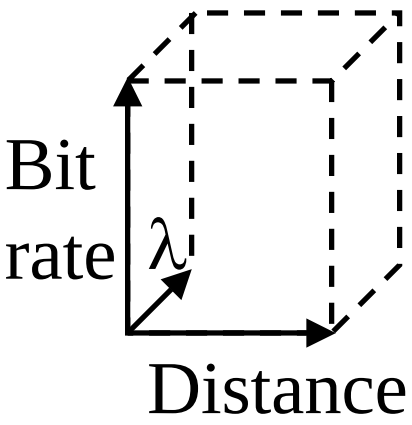
1. CLECs to ILECs
   ILEC: Slow, steady, predictable.
   CLEC: Aggressive, Need to build up fast
   New networks with newest technology
   No legacy issues
2. Back to Voice
   CLECs wanted to *start* with data
   ILECs want to *migrate* to data
   $\Rightarrow$ Equipment that support voice circuits but 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

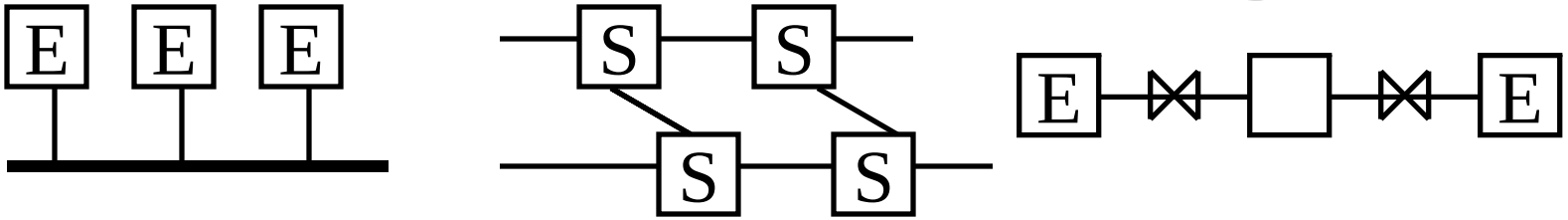
| Product | λ's | Gb/s | km | Avail-ability |
|---|---|---|---|---|
| Siemens/Optisphere TransXpress | 80 | 40 | 250 | 2001 |
| | 160 | 10 | 250 | 2001 |
| Alcatel 1640 OADM | 160 | 2.5 | 2300 | 2001 |
| | 80 | 10 | 330 | 2001 |
| Corvis Optical Network Gateway | 160 | 2.5 | 3200 | 2000 |
| | 40 | 10 | 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

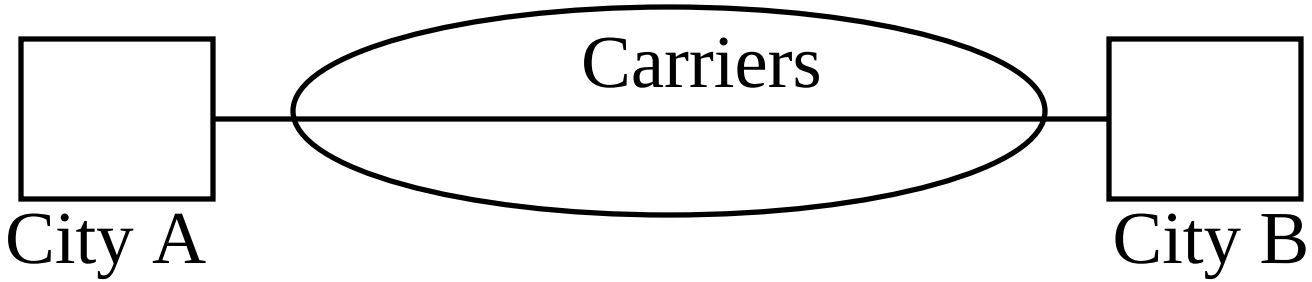
# Trend: LAN - WAN Convergence



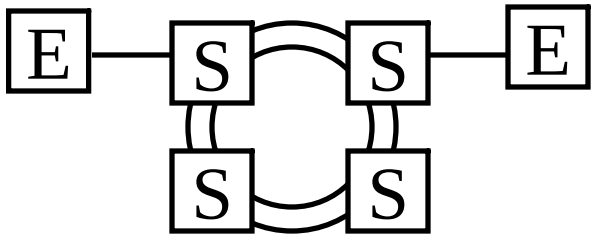

- Past: Shared media in LANs. Point to point in WANs.
- Future: No media sharing by multiple stations
  - Point-to-point links in LAN and WAN
  - No distance limitations due to MAC. Only Phy.
  - Datalink protocols limited to frame formats
- 10 GbE over 40 km without repeaters
- Ethernet End-to-end.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

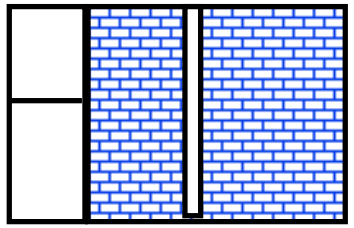
# SONET

- 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

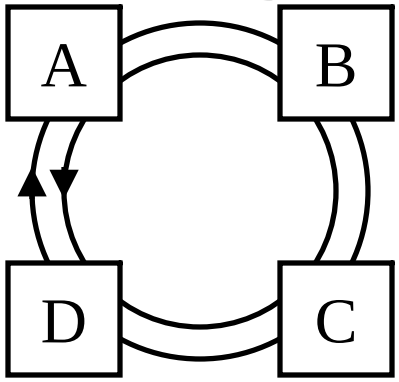
# SONET vs Ethernet

| 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

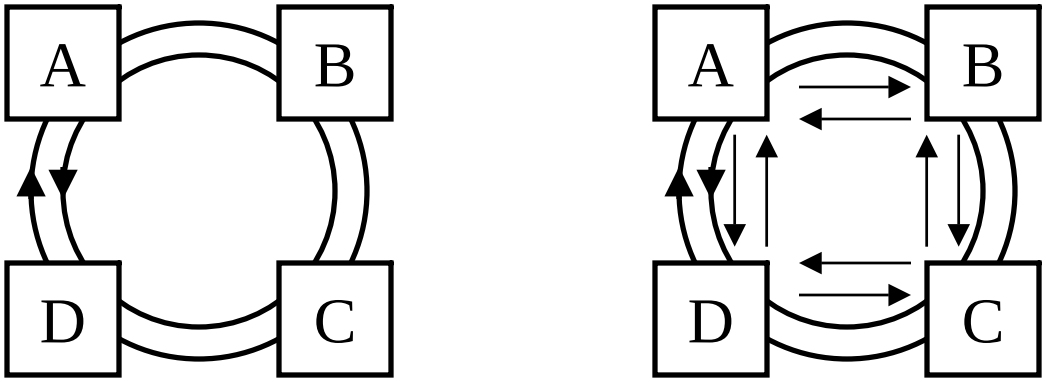
| Feature | SONET | Ethernet | Remedy |
|---|---|---|---|
| Payload Rates | 51M, 155M, 622M, 2.4G, 9.5G | 10M, 100M, 1G, 10G | 10GE at 9.5G |
| Payload Rate Granularity | Fixed | √Any | Virtual Concatenation |
| Bursty Payload | No | √Yes | Link Capacity Adjustment Scheme |
| Payload Count | One | √Multiple | 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



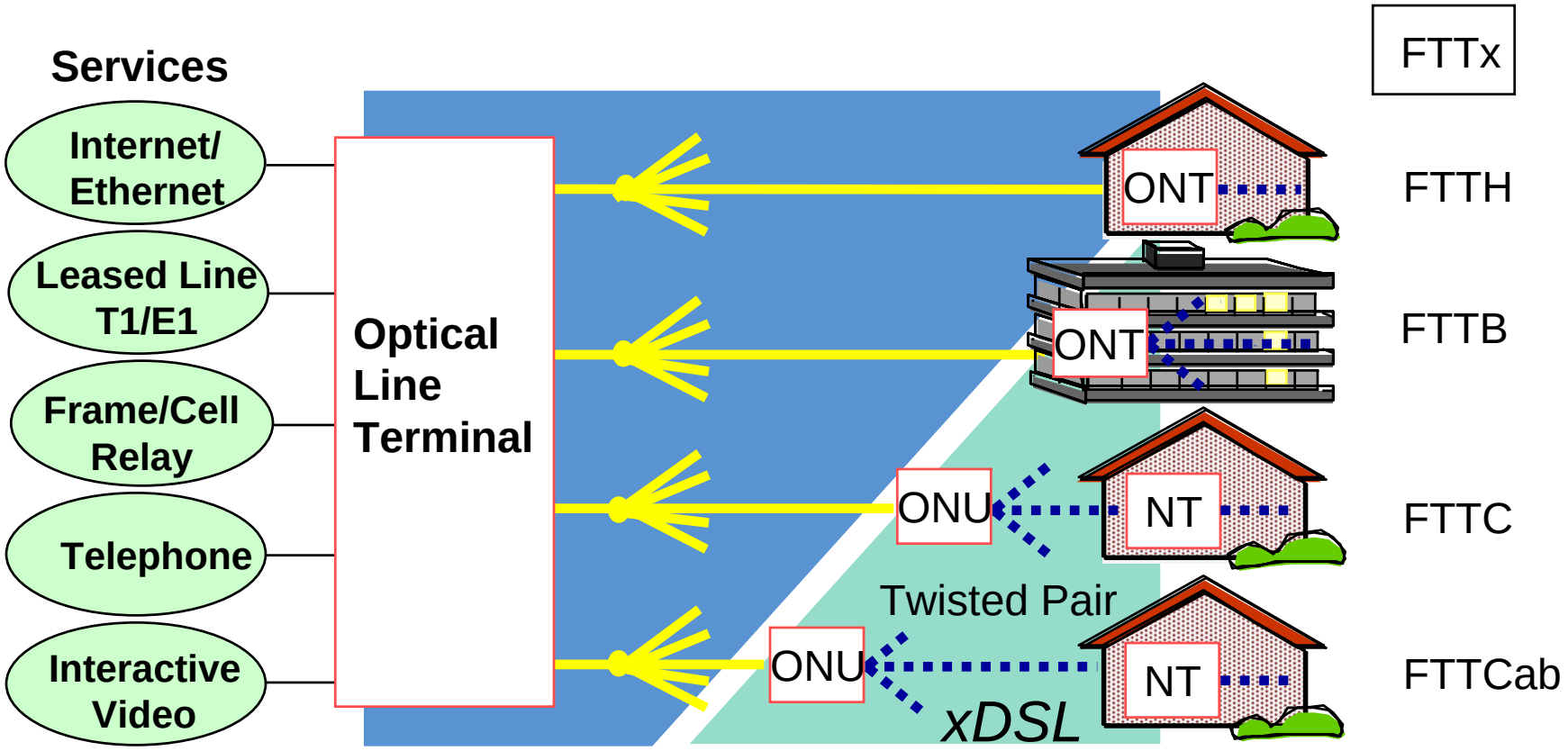

- Dual Ring topology
- Supports broadcast and multicast
- Packet based ⇒ Continuous bandwidth granularity
- Max 256 nodes per ring
- MAN distances: Several hundred kilometers.
- Gbps speeds: Up to 10 Gbps

# 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)



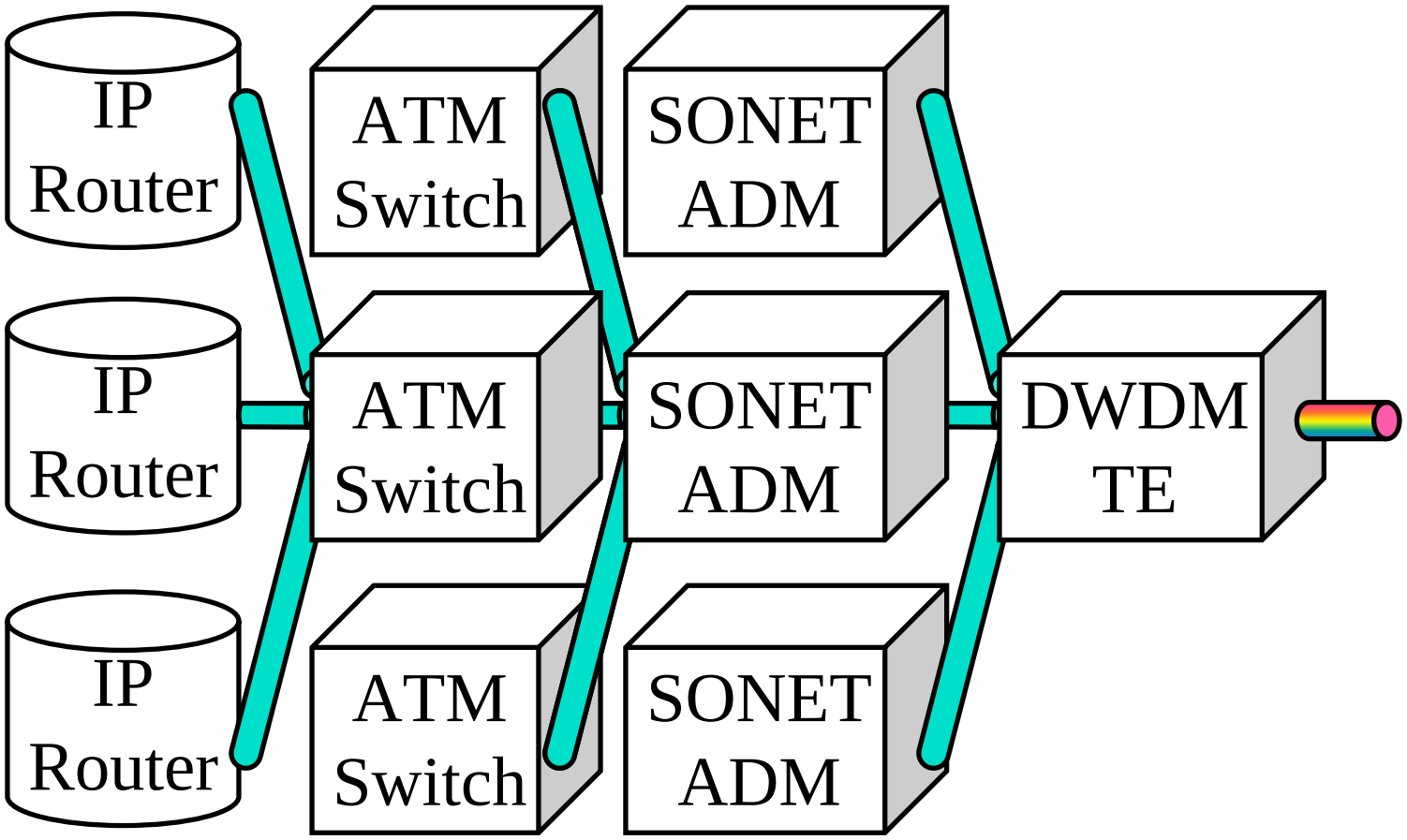

FTTH :Fiber To The Home
FTTB :Fiber To The Building
FTTC:Fiber To The Curb
FTTCab :Fiber To The Cabinet

# Why PONs?

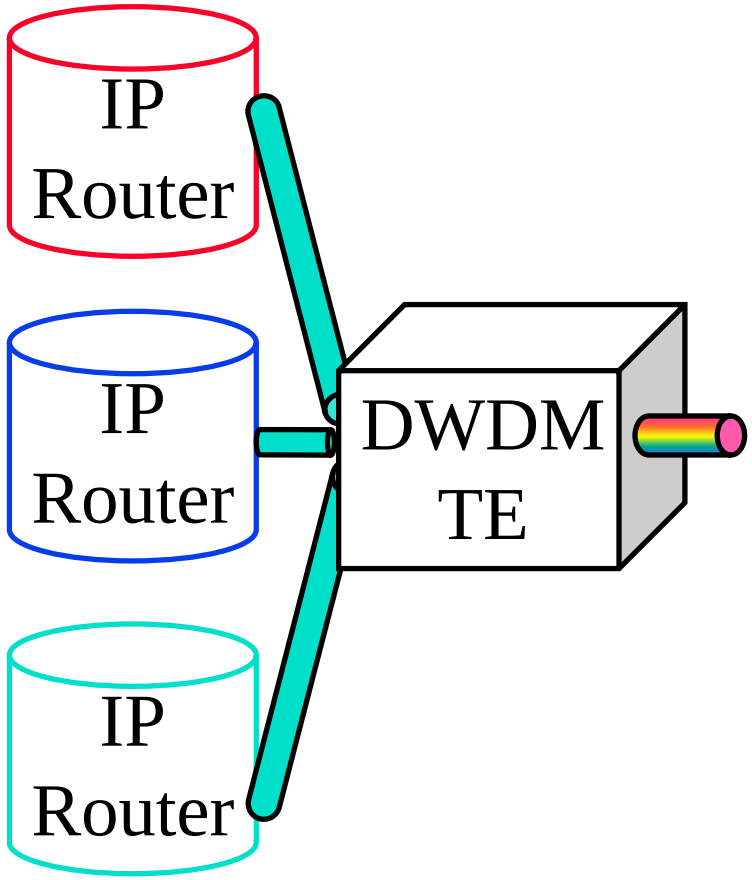
1. Passive ⇒ No active electronics or regenerators in distribution network ⇒ Very reliable. Easy to maintain. Reduced truck rolls. Shorter installation times. Reduced power expences. ⇒ Lower OpEx.
2. Single fiber for bi-directional communication ⇒ Reduced cabling and plant cost ⇒ Lower CapEx
3. A single 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)

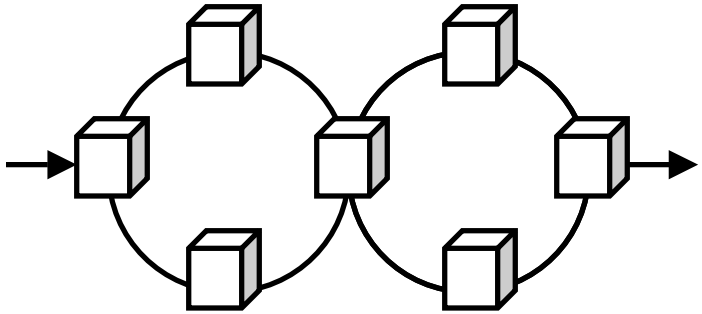


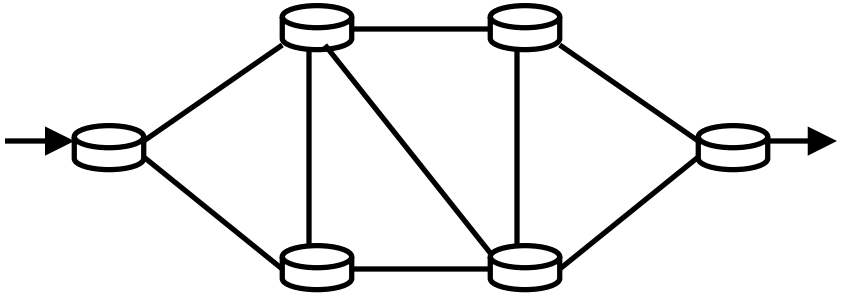
# IP over DWDM (Future)



# 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 |



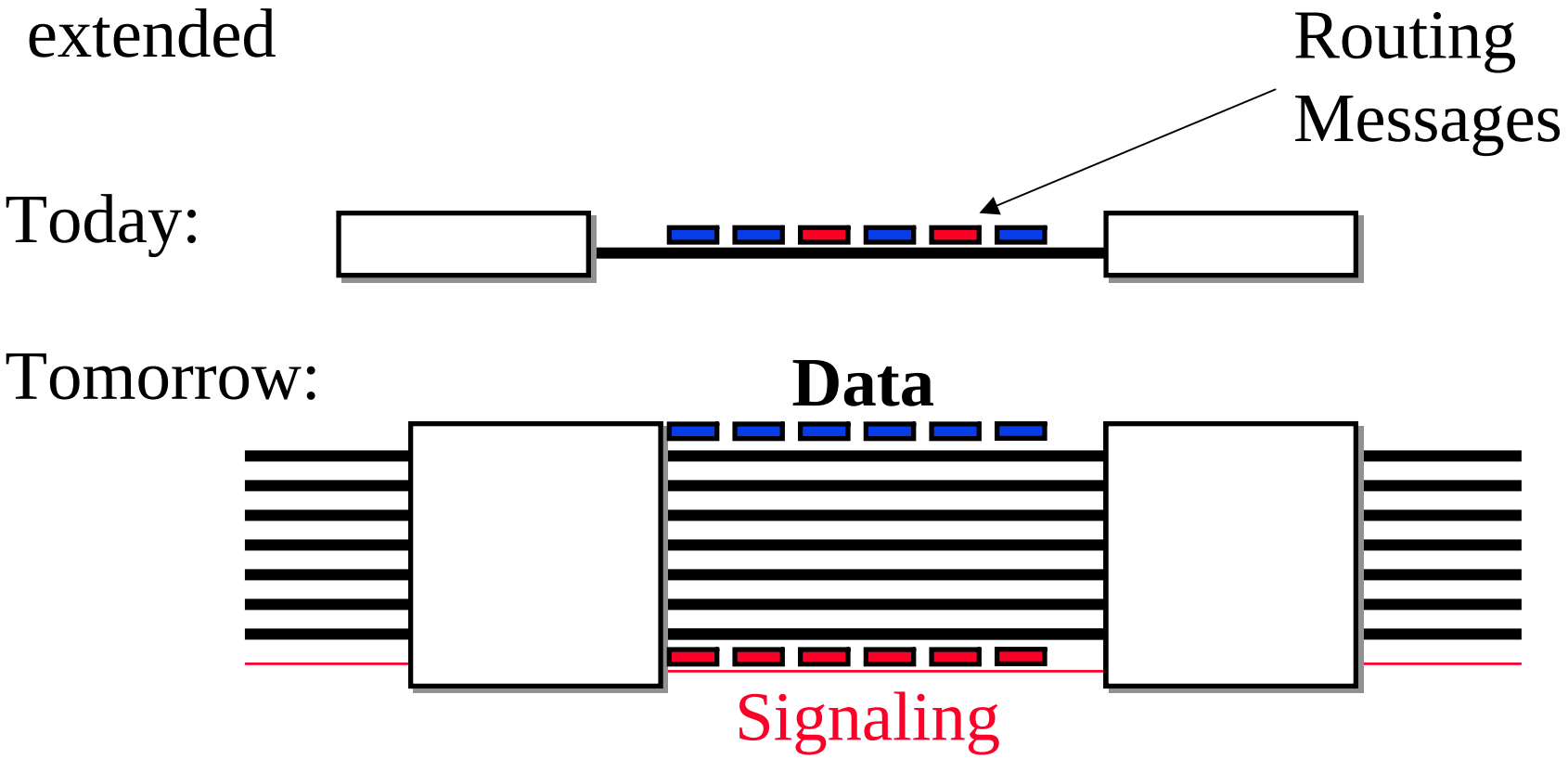


# IP over DWDM Issues

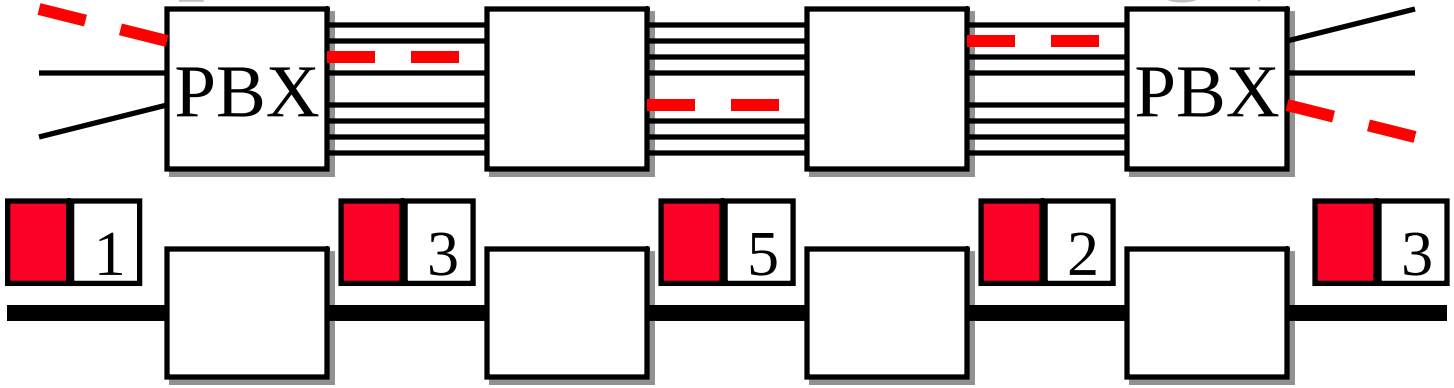
1. Data and Control plane separation
2. Circuits
3. Signaling
4. Addressing
5. Protection and Restoration

# Control and Data Plane Separation

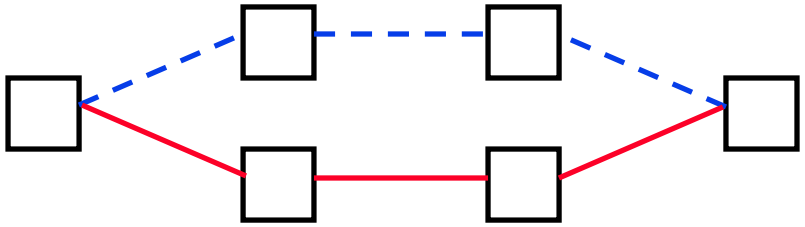
- Separate control and data channels
- IP routing protocols (OSPF and IS-IS) are being extended



# Multiprotocol Label Switching (MPLS)

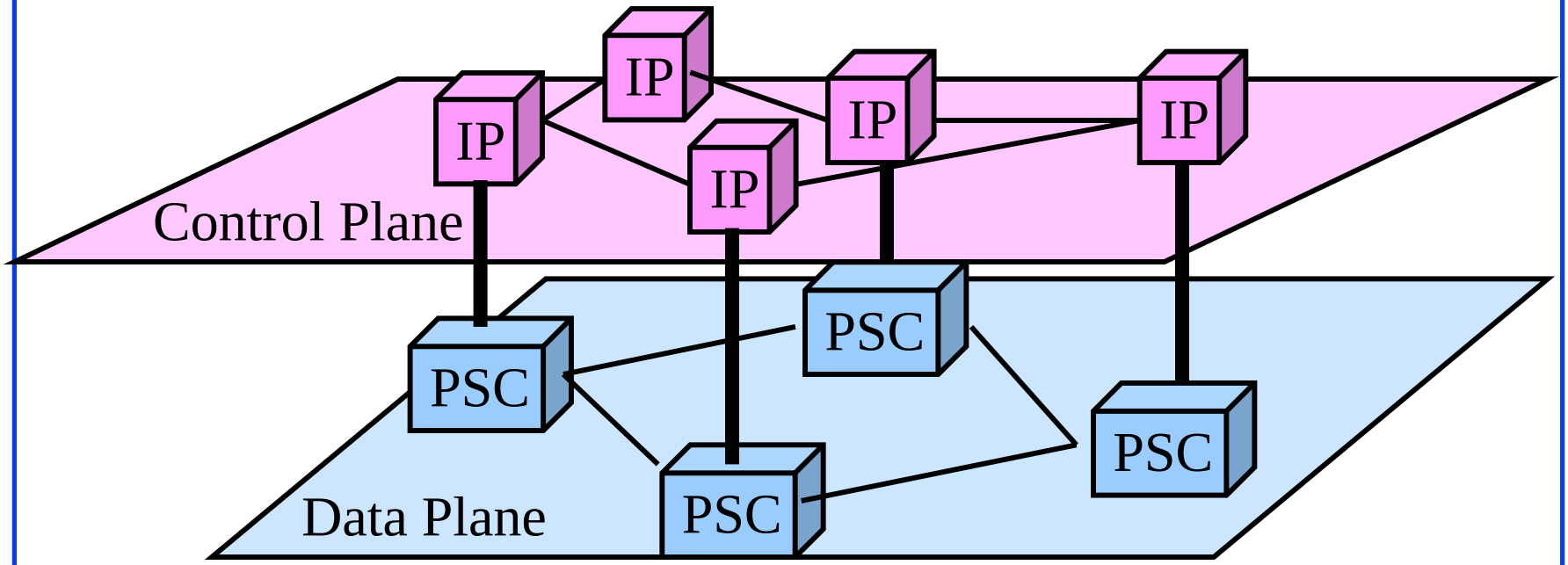



- Allows virtual circuits in IP Networks (May 1996)
- Each packet has a virtual circuit number called 'label'
- Label determines the packet's queuing and forwarding
- Circuits are called Label Switched Paths (LSPs)
- LSP's have to be set up before use
- Allows traffic engineering



# IP-Based Control Plane

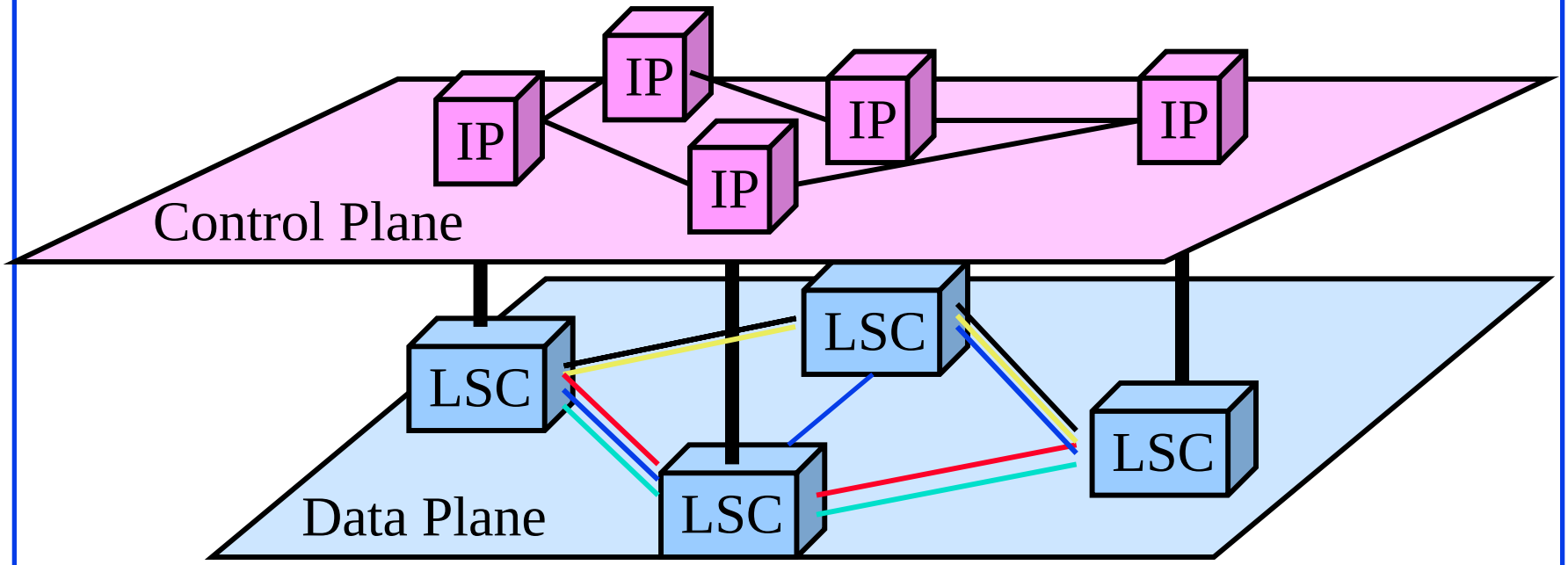
- Control is by IP packets (electronic).
  Data can be any kind of packets (IPX, ATM cells).
  ⇒ MPLS




PSC = Packet Switch Capable Nodes

# MPλS

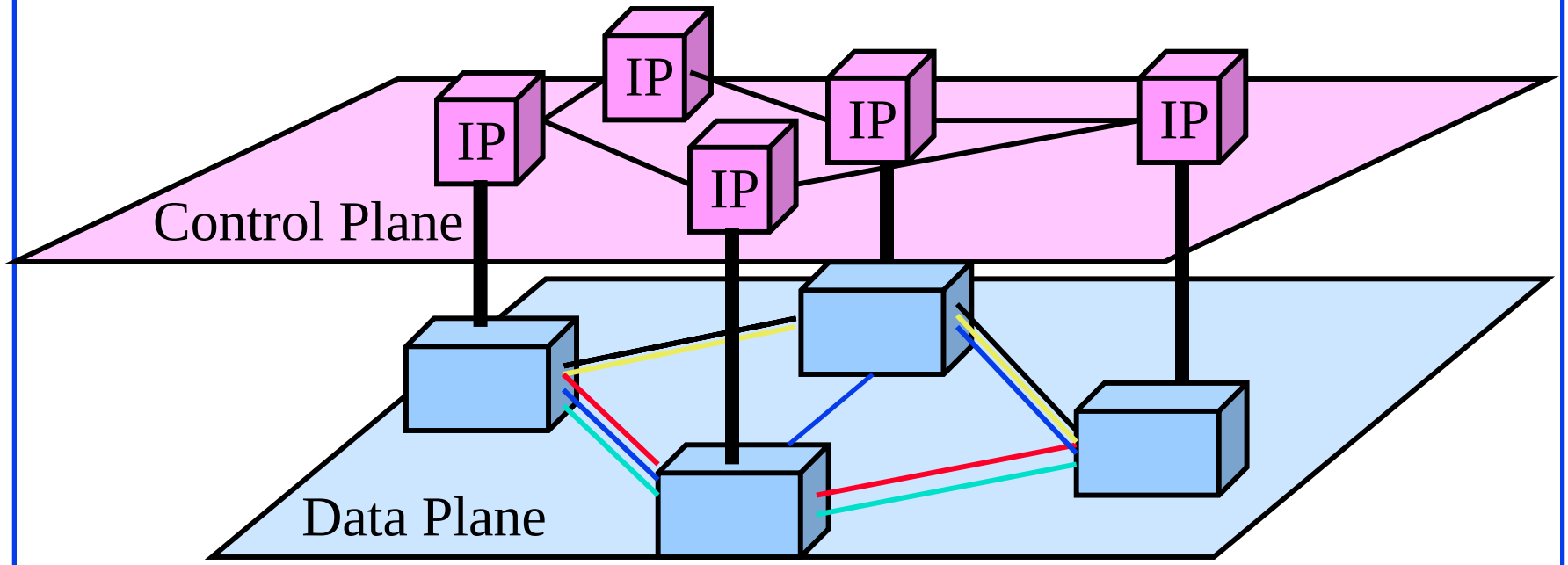
- Control is by IP packets (electronic).
  Data plane consists of wavelength circuits
  ⇒ Multiprotocol Lambda Switching (October 1999)



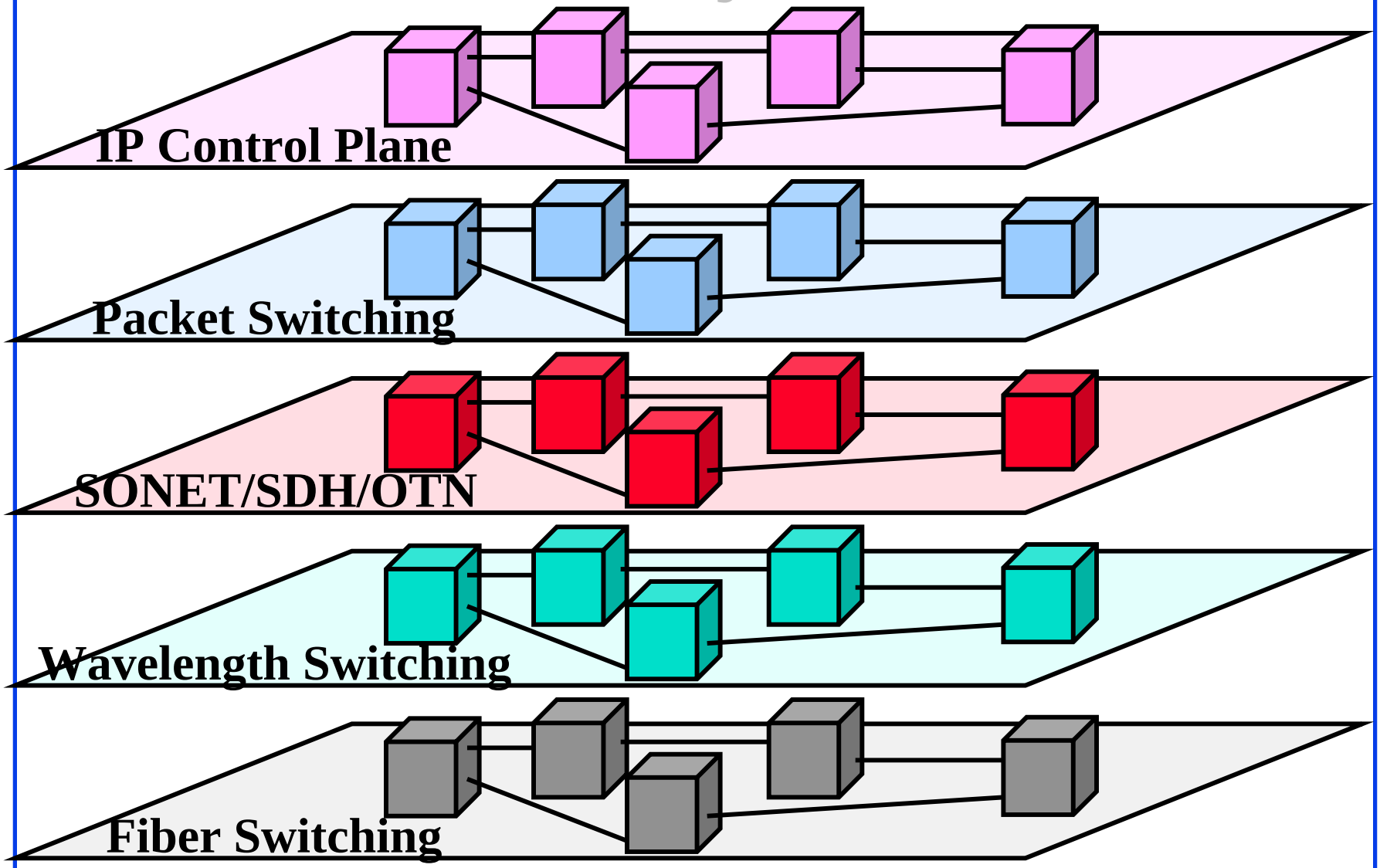

LSC = Lambda Switch Capable Nodes
= Optical Cross Connects = OXC

# GMPLS

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

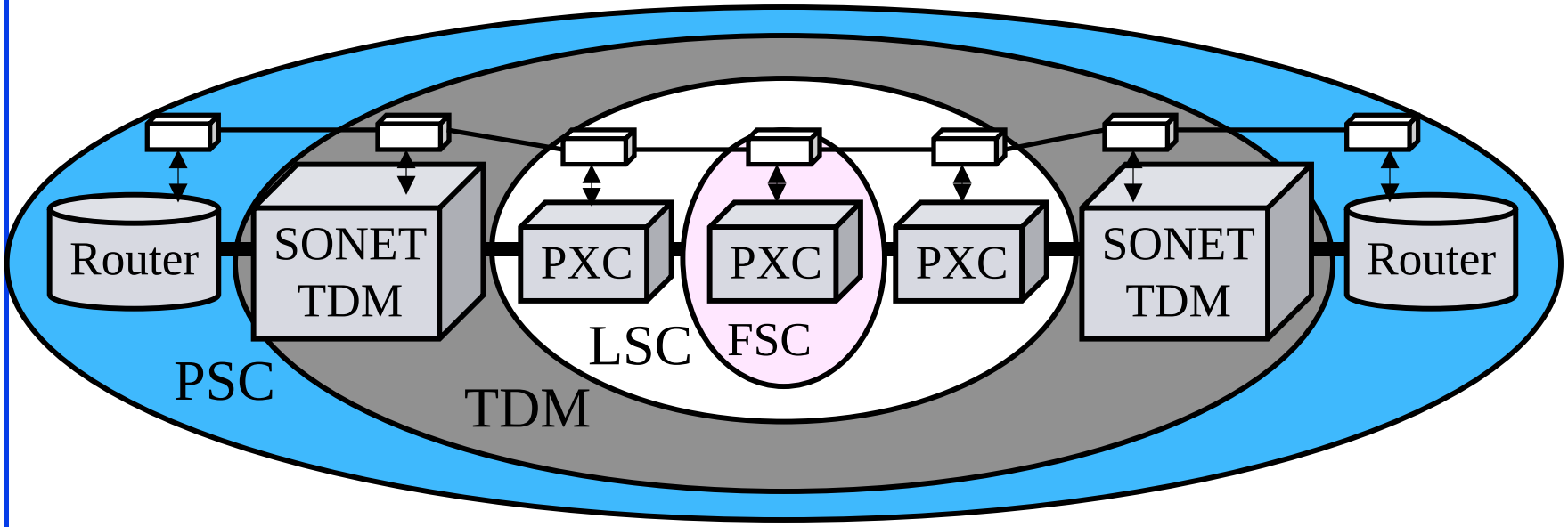


# GMPLS: Layered View



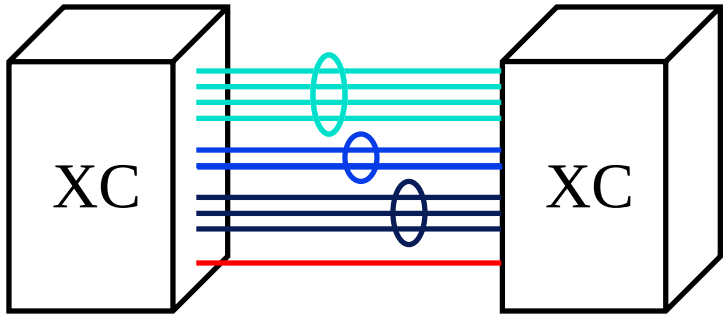
# GMPLS: Hierarchical View

- 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

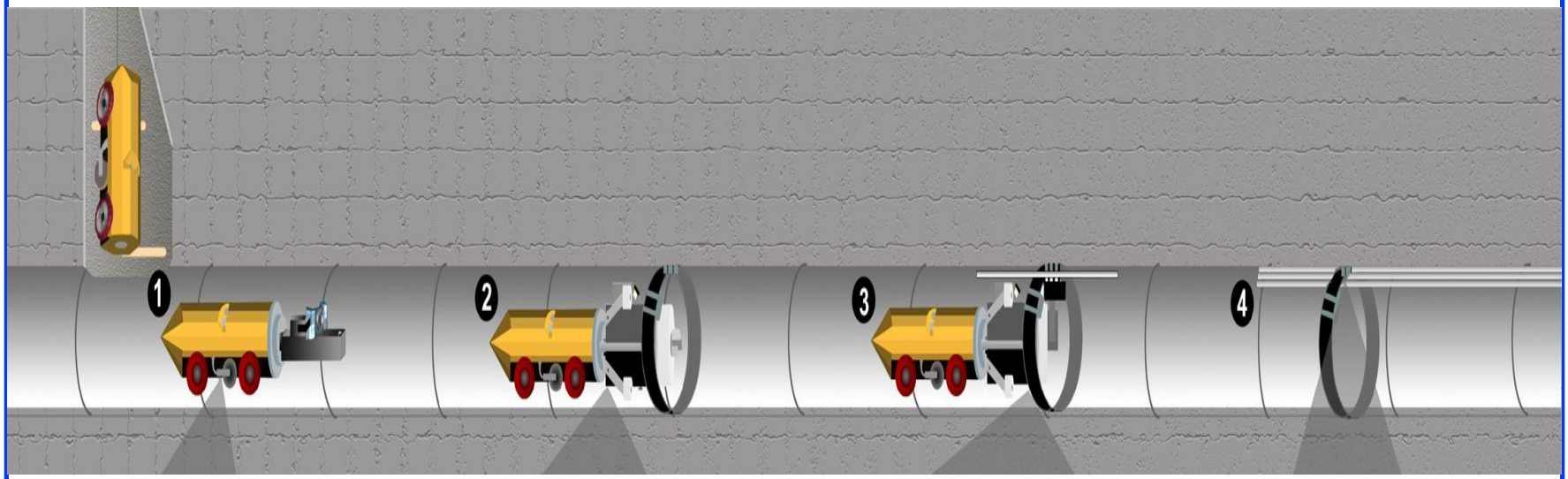
| Issue | MPLS | GMPLS |
|---|---|---|
| Data & Control Plane | Same channel | Separate |
| Types of Nodes and labels | Packet Switching | PSC, TDM, LSC, FSC, … |
| Bandwidth | Continuous | Discrete: OC-n, λ's, .. |
| # of Parallel Links | Small | 100-1000's |
| Port IP Address | One per port | Unnumbered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

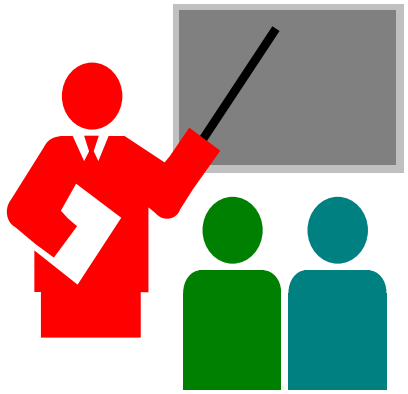
# FAST Installation



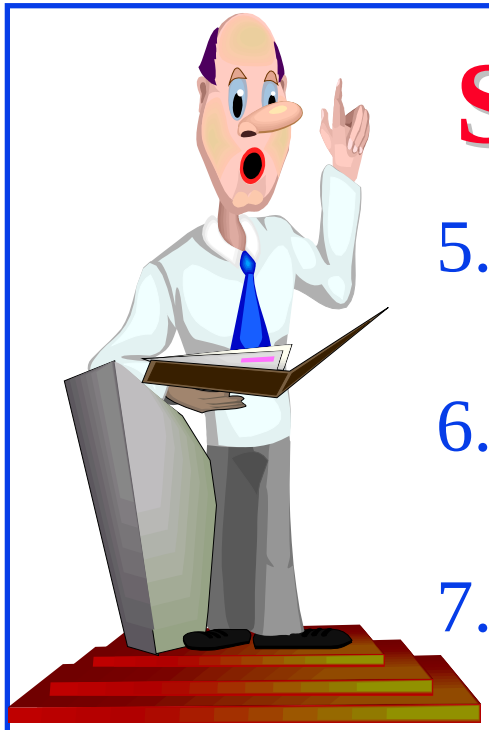

1. Robots map the pipe
2. Install rings
3. Install ducts
4. Thread fibers

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
   ⇒ IP directly over DWDM
6. Separation of control and data plane
   ⇒ IP-Based control plane
7. Transport Plane = Packets ⇒ MPLS
   Transport Plane = Wavelengths
   ⇒ MPλS
   Transport Plane = λ, SONET, Packets
   ⇒ 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