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2008 BICSI FALL CONFERENCE

Sept. 29-Oct. 2, Las Vegas, NV

Exhibition: Sept. 28-Oct. 1

10 GB Ethernet: Copper or Fiber?

Choosing the Right Media for the Application

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Outline

- Why 10 GB Ethernet?
- Current Standards
- Copper Choices
- Fiber Choices
- Comparison
- Summary

Why 10 GB Ethernet?

- Aggregation of 1GbE networks is the top driver of 10GbE growth in the enterprise
- Converging Networks
  - Video Conferencing or IPTV
  - VoIP
  - Data
- Back-ups to SAN or Remote Locations
- Regulatory Compliance
- Virtualization & Consolidation

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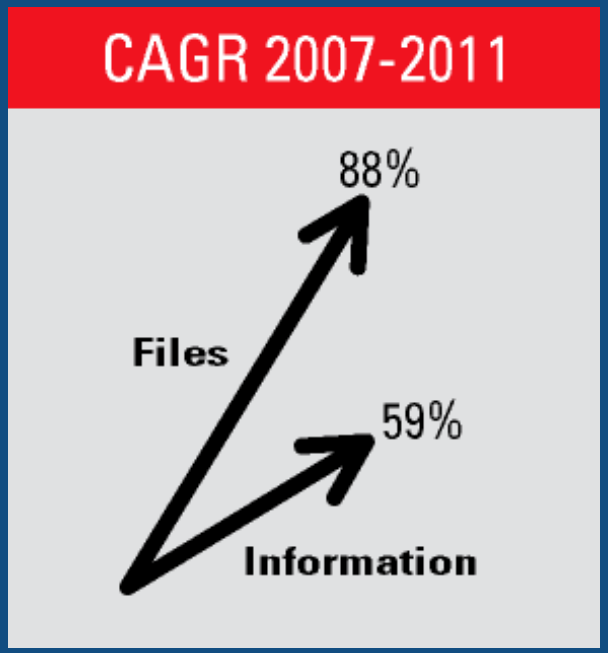
Demand for Bandwidth

- "By 2011, the digital universe will be 10 times the size it was in 2006"[1]
- Information growing at 59% CAGR
- "Files" growing at 88% CAGR
- Enterprise Storage requirements are increasing 50% per year[2]



Sources: (1) IDC, March 2008; (2) EMC

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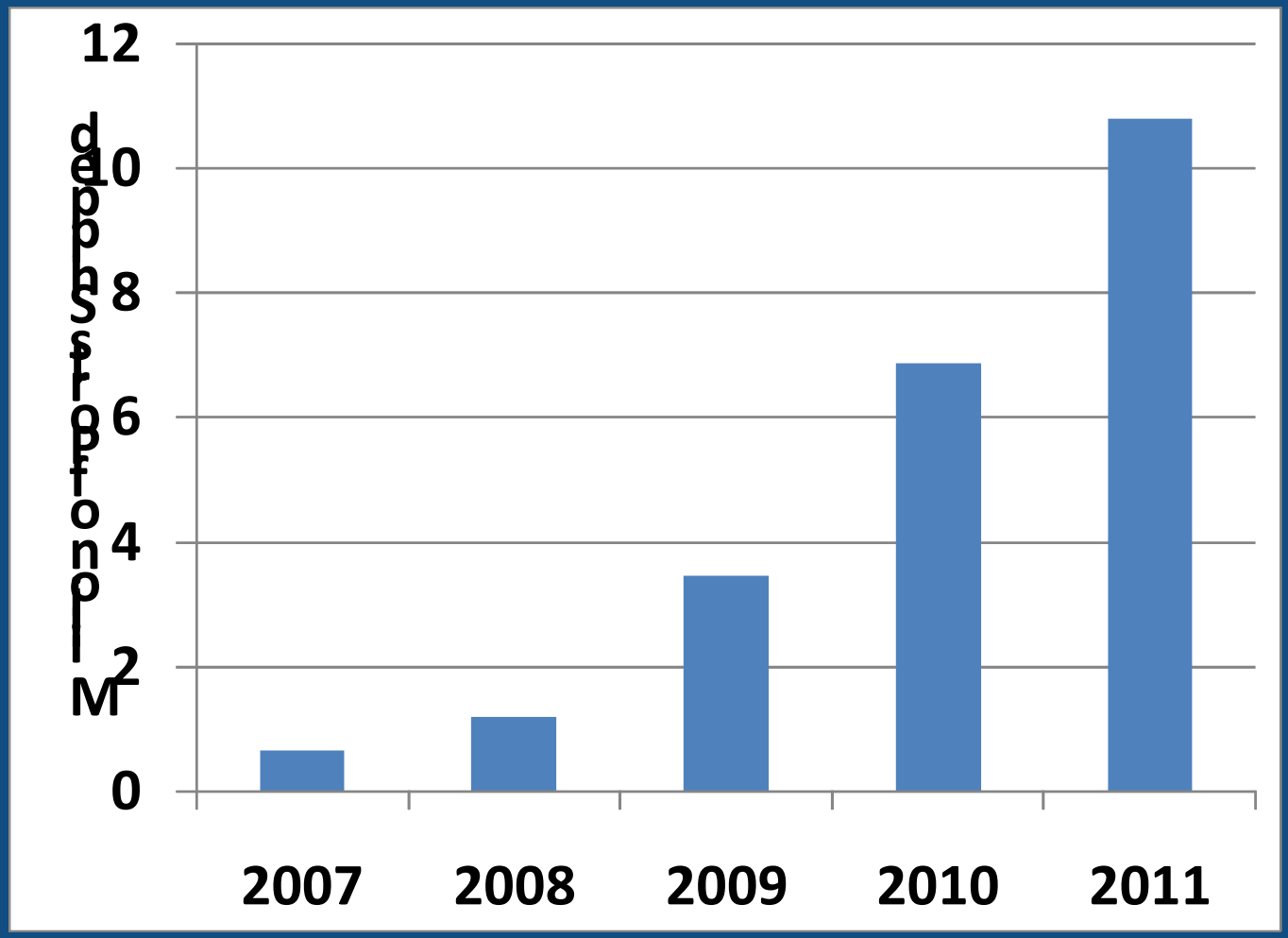
Current 10GbE Market

- Majority of current 10GbE ports used for Metro Ethernet
- 10GbE ports currently represent <1% of 1GbE Enterprise ports

10GbE Switch Ports Forecast



Source: Dell 'Oro Group

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Media Options: Copper and Fiber

- How do I choose?
  - Application Environment
  - Cost
  - Installation
  - Performance
- Are the standards in place?
- Is there more than one choice for a particular medium?

Media Options: Copper and Fiber

- What criteria should I use to choose between the two media?
- What are the advantages and disadvantages of each?
  - Installation
  - Channel Density
  - Longevity
  - Active Component Cost

Copper & Fiber Standards

Systems and Cables

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Copper System Standards

- IEEE 802.3ak – 10GBASE-CX4 (2004)
  - Short Range: 15 meters maximum
  - Transmits over 4-lanes of copper (Infiniband cable)
- IEEE 802.3an – 10GBASE-T (2006)
  - 100 m channels with CAT 6A cables
  - Defines only channel Requirements
    - Alien & Internal Crosstalk
    - Attenuation
    - Return Loss

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Copper Cable Standards

- TIA 568-B.2-10 (2008)
  - Greatly exceeds requirements of IEEE 802.3an
  - Contains channel, permanent link, and component requirements
  - Does not explicitly cover shielded cables

Copper Cable Standards

- IEC 11801, Amendment (Not Edition 2)
  - Expected publish date 4th Quarter 2008
  - Exceeds requirements of IEEE 802.3an and TIA 568
  - Only channel & connector requirements; includes shielded
  - Cable requirements: IEC 61156-5

Copper Cable Standards

- TSB-155 (Technical Service Bulletin, 2007)
  - Follows IEEE 802.3an channel requirements
  - Allows 55 m channels using of Cat 6 cables with caveats
  - Requires field testing & Alien Crosstalk mitigation techniques

Fiber System Standards

- 10GBASE-SR (Short Range, MMF)
  - Range of between 26 m and 82 m depending on bandwidth of legacy fiber at 850 nm
  - Supports 300 m using Laser Optimized 50 µm with 2000 MHz·km Bandwidth
- 10GBASE-LRM (Long Range MMF, 802.3aq)
  - ≤ 220 m on MMF at 1300 nm
  - Utilizes Electronic Dispersion Compensation
  - Will work with 98% of installed 62.5 µ Fiber

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Fiber System Standards

- 10GBASE-LX4
  - Uses WDM (4 x 3.125 Gbit/s) on MMF; supports ranges between 240 m and 300 m
  - Also supports 10 km over SMF using wavelengths around 1310 nm.
- 10GBASE-LR/ER/ZR (Long/Extended ; SMF)
  - LR – Serial Ethernet, 10 km – 25 km.
  - ER – $\leq$ 40 km at 1550 nm.
  - ZR – $\leq$ 80 km at 1550 nm (Not IEEE standard)

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Fiber & Fiber Cable Standards

- TIA 568-C.3
  - Includes all fiber types required for 10GbE
  - Performance requirements referenced in ICEA 596
- ICEA
  - S-83-596 – Premises Fiber Cable
  - S-104-696 – Indoor/Outdoor Cable
  - S-87-640 – OSP Loose Tube Cable

Fiber & Fiber Cable Standards

- ITU-T G-series specify SM fiber, i.e. G.652, etc.
- ISO/IEC 11801
  - OM1, OM2, and OM3 MMF designations
  - References IEC 60794, cable requirements
  - References IEC 60793, fiber requirements
- TIA-492
  - MMF specifications: Up to date.
  - SM fiber specifications: Out of date.

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Copper Media Options

Unshielded and Shielded

Why Copper?

- Existing Infrastructure
- Familiarity of Media
  - Same form factors & installation techniques
  - Some additional training over previous category levels
- Potential for Power over Ethernet
  - Security Cameras
  - Remote Devices
  - WiMax & WiFi

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Copper Media Solutions

- Unshielded Twisted Pair (UTP)
  - Designed for AXT Resistance
    - Very Tight Pair Twist
    - Cable to Cable Separation
  - Size Typically Larger than Standard CAT 6
  - Only 4-Pair Allowed by Standard
- Shielded Twisted Pair
  - STP (U/FTP)
  - ScTP (F/UTP)
  - Pair Counts Higher than 4-Pair Possible

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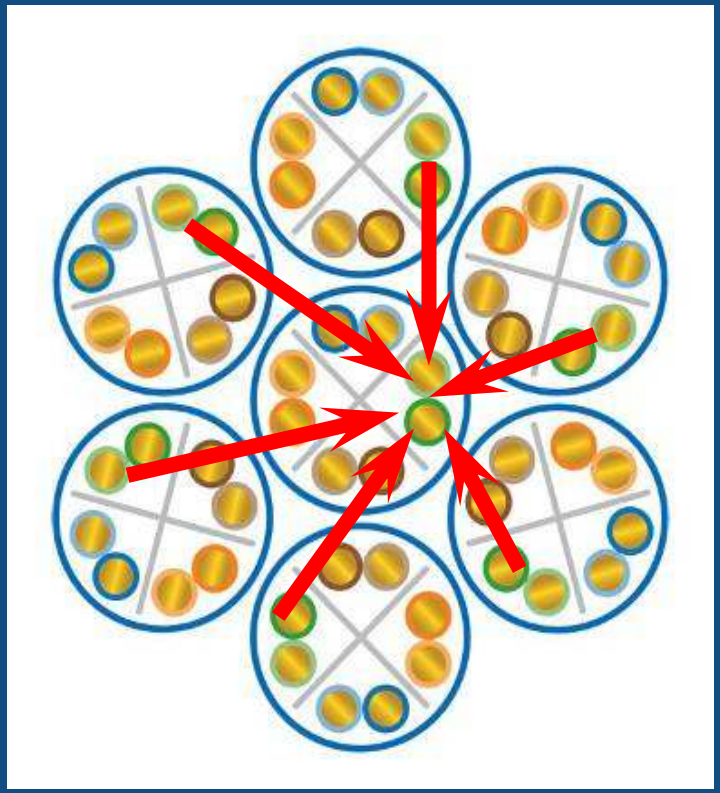
Common Copper Media Issues

- Maximum Distance 100 meters
- Internal Parameter Requirements
  - Crosstalk & Return Loss same as Cat 6 except extended to 500 MHz
  - Attenuation (IL) lower than Cat 6
- Alien Crosstalk (AXT)
  - Cable
  - Connectivity
  - Interaction between cable and connectivity

Power Sum Alien Crosstalk

- Alien crosstalk is the noise heard between cables
- Crosstalk on one pair in the disturbed cable is Power Summed from all pairs in adjacent cables
- Test cable tied every 8 inches



Copper UTP Performance

- Cable AXT Resistance
  - Tight Pair Twist
  - Distance of cable core to alien cable core
- Connectivity AXT Resistance
  - Various non-grounded “shielding” methods
  - AXT Resistant Circuitry
  - Non-grounded shielded patch cords allowed

Copper UTP Performance

- Interaction between cable and connectivity
  - Can add noise to the channel increasing AXT even though components meet requirements
  - Channel test to insure AXT compliance
- Installed Base of Cat 6 UTP and 10 GbE
  - Cat 6 “allowed” by TSB-155
  - AXT field testing & mitigation required
  - ≤ 55 m but length dependent on AXT level

Copper UTP Installation Issues

- Larger Cable Size (0.35” maximum) affects Bend Radius, Fill Ratio, and Routing
- Cable Routing
  - Loose Bundles – the more disorganized the better
  - Do not want to “pinch” cable
  - 0.33” Average / 0.35” Maximum OD
    - Larger bend radius
    - Larger size requires more space
  - Heavier Cable
  - Lubricants Not Recommended

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Copper UTP Installation Issues

- Connectivity
  - Pair twist must be maintained at the connector
  - Proper seating of the wires onto the connector
- No Grounding & Bonding Required
- Field Testing
  - Internal Parameters
  - AXT Verification Relatively Long and Involved

Shielded Copper Performance

- Cable/Connectivity AXT Resistance
  - Exceptional AXT Resistance using either U/FTP or F/UTP
  - Provides EMI/RFI Resistance
- Shielding Configuration
  - U/FTP shielding provides exceptional Internal Crosstalk Performance
  - F/UTP Internal Crosstalk Maintained by Twist and Separation

Copper Shielded Installation Issues

- Cable Routing
  - 0.29” Average OD – smaller than UTP
  - Cable Slightly Stiffer Due to Shielding
  - Lubricants Have Virtually No Impact
- Bonding and grounding important
- Maintain pair twist & properly seat wires onto the connector
- Field Testing - AXT Verification Not Required

Cable Media Configurations

- 4-Pair
  - Riser and Plenum
  - UTP and Shielded
- > 4-Pair
  - Not allowed by standards for UTP
  - Technically not allowed by standards for shielded but possible
- OSP and I/O
  - Possible but not covered by any standard
  - Currently unavailable

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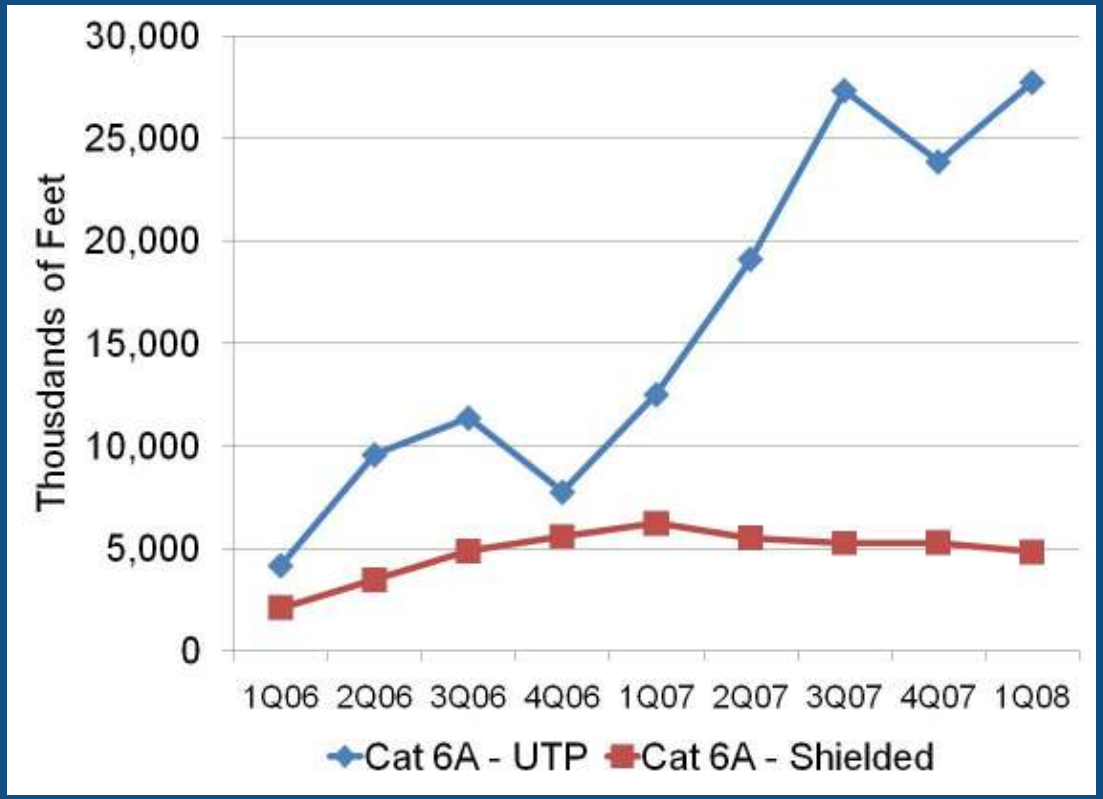
Cat 6A Demand – UTP vs. FTP



- Survey Data from top 8 U.S. Data Cable Manufacturers
  - Cat 6 F/UTP is not included
  - Cat 6A currently represents ~2% of total data cable market
- Two key factors are limiting shielded cable growth
  - Incremental costs of materials and installation
  - Familiarity

Source: Burroughs Industry Survey, North America

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Copper Media: Active Components

- Routers & NIC's Becoming Available
  - Intel, Tehuti, Chelsio, SMC & others
  - NIC Cost $1300 (SMC)
- 2008 Survey of Top Ethernet Suppliers
  - 40% support 10GBASE-T Today
  - Additional 35% have plans to support 10GBASE-T within 12 months
  - Use of integrated devices expected to result in much lower costs and power requirements

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Fiber Media Options

Choosing the Right Fiber

Why Fiber?

- Low Signal Loss
- High Bandwidth
- Greater transmission distance
  - SMF up to 80 km
  - MMF up to 550 meters
- Not Affected by EMI or RFI
- Small Size
- Lightweight

Fiber Media Solutions

- Single Mode Fiber
  - Low Water Peak
  - Zero Water Peak
- 62.5 µm Multimode Fiber
  - 180/500 MHz-km @ 850/1300 nm*
  - Legacy Fiber with Largest Installed Base
  - Limited Bandwidth
- 50 µm Multimode Fiber
  - 500/500 MHz-km @ 850/1300 nm*

* Overfilled Launch Bandwidth

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Fiber Media Solutions

- 50 µm Laser Optimized Multimode Fiber
  - Bandwidth Optimized at 850 nm
  - 10 GbE up to 150 m
    Bandwidth: 950 MHz-km*
  - 10 GbE up to 300 m (OM3)
    Bandwidth: 2000 MHz-km*
  - 10 GbE up to 550 m
    Bandwidth: 4700 MHz-km*

*Effective Modal Bandwidth @ 850 nm

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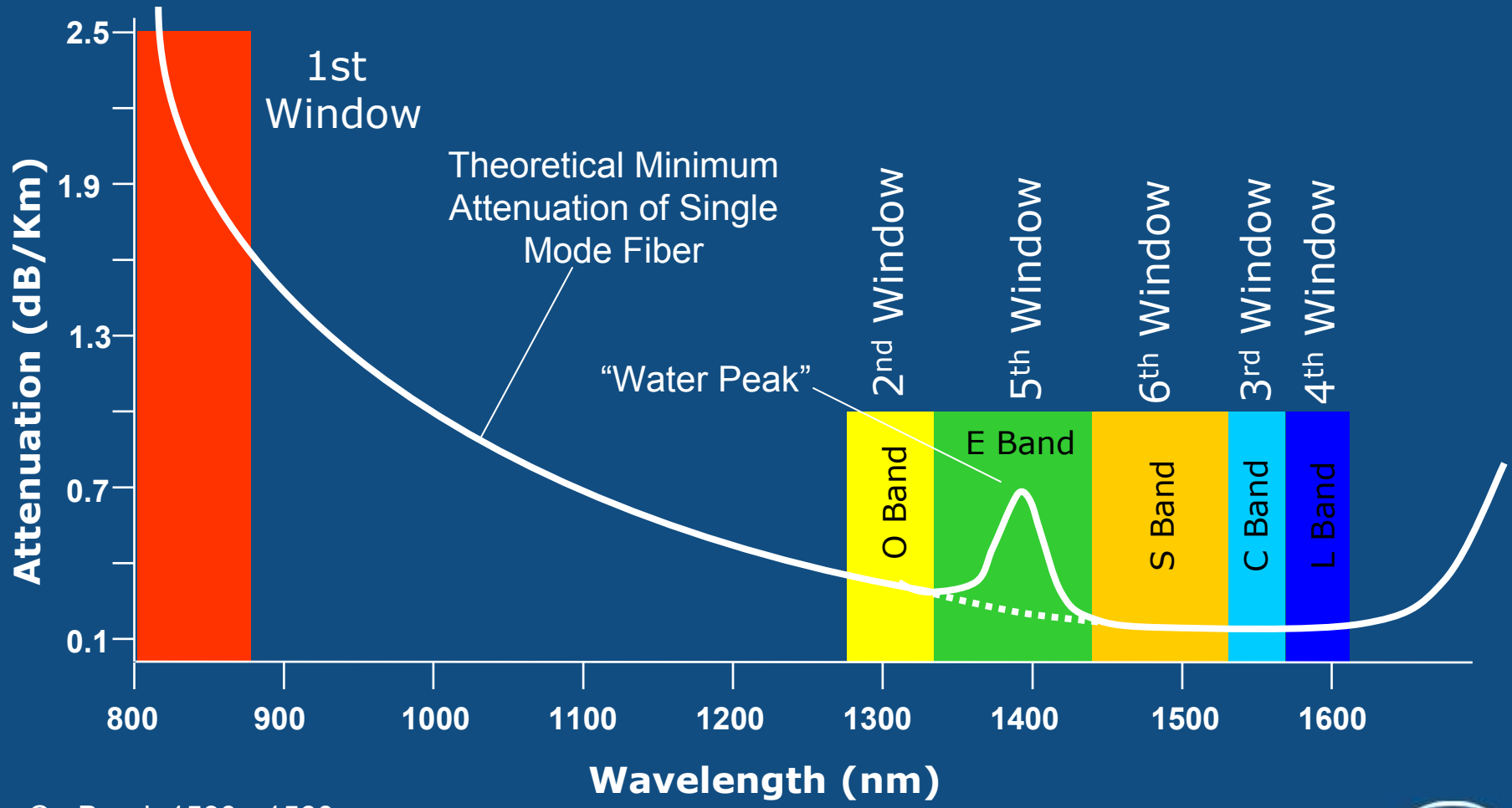
Windows of Operation

Reference Point: Visible Light is between 450 and 650 nm



C - Band 1530 - 1560
L - Band 1565 - 1610

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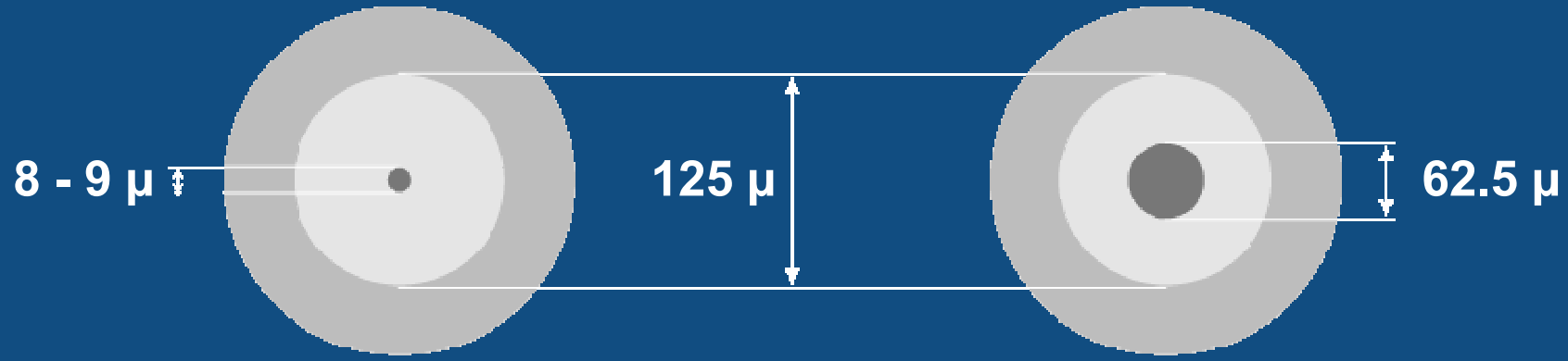
Fiber Media Performance Issues

- Attenuation
- Bandwidth Limited by Dispersion
- Installation
  - Tight bend induced attenuation
  - Splicing induced point discontinuities
  - Field Testing with power meter or OTDR
- Transmission Distance Dependent on Fiber Type and Channel Attenuation

Optical Fiber Type Comparison



Single Mode		Multi-mode	
Lower Fiber Cost	Inexpensive Cable	Higher Fiber Cost	Expensive Cable
Very small core	Expensive Connectivity	Very Large Core	Inexpensive Connectivity
Lower Attenuation	Longer Distance	Higher Attenuation	Shorter Distance
Higher Bandwidth	Higher Capacity	Lower Bandwidth	Lower Capacity

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Performance: Attenuation

- Attenuation is amount of signal (light) that is lost as the light travels along the fiber.
- Attenuation is measured in dB per km at specified wavelengths, measured in nanometers (nm).
- Typical Attenuation for various types of optical fiber

Fiber Type	850 nm	1310 nm	1550 nm
Single Mode	N/A	0.35 dB/km	0.25 dB/km
Multimode	3.5 dB/km	1.0 dB/km	N/A

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Sources of Attenuation

- Intrinsic
  - Raleigh Scattering
  - Water Peak Absorption
- Splice Loss
  - Fusion or Mechanical: core alignment
  - Mechanical: dirt on end face, reflection
  - Mode Field Diameter in Single Mode Fibers
  - Numerical Aperture Mismatch in Multimode Fibers

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Sources of Attenuation

- Bending
  - Macrobending (Single Mode Fiber)
    - Bending radius ~ 2 – 15 mm
    - Affects long wavelengths first
    - Affected mostly by fiber design
  - Microbending (All Fiber Types)
    - Bending radius ~ radius of core
    - Fiber & cable design and manufacturing
    - Installation due to point pressures
    - Sensitivity: SM << 62.5 μ < 50 μ

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Bandwidth Performance: Dispersion or Pulse Broadening

- Chromatic Dispersion (SMF)
  - Laser output is distribution of wavelengths
  - Different wavelengths travel different speeds
  - Dispersion compensating fiber
- Polarization Mode Dispersion (SMF)
  - Radially imperfect core
  - Causes delay in 1 of 2 Orthogonal Modes

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Bandwidth Performance: Dispersion or Pulse Broadening

- Modal Dispersion (Multi-mode Fibers)
  - Mode is quantum level in light pulse
  - Each mode spatially occupies different area of core
  - Core index of refraction profile causes modes to have different speeds

Measuring Modal Dispersion

- Over-Filled Launch (OFL)
  - Uses LED
  - Completely fills all modes of multimode fiber
  - Specify for standard OM1 and OM2 Fibers
- Differential Modal Dispersion
  - Uses laser scanning technique
  - Measures Pulse Intensity and Time of Arrival
  - Effective Modal Bandwidth (EMB) determined
  - Specify EMB for Laser Optimized 50 micron fibers

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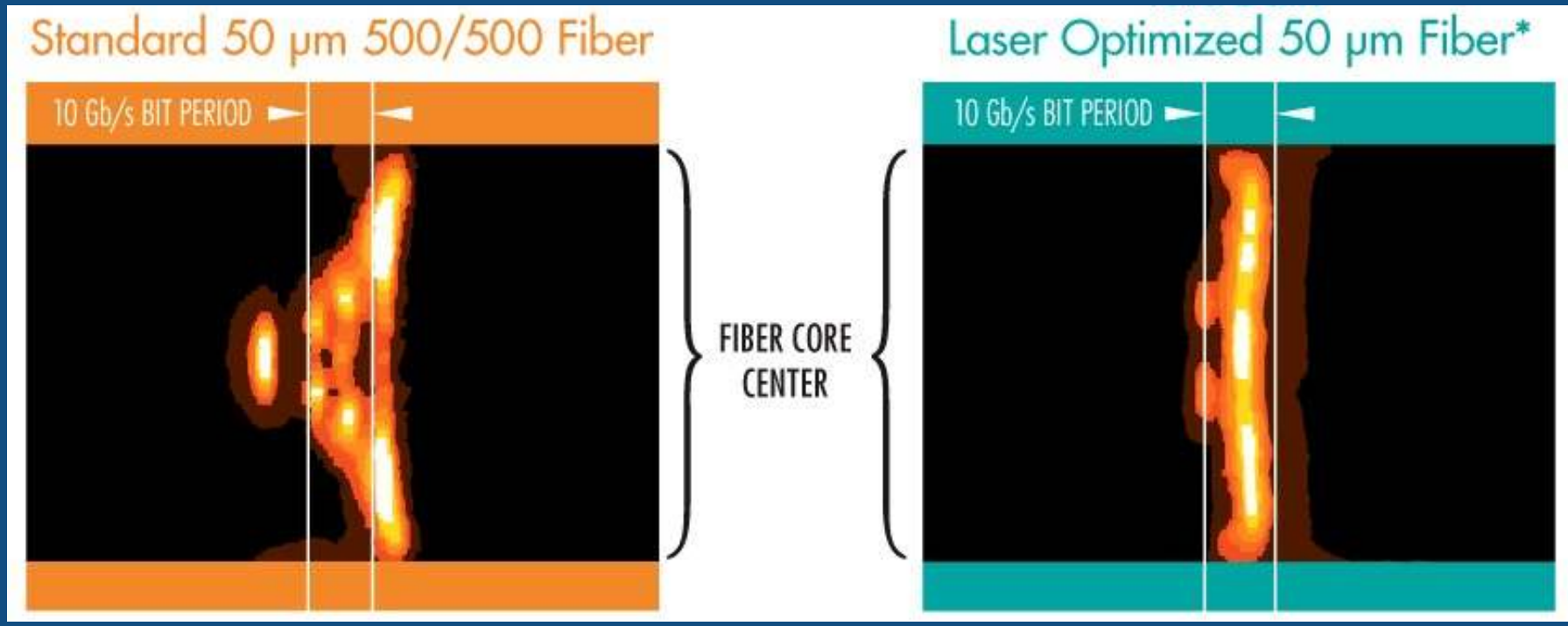
Differential Modal Dispersion

Standard 50 µm vs. Laser Optimized 50 µm Fiber:
Received pulse at 10 Gb/s over 300 meters



Optical Fiber Mechanical Reliability

- Manufacturing Virtually “Flawless” Fiber
  - Typically Proof Tested to 100 kpsi Stress or 10% Strain
  - Glass breaks at flaws
- Most failures occur at splices where stripping the fiber introduces flaws

Multimode Fiber: Performance Comparison

Fiber Type	Bandwidth[1]	10GbE Link Length	% Length Increase
62.5 µm	220	26 m	---
50	500	82 m	215 %
10G/150	700 (950)[2]	150 m	477 %
10G/300	1500 (2000)[2]	300 m	1053 %
10G/550	3500 (4700)[2]	550 m	2015 %

1. Overfilled Launch MHz-km @ 850 nm; 2. Effective Modal Bandwidth MHz-km @ 850 nm

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Fiber Media Configurations

- Premises (Tight Buffered; ≤ 144 fibers)
  - Plenum or Riser
  - Interconnect , Distribution or Breakout
  - Interlocked Armored
  - Indoor/Outdoor
- OSP (Loose Tube; ≤ 1080 fibers)
  - Stranded or Central Tube
  - Ribbon or Individual Fiber
  - Armored /Dielectric/Self-Supporting
  - Indoor/Outdoor

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Fiber Installation Issues

- Proper Installation Techniques
  - Maintaining proper bend radii
  - Avoiding all pinch points
- Field Connectorization
  - Requires more training and experience than copper
  - Pre-connectorized cables and assemblies speed up installation

Fiber Installation Issues

- Fusion Splicing
  - Lowest splice loss
  - High cost of splicer
- Mechanical Splicing
  - Variety of standard and small form factor connectors available
  - SM connectors much more expensive than MM

Channel Attenuation Requirements

Fiber Type	Protocol	Bandwidth (MHz-km)	λ (nm)	Maximum Channel Length (m)	Maximum Channel Attenuation (dB)
62.5 µm	10GBASE-SR	180	850	26	2.6
	10GBASE-LRM	500	1300	220	1.8
50 µm	10GBASE-SR	500	850	82	2.3
		700		150	2.6
		1500		300	2.6
		3500		550	2.6

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Fiber Module Costs & Availability

Media	10GBASE Format	Module/Port Cost
Multimode Fiber	SR	$ 1,200
	LRM	$ 1,800
	LX4	$ 2,500
Single Mode Fiber	LR	$ 2,400
	ER	$ 6,500
	ZR	$ 10,600

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Copper vs. Fiber Comparison

Applications, Performance,
Installation, & Cost

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10GBase Application Spaces

Application	Fiber	Copper	Copper-CX4
Data Center Server Clustering	Yes	Yes	Yes (< 15 meters)
Horizontal	Yes	Yes	No
Vertical (Riser)	Yes	No	No
Campus & Metro	Yes	No	No

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Copper vs. Fiber: Performance

Parameter	Copper	Fiber
EMI/RFI	UTP: Susceptible STP: Minimally affected	Complete Immunity
Effect of Adjacent CAT 5e/6 Cables	UTP: Theoretically none STP: None	Not Applicable
Distance	100 meters maximum	MMF: 550 meters SMF: 80,000 meters
Module Power Consumption	14 to 17 Watts	1 – 3 Watts
Module Heat Generation	More than Fiber	Less than Copper
Cable Compatibility	Backward Compatibility	Backward Compatibility

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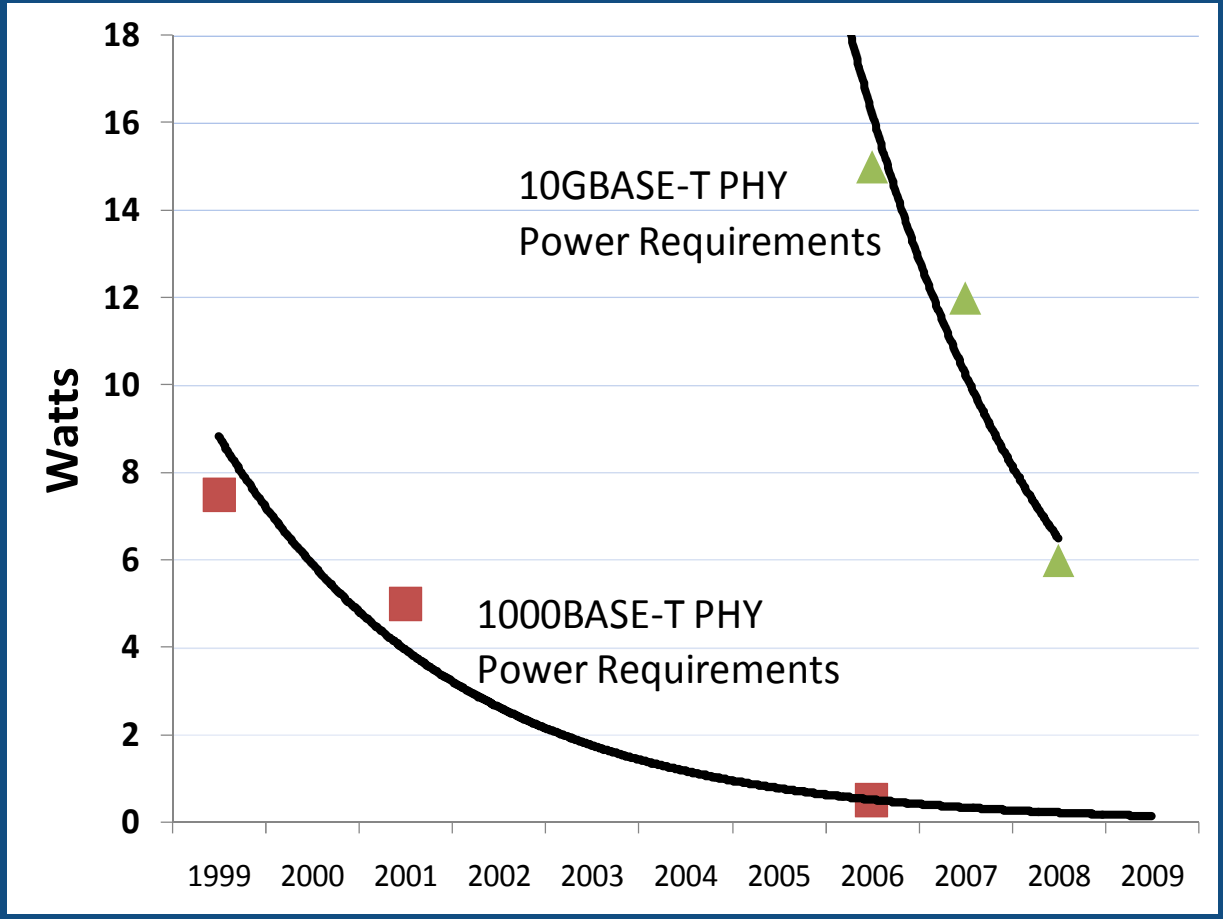
Power Usage Trends



- Power consumption of 10GBASE-T PHY is on a trend line of 4 Watts by 2009
- 4 watt 10G PHY will enable 48 port 1RU (assuming 200W per switch limit)

Source: SolarFlare

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Copper vs. Fiber: Active Equipment Cost & Availability

Parameter	Copper	Fiber
Module Cost	Similar to MM Fiber	Varies with Fiber Type
Future Module Costs	Expected to Drop Significantly	Very Gradual Drop
Equipment Availability	10GBASE-T – Limited CX4 - Widely Available	Widely Available
NIC's	Recently Available	Widely Available
Module Suppliers	SMC, Cisco	Cisco, SMC, Intel, 3COM, Foundry, Enterasys, etc.
Power over Ethernet	Possible	Not Possible

Copper vs. Fiber: Cable Form Factor

Parameter	Copper	Fiber
Size	UTP – 0.31 to 0.35” Shielded – 0.28 to 0.30	0.20” (2-Fiber)
Data Paths/Cable	1 per 4-pair cable (0.29”)	9 per 18-MMF (0.28”)
Maximum Data Paths/Cable	1	72 for 144-MMF
Connector	RJ-45 110 Block	Small Form Factor: LC Standard: SC Array: MTO/MTP (12/24-F)
Environments	Premises Only	Premises, Outdoor & I/O
“Plug-n-Play”	Available	Available

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Copper vs. Fiber Cable Installation

Issue	Copper	Fiber
Field Connectorization	Same as Cat 6/5e	Same as Standard MMF
Pre-connectorization	Not necessary	Reduces installation cost
Grounding & Bounding	Required for Shielded Solutions	Not Required
Installation Temperature	+ 20 °C to + 65 °C	– 20 °C to +65 °C
Operating Temperature	+ 0 °C to + 65 °C	Plenum: – 20 °C to +65 °C Riser & I/O: – 40 °C to +65 °C
Pulling Tension	≤ 25 lbs-f	≤ 150 lbs-f for 2 – 12 fibers ≤ 600 lbs-f for 60 – 144 fibers

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10GbE Data Center – Copper or Fiber?

- Fiber would seem to have a clear advantage, however…

10 GbE Media	Fiber (SR/LRM)	Copper (BASE-T)
Power Consumption (PHY + Adaptor)	1– 3 Watts ✓	14 – 17 Watts
Distance	300 meters ✓	100 meters
Future Data Rates	40 – 100 Gb/sec ✓	10 Gb/sec
Density per Rack Unit*	32 ✓	24
Cable Density	10% ✓	100%
Cost/Link (server + switch ports)	$3,000 - $4,000	$2,500 – 3,000 ✓

Cisco Nexus 7000 SFP + 10GBASE-SR

- Majority plan to implement **10G**BASE-T within next 5 years

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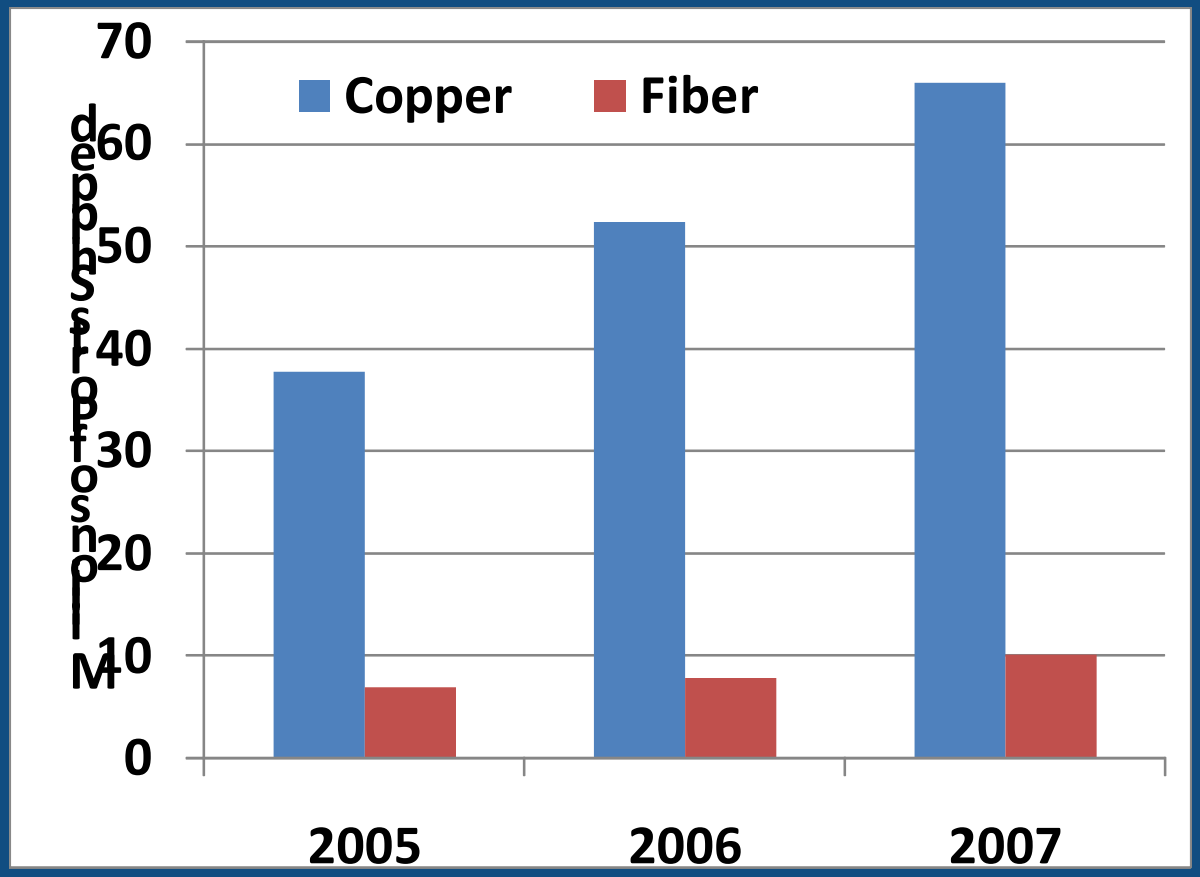
1 GbE Cu & Fiber Switch Ports

Copper dominates in the 1 GbE market and is expected to in the 10 GbE market



Source: Nyquist Capital

Market Forecast

- Fiber - Likely to dominate in “large” data centers (>100 racks)
- Copper
  - Port costs will be down to 20-25% of fiber switch/server port costs driven by economies of scale for 10GBASE-T electronics
  - Cat 6A Cable
    - Dominant choice of small/medium data centers within 4 years
    - Will begin to displace fiber in some backbone installations and Cat 6 in horizontal installations

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Summary: Making the Choice

- Bandwidth Requirements?
  - Consolidation, Back-up, etc.
  - Future Proofing
    - Copper at its maximum for 100 meters
    - Fiber will go to 40 or 100 GB depending on distance and fiber type
- Installation Requirements?
  - Channel Distance
  - Space Limitations
  - Fire Requirements

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Summary: Making the Choice

- Environmental Requirements?
  - Temperature
  - Humidity/Moisture
  - EMI/RFI
- = Total System Cost

Questions?

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