Trends for Research and Educational Optical Networks

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Trends

- Technology trends from 2.5G to 100G.
- Technology trends from single-carrier to DWDM.
- Trends in the migration from TDM to Packets.
- Conclusion for future Research & Education needs.
## TDM History

<table>
<thead>
<tr>
<th>~Year</th>
<th>Commercial Introduction</th>
<th>Key Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>135 Mb/s</td>
<td>Multimode fiber</td>
</tr>
<tr>
<td>1985</td>
<td>565 Mb/s</td>
<td>1310 FP laser, Singlemode fiber</td>
</tr>
<tr>
<td>1986</td>
<td>1 Gb/s</td>
<td>1550 DFB laser</td>
</tr>
<tr>
<td>1991</td>
<td>2.5 Gb/s</td>
<td>SONET</td>
</tr>
<tr>
<td>2007</td>
<td>?</td>
<td>Phase Shift Keying</td>
</tr>
<tr>
<td>2009-10</td>
<td>100 Gb/s</td>
<td>Multi-level? Coherent? Polarization Multiplexing?</td>
</tr>
</tbody>
</table>
TDM Going Forward

- ITU grid is aligned on 100 GHz spacing
  - 50 GHz, 25 GHz sub channels are realizable.
- Constrains Potential higher-rate TDM solutions
  - Channelized, Specified Channel Width.
- New 40 Gb/s modulation formats are spectrally efficient
  - No excess bandwidth remaining.
- 100 Gb/s must either utilize more spectral bandwidth
  - (lower efficiency) – wider band or multi-lambda, or
  - Provide more effective utilization of spectral bandwidth
  - (higher efficiency) – higher order modulation: Amplitude, Phase, Polarization, Trellis.
LiNbO3 Modulators for 40Gb/s

- 40 Gb/s low drive voltage modulators
- 40 Gb/s 1.8 V dual-drive with advanced electrode design
- Dual-drive for zero chirp
- C- and L-band operation

- 40 Gb/s compact modulators for new modulation formats
- New modulation formats: RZ-DPSK, RZ-DQPSK
- Integration of phase- and intensity- modulators
# Comparison of 40Gbit/s modulation Formats

<table>
<thead>
<tr>
<th></th>
<th>NRZ</th>
<th>Duobinary</th>
<th>CS-RZ</th>
<th>RZ-DPSK</th>
<th>RZ-DQPSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical noise tolerance</td>
<td>Poor</td>
<td>Poor</td>
<td>Medium</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Chromatic dispersion tolerance</td>
<td>Medium</td>
<td>Good in linear regime</td>
<td>Medium</td>
<td>Medium</td>
<td>Good</td>
</tr>
<tr>
<td>PMD tolerance</td>
<td>Poor</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Good</td>
</tr>
<tr>
<td>Optical nonlinear tolerance</td>
<td>Medium</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>OADM cascadability</td>
<td>Good</td>
<td>Very good</td>
<td>Medium</td>
<td>Medium</td>
<td>Very good</td>
</tr>
</tbody>
</table>

### Optical spectra

- **NRZ**
  - Optical spectrum with peaks at various frequencies.

- **Duobinary**
  - Optical spectrum showing the modulation of the phase between "1" and "0".

- **CS-RZ**
  - Optical spectrum with distinct peaks indicating the modulation.

- **RZ-DPSK**
  - Optical spectrum showing the phase transitions between "1" and "0".

- **RZ-DQPSK**
  - Optical spectrum showing the phase transitions between "1" and "0" with additional phase changes.

### Key Points
- **Optical noise tolerance**: NRZ is poor, Duobinary is poor, CS-RZ is good, RZ-DPSK is good, RZ-DQPSK is good.
- **Chromatic dispersion tolerance**: NRZ is medium, Duobinary is good in linear regime, CS-RZ is medium, RZ-DPSK is medium, RZ-DQPSK is good.
- **PMD tolerance**: NRZ is poor, Duobinary is medium, CS-RZ is medium, RZ-DPSK is medium, RZ-DQPSK is good.
- **Optical nonlinear tolerance**: NRZ is medium, Duobinary is poor, CS-RZ is good, RZ-DPSK is good, RZ-DQPSK is good.
- **OADM cascadability**: NRZ is good, Duobinary is very good, CS-RZ is medium, RZ-DPSK is medium, RZ-DQPSK is very good.
# WDM History

<table>
<thead>
<tr>
<th>~Year</th>
<th>Commercial Introduction</th>
<th>Key Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>2-wavelength</td>
<td>1310 + 1550 coupler</td>
</tr>
<tr>
<td>1992-5</td>
<td>CWDM</td>
<td>Thin film filter</td>
</tr>
<tr>
<td>1996</td>
<td>DWDM</td>
<td>Fiber Bragg Grating (FBG) filter, Optical Amplifier</td>
</tr>
<tr>
<td>1999</td>
<td>OXC</td>
<td>2D MEMS Optical Switch</td>
</tr>
<tr>
<td>2001</td>
<td>Dense DWDM</td>
<td>Arrayed Waveguide Grating Mux (AWG)</td>
</tr>
<tr>
<td>2004</td>
<td>Re-configurable ROADM</td>
<td>Wavelength Selective Switch (WSS)</td>
</tr>
</tbody>
</table>
Automatic Power Balancing

- Maintains equal channel output power in face of wavelength assignment/rearrangement/network failure
- Enables software provisionable wavelength add/drop/thru and reconfigure
- No manual adjustments anywhere

Fujitsu patented technology

All wavelength power levels equal

Analysis and Control of Transient Dynamics of EDFA Pumped by 1480- and 980-nm Lasers

Cechan Tian and Susumu Kinoshita, Member, IEEE
Today’s networks, deploying 2.5Gb/s and 10Gb/s rates extensively. Will migrate to 40Gb/s per wavelength for:
- Higher rate client interfaces
- Overall capacity growth requirements

Challenges
- OSNR requirement is more stringent at 40G than 10G: 6 dB
- Dispersion sensitivity increases: x 16
- PMD sensitivity increases: x 4
- Optical filtering effects due to OADM filters
Variable Dispersion Compensation for 40Gbps

VIPA (Virtually Imaged Phased Array) based VDC

- Chromatic dispersion in 40Gbps systems
  - More severe dispersion tolerance
    - ~ 50 ps/nm
    - 1/16 of 10G systems
  - Chromatic dispersion changes with temperature
    - ~60 ps/nm @ 600 km, 50°C change

- Advantages of available Variable Dispersion Compensation
  - Replaces “menu” of fixed DCM
  - High tunable dispersion resolution: 1 ps/nm
  - Large variable dispersion range: ± 800 ps/nm
  - No penalty due to fiber nonlinear effect
## Ethernet History

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<tr>
<th>~Year</th>
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<th>Key Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>10-Base5</td>
<td>Thick Cable AUI</td>
</tr>
<tr>
<td>1991</td>
<td>10-BaseT</td>
<td>Twisted Pair, Hub</td>
</tr>
<tr>
<td>1990</td>
<td>Switched Networks</td>
<td>Bridge, Spanning Tree</td>
</tr>
<tr>
<td>1995</td>
<td>100-BaseT</td>
<td>DSP, Auto-negotiation, Switching</td>
</tr>
<tr>
<td>1998</td>
<td>VLANs</td>
<td>Routers, VLAN-switches, VLAN Trunks</td>
</tr>
<tr>
<td>1998</td>
<td>1 GbE</td>
<td>Silicon Ethernet Switches, Fabrics, Optical Interconnects</td>
</tr>
<tr>
<td>2002</td>
<td>10 GbE</td>
<td>Low-cost standardized Optical Interconnect (XFP et al.)</td>
</tr>
<tr>
<td>2002</td>
<td>Ethernet WAN</td>
<td>Ethernet over SONET, Metro Ethernet</td>
</tr>
<tr>
<td>2009 ?</td>
<td>100 GbE</td>
<td>Optical LAN Interconnect, WAN Support on Existing Spans</td>
</tr>
</tbody>
</table>
Ethernet Going Forward

- **Ethernet will become pervasive**
  - Overlays on existing optical infrastructure (EoS, EoCu)
  - Supporting new (eventually all?) types of services (real time, video, etc.)

- **Some approaches to converge Packets and TDM in the Metro:**
  - Packet over Ethernet over SONET over WDM.
  - TDM over Circuit Emulation Services over Packet over …
  - These are not as efficient as mapping non-native formats.

- **Muxponders, etc. provide efficient mapping**
  - Resulting network topology is usually point-to-point.
  - Ring and multi-point are possible (but more difficult).

- **Ethernet switching and aggregation is ultimately a better approach than fixed payload mappings.**
Transponding

Basic Transponding
Simple but Inflexible

Somewhat more
Flexible Transponding
Switching

Adding Packet Services To Existing SONET Network

Adding TDM Services To Existing Packet Network
Probable Future Direction

Most Flexible Approach, Yet efficient Mapping
Channel Compatibility

- Data Service rates will continue to increase.
- Existing systems are channelized.
- Research and Education environment generally needs flexibility:
  - New experiments, new formats, new rates alongside existing equipment and formats.
  - Compatibility with carrier systems for remote-location reach (GFP / VCAT etc.)
- Maximally-flexible equipment must accommodate intermixing of optical line formats and data rates.
  - Otherwise existing systems need to be replaced for rate & format upgrades.
  - Alien lambda support allows transparent transport (clear channel).
- Maximally-flexible equipment should accommodate both wavelengths and packets in flexible & switched architectures.
A control plane allows setup and teardown of Optical and TDM paths through a network.

GMPLS enabled network elements provide a method to simplify the establishment of these paths.

- A subset of options can be chosen for simple network topologies:
  - RSVP-based signaling,
  - Hard-state (explicit tear message required to delete a path),
  - Bidirectional requests
  - Centralized Path Computation Element (PCE) can advise on suitability of optical path.

- Well aligned for R & E environment needing path flexibility.

LDP not normally needed in optical/SONET GMPLS

- Optical paths and SONET paths are very static.
- Can determine (assume) label values without the need to run a distribution protocol.

Add IP/MPLS, LDP when packet switching is integrated into NE.
Conclusions

R & E Networks

1. Should include compatibility for forward-looking rates and formats in today’s equipment and spans.
2. Should focus on simplification of node designs in the face of multiple types of traffic.
3. Should be more easily optimized for Ethernet services.
4. Should plan for switch fabrics with multiple capabilities.
FLASHWAVE® 7500 ROADM
One Platform - Three Powerful Configurations

**FLASHWAVE 7500 core**
- 40 channels WSS ROADM, 8-degree Hubbing
- Best-in-Class transmission performance
  - <= 24 nodes, <= 1000 km ring size, without OEO
- Active, non-banded
- Dynamic, self-tuning optical network
- Common Transponders and Software
- Perfect for metro & regional applications

**FLASHWAVE 7500 small system**
- 32 Channel FOADM and ROADM
- 19” shelf; 19” & 23” rack mounted option
  - <= 16 nodes, 800km ring size without OEO
- Active, non-banded, self-tuning
- Common Transponders and Software
- Compact, low cost Metro/Edge applications

**FLASHWAVE 7500 extension system**
- Lower-cost, smaller capacity FLASHWAVE 7500 Extension
  - Perfect for Pt - Pt spurs or extensions
  - Combine with Passive Coupler and Amp where needed
  - Common Optical Line Cards (ie Transponders) and OLC shelf