Optical Networking: Recent Developments, Issues, and Trends

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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: Multi-Service Provisioning Platforms
Life Cycles of Technologies

Number of Problems Solved vs Time

- Research
- Productization

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Hype Cycles of Technologies

- Potential
- Research
- Hype
- Disillusionment
- Success or Failure
- Time
Industry Growth

- New Entrants
- Consolidation
- Stable Growth

Number of Companies vs. Time
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
   CLEC$s$ wanted to \textit{start} with data
   ILEC$s$ want to \textit{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

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

Potential: 58 THz = 50 Tbps on 10,000 $\lambda$’s

Core Optical Networks

- Higher Speed: 10 Gbps to 40 Gbps
- Longer Distances: 600 km to 6000 km
- More Wavelengths: 16 $\lambda$’s to 160 $\lambda$’s
- All-optical Switching: OOO vs OEO Switching
## Optical Transport Products

<table>
<thead>
<tr>
<th>Product</th>
<th>λ’s</th>
<th>Gb/s</th>
<th>km</th>
<th>Availability</th>
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<tbody>
<tr>
<td>Siemens/Optisphere TransXpress</td>
<td>80</td>
<td>40</td>
<td>250</td>
<td>2001</td>
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<tr>
<td></td>
<td>160</td>
<td>10</td>
<td>250</td>
<td>2001</td>
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<tr>
<td>Alcatel 1640 OADM</td>
<td>160</td>
<td>2.5</td>
<td>2300</td>
<td>2001</td>
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<tr>
<td></td>
<td>80</td>
<td>10</td>
<td>330</td>
<td>2001</td>
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<tr>
<td>Corvis Optical Network Gateway</td>
<td>160</td>
<td>2.5</td>
<td>3200</td>
<td>2000</td>
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<tr>
<td></td>
<td>40</td>
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<td>3200</td>
<td>2000</td>
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<td>Ciena Multiwave CoreStream</td>
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<td>1600</td>
<td>2001</td>
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<td>Nortel Optera LH4000</td>
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<td>10</td>
<td>4000</td>
<td>2000</td>
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<td>Optera LH 5000</td>
<td>104</td>
<td>40</td>
<td>1200</td>
<td>2002</td>
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<tr>
<td>Sycamore SN10000</td>
<td>160</td>
<td>10</td>
<td>800</td>
<td>2001</td>
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<tr>
<td></td>
<td>40</td>
<td>10</td>
<td>4000</td>
<td>2001</td>
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<tr>
<td>Cisco ONS 15800</td>
<td>160</td>
<td>10</td>
<td>2000</td>
<td>2002</td>
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</table>

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
    ⇒ 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
  ⇒ 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

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

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## SONET vs Ethernet: Remedies

<table>
<thead>
<tr>
<th>Feature</th>
<th>SONET</th>
<th>Ethernet</th>
<th>Remedy</th>
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<tbody>
<tr>
<td>Payload Rates</td>
<td>51M, 155M, 622M, 2.4G, 9.5G</td>
<td>10M, 100M, 1G, 10G</td>
<td>10GE at 9.5G</td>
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<tr>
<td>Payload Rate</td>
<td>Fixed</td>
<td>√ Any</td>
<td>Virtual Concatenation</td>
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<tr>
<td>Granularity</td>
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<td></td>
<td></td>
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<tr>
<td>Bursty Payload</td>
<td>No</td>
<td>√ Yes</td>
<td>Link Capacity Adjustment Scheme</td>
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<td></td>
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<tr>
<td>Payload Count</td>
<td>One</td>
<td>√ Multiple</td>
<td>Packet GFP</td>
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<tr>
<td>Protection</td>
<td>√ Ring</td>
<td>Mesh</td>
<td>Resilient Packet Ring (RPR)</td>
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<tr>
<td>OAM&amp;P</td>
<td>√ Yes</td>
<td>No</td>
<td>In RPR</td>
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<td>Synchronous Traffic</td>
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<td>No</td>
<td>MPLS + RPR</td>
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<td>Restoration</td>
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<td>Minutes</td>
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<tr>
<td>Cost</td>
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<td>Converging</td>
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<td>Enterprise</td>
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</table>
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
Both rings are used (unlike SONET)

Normal transmission on the shortest path

Destination stripping $\Rightarrow$ Spatial reuse
Multicast packets are source stripped

Five Classes of traffic: Reserved, High-Priority, Medium Priority, Low Priority, Control
Access: Fiber To The X(FTTx)

Services:
- Internet/Ethernet
- Leased Line T1/E1
- Frame/Cell Relay
- Telephone
- Interactive Video

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

Optical Line Terminal

ONT

Twisted Pair

xDSL

ONU
Passive Optical Networks (PONs)

- PONs use a single fiber for bi-directional communication compared to four for point-to-point technologies ⇒ Reduced cabling and plant cost
- A single fiber is shared among 16 to 32 customers ⇒ Customer bandwidth can change/grow dynamically ⇒ Relieves fiber congestion
- Multi-service PONs: Voice, T1/E1, SONET/SDH, ATM, Video, Ethernet
- Passive ⇒ More reliable
- Useful if customers are clustered ⇒ PONs are succeeding in Asia (Korea, China) because of high-rise living/business
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)
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

- ILEC vs CLECs ⇒ Evolution vs Revolution
- Core market is stagnant  
  ⇒ No OOO Switching and Long Haul Transport
- Metro Ethernet ⇒ Ethernet Service vs Transport  
  ⇒ Next-Gen SONET vs Ethernet with RPR
- Multi-Service Provisioning Platform (MSPP)
References

- Detailed references in http://www.cis.ohio-state.edu/~jain/refs/opt_refs.htm