40Gbit/s & 100Gbit/s Implementation Tradeoffs

Internet2 Meeting
April 29, 2009

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Topics

- Applications for 100GbE & 40GbE in R&E Networks
- Tradeoffs between 40G and 100G transmission
  - Physical comparison of bit rates
- Short reach vs long reach interfaces
- 40G modulation format evolution
  - PSBT, CS-RZ, DPSK, DQPSK, DP-QPSK
- 100G modulation format evolution
  - DQPSK, DP-DQPSK, DP-QPSK, DW-DP-QPSK
  - N-ASK/DPSK, OFDM, N-QAM
- Innovation and development areas

Alphabet Soup!
100G Objectives for R&E Networks

- Enable very high speed router interconnect across R&E backbone. Support 100GbE interface transport.
- Optical switching and restoration of 100G as single OTN wavelength
- Simplify network operation – design, troubleshooting etc. through big-pipes rather than wavelength bundling
- Efficiently enable statistical multiplexing of multiple 10GbE interfaces
- Improve overall system capacity to multiple Terabit/s
- Reduce cost per bit transport
## Comparisons between 40G and 100G

### Transmission impairments

<table>
<thead>
<tr>
<th>Transmission Impairment Sensitivity for Simple Modulation</th>
<th>10Gbit/s</th>
<th>40Gbit/s</th>
<th>100Gbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromatic Dispersion Sensitivity</td>
<td>1</td>
<td>x 16</td>
<td>x 100</td>
</tr>
<tr>
<td>Polarization Mode Dispersion (PMD) Sensitivity</td>
<td>1</td>
<td>x 4</td>
<td>x 10</td>
</tr>
<tr>
<td>OSNR requirement</td>
<td>1</td>
<td>+6dB</td>
<td>+10dB</td>
</tr>
<tr>
<td>Optical band-pass sensitivity</td>
<td>1</td>
<td>x 4</td>
<td>x 16</td>
</tr>
<tr>
<td>Sensitivity to fiber nonlinearity</td>
<td>1</td>
<td>x 4</td>
<td>x 10</td>
</tr>
</tbody>
</table>

- 40G symbol rates compatible with 50GHz DWDM multiplexing
  - 2+ bits / symbol beneficial but not mandatory
- 100G symbol rates not compatible with 50GHz DWDM grid
  - 2+ bits / symbol mandatory to achieve 50GHz filter compatibility
100G Short Reach interfaces
Multi-lane approaches

- Short reach optical interfaces will be provided by low-cost multi-lane approaches
- MSAs for vendor interworking

Source: Finisar

**CFP**
120mm x 86mm

4 x 25G CWDM wavelengths for 100GbE

Source: Finisar

**CXP**
45mm x 27mm

12 x 10G ribbon for 100GbE, QDR Infiniband (120Gbit/s)

Courtesy of Molex
Transport Interfaces
40G Modulation Formats

- PSBT
  - Simple, low cost transmitter / receiver design
  - Spectrally efficient but limited reach

- CS-RZ
  - Simple, low cost transmitter / receiver design
  - Relatively wide spectrum suffers from bandpass narrowing with ROADMs

- RZ / NRZ-DPSK
  - Differential receiver
  - Good OSNR tolerance
  - Moderate spectral efficiency and filtering tolerance

- RZ-DQPSK
  - Differential receiver
  - 2bits / symbol
  - Improved filtering tolerance

- Others: QPSK, DP-QPSK (coherent)
  - Coherent detection with DSP
  - Good spectral efficiency and OSNR tolerance
  - 2 or 4 bits / symbol
  - More complex transmitter / receiver and electronics
Comparison with ROADM Bandpass
40G Modulation Formats

- **NRZ-DPSK**
  - Wider spectrum shows moderate sensitivity to bandpass narrowing

- **RZ-DQPSK**
  - 2 bits / symbol improves spectral efficiency
  - Improved tolerance to multiple ROADM concatenation
  - Improved tolerance to PMD
  - More complex transmitter / receiver design

- **Others : QPSK, DP-QPSK (coherent)**
  - Coherent detection with DSP
  - Good spectral efficiency and OSNR tolerance
  - Significantly more complex transmitter / receiver

40G modulation formats spectra compared with filter bandwidths
Challenges for 100G Transmission

Requirements for 100G transmission
- Compatible with existing, mostly 10G networks
- Allow upgrades from 10G to 40G to 100G, or from 10G to 100G
- Minimal change to deployed optical layer infrastructure
- Compatible with ROADM deployments

Solutions
- Implementation of advanced modulation formats
- Bandwidth of common modulation formats for 10G and 40G may be too broad for ROADM devices
  - More complex and bandwidth efficient modulation formats are needed
- For new deployments, improvements in ROADM characteristics: passband width & shape
Primary modulation formats
40Gbit/s and 100Gbit/s

1 bit/symbol
- NRZ / RZ-OOK
- PSBT
- CS-RZ
- DPSK

2 bits/symbol
- QPSK
- DQPSK

4 bits/symbol
- PM-QPSK
- PM-DQPSK

>4 bits/symbol
- N-QAM
- OFDM
- N-ASK/M-PSK

Constellation diagrams

Symbol Rates:
- 40Gbit/s: 40Gsym/s
- 100Gbit/s: 100Gsym/s

40G

100G
Improved spectral efficiency enables 40G, 100G to operate over many existing 10G networks
100Gbit/s Pol. Mux. DQPSK (PM-DQPSK)

- Polarization-multiplexed DQPSK – 28GSym/s - bandwidth efficient and robust to optical filtering
- 50GHz ROADM, 3dB bandwidth 44–45GHz in recirculating loop experiment
- <1dB penalty after 8 ROADM passes with symbol-aligned polarization

S. Chandrasekhar and X. Liu – OFC/NFOEC 2008, OThU7

50GHz filter compatibility with 100Gbit/s PM-DQPSK
100Gbit/s Pol. Mux. QPSK
PM-QPSK (coherent detection)

PM-QPSK coherent detection
- 2dB higher Q factor compared to PM-DQPSK
- No penalty for BW higher than 23GHz

Renaudier et al.
- 0 pen. for BW>35GHz

More complex receiver design than PM-DQPSK

Bandwidth comparison
T. Schmidt et al. IEEE LEOS Summer Topical 2008

Improved Tolerance to bandpass narrowing using PM-QPSK
Benefits of Coherent Detection

- Coherent detection provides high sensitivity receivers
- Electrical field detection enables compensation of some transmission impairments in the digital domain
  - Chromatic dispersion
  - Polarization mode dispersion
- Using DSP, the local oscillator (laser) does not have to be optically phase locked – phase estimation in the digital domain
- Electrical field detection also supports polarization demultiplexing

Issues:
- Complex receiver design.
- Very high speed ADC (50GS/s) and DSP required. No devices available yet for single wavelength 100G.

Existing reported 100G coherent detection results have used offline processing – not real time
Metro optimized modulation format
111Gbit/s DPSK-3ASK

- 2.5 bits per symbol (5 bits/2 symbols)
- 44 GBd (use of 40G components)
- Single-drive MZ modulator at TX
- Balanced DLI-RX (DPSK)
- Dual-Threshold-DD-RX (3ASK)

Cost-effective metro 100G
100G application space

Campus (<40km)

**IEEE 802.3ba**
- 4 x 25Gbit/s
- 4 wavelengths in 1310nm window
- Short reach
- Bad spectral efficiency
- Connectivity for client interfaces

Metro & regional (40km–600km)

**DPSK–3ASK**
- Direct detection
- 40G electronics
- Components available, proven and affordable
- Compatible with deployed WDM systems
- Low power consumption
- Fast time to market
- ...

(U)LH (>600km)

**DP-QPSK + others?**
- Coherent detection
- High-speed electronics (still under development, expensive)
- High power consumption
- ...

Investigation area
Thank you

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