40/100 Gb/s Ethernet Over Multi-mode Optical Fiber

Planning for Infrastructure Readiness
40/100 Gb/s over MMF

• Evolution of Ethernet
  – 40/100 Gb/s Ethernet Adoption Timeline
  – Server port growth
  – IEEE 802.3ba Objectives
  – OM3
  – Link and Cable Characteristics

• Achieving 40/100 Gb Ethernet

• Issues

• Cabling Recommendations

• What’s the Bill

• Summary
Ethernet Timeline

<table>
<thead>
<tr>
<th>Time to Reach (years)</th>
<th>Million Port Sale (after Ratification)</th>
<th>60% Market Penetration</th>
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</thead>
<tbody>
<tr>
<td>10 Mb E</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>100 Mb E</td>
<td>1</td>
<td>5</td>
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<tr>
<td>1000 Mb E</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>10 Gb E</td>
<td>6</td>
<td>10+</td>
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Flatman, LAN Technologies, 2007
40/100 Gb Ethernet

x86 Servers by Ethernet Connection Speed

Source: Intel/Broadcom (Nov 2007)
IEEE 802.3ba Objectives

• Provide Physical Layer specifications which support 40 Gb/s operation over:
  – At least 100m on OM3 MMF
  – At least 10m over a copper cable assembly
  – At least 1m over a backplane

• Support a MAC date rate of 100 Gb/s

• Provide Physical Layer specifications which support 100 Gb/s operation over:
  – At least 40km on SMF
  – At least 10km on SMF
  – At least 100m on OM3 MMF
  – At least 10m over a copper cable assembly
... at least 100m on OM3 MMF

• OM3* multi-mode fiber is:
  – 50/125 µm
  – 2000 MHz•km EMB**, minimum, at 850 nm

• ANSI/TIA-598-C Optical Fiber Cable Color Code
  – Indoor cable with AQUA jacket

* Type A1a.2 as specified in IEC 60793-2-10
** Effective Modal Bandwidth
Link and Cable Characteristics*

- Supported fiber types
  - 50/125 µm, OM3

- Effective Modal Bandwidth (EMB)
  - 2000 MHz•km** minimum

- Power Budget
  - Greater than 8.3 dB***

- Channel Insertion Loss
  - 1.9 dB

*As of December 2008  **Launch Condition Dependent  ***For Further Study  Connector Loss Under Study
40/100 GbE over MMF

- Evolution of Ethernet
- Achieving 40/100 Gb/s Ethernet
  - Enabling Technology
  - Parallel Optics, 40 Gb/s
  - Polarity Today
  - Parallel Optics, 100 Gb/s
  - Polarity
  - Recap
- Issues
- Cabling Recommendations
- What’s the Bill
- Summary
Enabling Technology

- **Multilane Distribution (MLD) – Parallel Links**
  - 40 Gb/s equals 4x fibers each for Tx and Rx
    - Each carrying a 10 Gb/s signal
  - 100 Gb/s equals 10x fibers each for Tx and Rx
    - Each carrying a 10 Gb/s signal

Today, two fibers can support full duplex 10 Gb/s

40 Gb/s will require 4x the fiber count
Parallel Optics, 40 Gb/s

- MTP™*/MPO (Multi-fiber Push On) Connectors
- 8 or 12 Fiber Loose Tube or Ribbon cable
- Likely a pre-terminated assembly solution

*MTP is a registered trademark of USCONEC
Parallel Optics – Polarity Today

Type-A MPO-to-MPO array cable

Type-B MPO-to-MPO array cable

Type-C MPO-to-MPO array cable

TIA-568-C.3
Parallel Optics, 100 Gb/s

- 100 Gb/s will use 10 fibers per Tx to Rx link
- Two 12F MTP/MPO connectors, or
- 24-Fiber MTP/MPO connections can significantly reduce pre-terminated connection costs and increase connection densities
- No standards on 24F polarity at this time
Parallel Optics – 24F Polarity

- 10 channel links for 100 Gb/s
  - Require 2x quantity of 12F MTP/MPO’s, or
  - 24F MTP/MPO’s
  - 24F Polarity resolution undefined
Recap

- 40/100 Gb/s will use
  - Multiple fibers per Tx/Rx link
  - Minimum of OM3 specified, 2000 MHz•km @ 850 nm
  - MTP/MPO connectors
  - Loose tube or ribbon cabling compatible with MTP/MPO
  - Preterm likely the norm
  - Polarity puzzle
40/100 GbE over MMF

- Evolution of Ethernet
- Achieving 40/100 Gb Ethernet
- Issues
  - Arrival Time
  - Optical Skew
  - Skew Measurement
  - Skew Results
- Cabling Recommendations
- What’s the Bill
- Summary
Arrival Time

- Multi-lane signals launch simultaneously
- Fiber length and modal paths vary
- Signal components arrive out of sync

This difference in arrival time is optical skew
Is Optical Skew a Problem?

- Transmission media (optical fiber) major contributor to skew
  - Proposed allowance* for skew due to transmission media
    - 100 ns
  - Expected maximum contribution from optical media
    - 13.6 ns

- Is a particular cable construction better in minimizing transmission optical skew?

* 100GE/40GE skew budget, IEEE 802.3ba TF, Dallas November 2008, Gustlin/Anslow/Giannakopoulos
Optical Skew Measurement

- **Method A**
  - Transmit a pulse down the fiber
  - Measure arrival time
  - Repeat for all fibers
  - Calculate maximum difference

- **Method B**
  - Transmit a pulse down the fiber
  - Measure arrival time of reflections
  - Repeat for all fibers
  - Calculate maximum difference

a. Time of flight - transmission method

b. Time of flight - reflection method (such as standard OTDR)
Optical Skew Measurement

- **Method C**
  - Launch RF modulated optical signal down each fiber using single mode optics
  - Measure the phase difference of received RF signal with the reference, using a precise phase meter: propagation delay
  - Calculate maximum delay difference
Skew Measurement Results

- Quadrature Phase Shift Testing
  - 100 meter test length
    - Loose Tube tested maximum
      - 0.8 ns
    - Ribbon tested maximum
      - 0.3 ns

- Proposed Skew Allowance for 40GBASE-SR4 and 100GBASE-SR10
  - 100 meter length
    - 100 ns (over 100 times measured maximums)

For Optical Skew neither loose tube cabling or ribbon cabling a problem
40/100 GbE over MMF

• Evolution of Ethernet
• Achieving 40/100 Gb Ethernet
• Issues
  • Cabling Recommendations
    – Size and Bend
    – Fiber Count
• What’s the Bill
• Summary
Size and Bend

- **Optical Skew**
  - Loose Tube and Ribbon cabling
    - Optical skew adequately handled by electronics

- **Preferential Bending Limits Flexibility**
  - Loose Tube Cabling
    - No preferential bend
  - Ribbon Cabling
    - Has preferential bend

- **Reduced O.D. 48F Loose Tube Cable (0.231")**
- **48F Loose Tube Cable (0.370")**
- **48F Stacked Ribbon Cable (0.520")**
Fiber Count Requirements (1)

- Today, a 12F, OM3, MPO-MPO backbone link
  - Provides up to six full duplex 10Gb/s Tx/Rx pairs

- 40GBASE-SR4
  - Requires a minimum of eight OM3 fibers for a Tx/Rx link
    - 4 fibers Tx
    - 4 fibers Rx
  - Should be able use installed legacy 10GBASE-SR links
    - 100m length

- 100GBASE-SR10
  - Requires a minimum of 20 OM3 fibers for a Tx/Rx link
    - 10 fibers Tx
    - 10 fibers Rx
Fiber Count Requirements (2)

• Legacy 10 GbE systems may not be directly mappable to 40/100 Gb/s
  – A legacy 144F MPO-MPO backbone
    • Will support 12x 40GBASE-SR4 duplex links
    • May support 6x 100GBASE-SR10 duplex links

• For 40GBASE-SR4
  – Anticipate 8/1 ratio on fiber count to link
    • A 144F cable will support 18x 40Gb/s Tx/Rx links

• For 100GBASE-SR10
  – Anticipate 20/1 ratio on fiber count to link
    • A 144F cable will support 7x 100Gb/s Tx/Rx links
40/100 GbE over MMF

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  - What's the Bill
    - Link Cost on OM3
    - About single mode
    - OM3 and OS2
    - About OM4
- Summary
Link Cost on OM3

• Traditional rule of thumb, 3x cost increase for 10x performance increase
  – Not likely to hold for 40/100 Gb/s
  – Estimates very preliminary, around 4x for 40GBASE-SR4

• 10GBASE-SR, XFP
  – About $1300, 2008
  – 4x equals $5200. 2x ports equals $10,400

• 12F, OM3, Loose Tube Plenum, 100m length
  – About $500

Total Link Cost $10,900, estimated
About Single Mode

• Not Parallel Optics
  • Initial release using CWDM
    – 40GBASE-LR4 uses 4x 10 Gb/s wavelengths
    – 100GBASE-LR4 will likely use 4x 25 Gb/s wavelengths
  • Estimate of 6x* cost of 10GBASE-LR
    – Expected cost reductions with technology/optimization improvements

- 10GBASE-LR, XFP $1600
  - 6x = $9600, Times 2 ports = $19,200

- 12F, OS2, Loose Tube Plenum, 100 m length
  - $200

OM3 and OS2

• Estimated link cost for 40GBASE-SR4
  – $10,900

• Estimated link cost for 40GBASE-LR4
  – $19,400

• Cost difference OM3 → OS2
  – + $8,500
About OM4

• Current 10GBASE-SR uses VCSEL’s
  – RMS Spectral width about 0.25 nm
  – That is a tight light source
  – When you combine low modal dispersion of OM4/OM3 fiber with low chromatic dispersion of this laser – you go farther

• Initial 40/100 Gb/s specification calls for
  – RMS Spectral width of 0.65 nm

• Why?
  – Reduce costs of transmitters and receivers
  – Early adopters of 40/100 Gb/s will be data centers/SAN’s
40/100 GbE over MMF

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• Summary
  – 40/100 Gb/s Redux
40/100 Gb/s Redux

- OM3 multi-mode fiber specified
  - 2000 MHz•km EMB at 850 nm

- At least 100 meter runs supported

- Parallel optics used
  - MTP/MPO

- Optical skew exists but is compensated for by active components
  - Observed skew 100 times less than specified

- Optical cabling recommendations
  - Loose tube, no bending preference

- Cost
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