CFI - 100GbE
Beyond 10km Optical PHYs

Consensus Presentation
Objective for this Meeting

• To *measure the interest* in starting a study group to address:
  • Beyond 10 km Optical PHYs for 100GbE

• We don’t need to
  • Fully explore the problem
  • Debate strengths and weaknesses of solutions
  • Choose any one solution
  • Create PAR or five criteria
  • Create a standard or specification

• Anyone in the room may speak / vote
• RESPECT... give it, get it
Agenda

• Market Drivers
• Technical Feasibility
• Why Now?
• Q&A Panel
• Straw Polls

Presenters and Panelists

• Mark Nowell – Cisco
• Ilya Lyubomirsky - Inphi
• Tom Williams - Acacia
• Fernando Villarruel - Cisco
Overview: Motivation

Applications have been identified that are looking for new Ethernet optical solutions at reaches greater than 10 km at 100 Gb/s

- Cable/MSO distribution networks
- Mobile backhaul aggregation networks

The existing “Beyond 10km Optical PHYs” Study Group has significant participation and energy around the already identified market applications @ 50 Gb/s, 200 Gb/s and 400 Gb/s.

This CFI’s aim is to include 100 Gb/s into that effort
What Are We Talking About?

Scenario #1

>10km
IEEE defined Ethernet (100 GbE)

OUR SCOPE

Scenario #2

>10km
IEEE defined Ethernet (100 GbE)

X,000 km
ITU-T defined “Core OTN Transport” carrying Ethernet traffic

>10km
IEEE defined Ethernet (100 GbE)

OUR SCOPE
Market Drivers for 100GbE beyond 10km
Beyond 10km Optics Throughout The Ecosystem

- Not “Data Center”
- Exists throughout the Eco-System
- 3 Million units for 40km and beyond shipped annually
- Continuing bandwidth growth factors resonate throughout the ecosystem
- Being addressed in B10K study group for 50 Gb/s, 200Gb/s, and 400 Gb/s
- This CFI’s goal is to add 100 Gb/s into that study group discussion
## Today’s Point-to-Point SMF Ethernet Family

<table>
<thead>
<tr>
<th>Lanes</th>
<th>500m</th>
<th>2km</th>
<th>10km</th>
<th>20km</th>
<th>40km</th>
<th>Up to 80km</th>
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<tbody>
<tr>
<td>1000BASE-</td>
<td>1</td>
<td>LX</td>
<td>LX10 / LH</td>
<td>EX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10GBASE-</td>
<td>1</td>
<td>LR</td>
<td>ER</td>
<td>ZR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25GBASE-</td>
<td>1</td>
<td>LR</td>
<td>ER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40GBASE-</td>
<td>4</td>
<td>PSM4</td>
<td>LR4</td>
<td>ER4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>FR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50GBASE-</td>
<td>1</td>
<td>FR</td>
<td>LR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100GBASE-</td>
<td>10</td>
<td>PSM4</td>
<td>10X10</td>
<td>LR4 / WDM4-10</td>
<td>WDM4-20</td>
<td>ER4 / WDM4-40</td>
</tr>
<tr>
<td></td>
<td>&lt;4</td>
<td>DR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200GBASE-</td>
<td>4</td>
<td>FR4</td>
<td>LR4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>FR8</td>
<td>LR8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400GBASE-</td>
<td>4</td>
<td>DR4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Black Text**: IEEE Standard
- **Red Text**: In Standardization
- **Blue Text**: Non-IEEE standard but complies to IEEE electrical interfaces

*Longer Reach Opportunity*  
*Lane width Opportunity*  
*Addressed in Beyond 10km Study Group*
Driven by the requirement to support higher bandwidths and more endpoints the Cable market is undergoing an architecture migration. Analog optical distribution links are moving to digital @ 100 Gb/s and above to facilitate distribution to 10 Gb/s endpoints. Note, endpoint usage is <10Gbps initially with capacity for growth over lifetime.

Key transition: field aggregation of 10G endpoints create need @ 100 Gb/s + backhaul.
Hybrid Fiber Coaxial Market Evolution

• Distributed Access Architecture (DAA) Nodes: **12 M**
  • 10x scale vs. classic optical node
  • Not including China / India
  • Avg. homes passed / node: ~50
   → **1.2 M** 100G wavelength channels to field aggregation points

• Evolution timeframe
  • 10 yr +

• Further Growth Potential: Mobile, business services

H.I.S. (Infonetics) Node Market Study 2015

NOTE 1: Graph derives 100G optical endpoint counts from node count in original market study (see back-up)
NOTE 2: Remote CCAP / CMTS / RPHY refer to separate breakpoints in the MAC and PHY range of the cable packet core (known as DOCSIS).

- CMTS – Cable Modem Termination System (Includes DOCSIS MAC/PHY and subscriber management)
- CCAP – Converged Cable Access Platform (Includes DOCSIS MAC/PHY)
- Remote PHY – only DOCSIS PHY included

Evolution of DOCSIS Architectures:
Mobile Backhaul capacity segmentation

5G transport: an evolution, not a revolution

5G capacity drivers

Backhaul capacity requirements per radio site*

<table>
<thead>
<tr>
<th>Advanced mobile broadband</th>
<th>2016</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>80% of sites</td>
<td>90 Mbps</td>
<td>300 Mbps</td>
</tr>
<tr>
<td>20% of sites</td>
<td>300 Mbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Few % of sites</td>
<td>1 Gbps</td>
<td>3-10 Gbps</td>
</tr>
</tbody>
</table>

* Global average perspective

Courtesy of Antonio Tartaglia, Ericsson
5G backhaul Capacity through 2021

evolution, not revolution

Continued growth of 10G and 100G interfaces
more connections, better utilized
• 50G and 200G might play a longer term role

=> opportunity for standard interfaces with improved cost structure
=> opportunity for new standard interfaces

• In the lower aggregation tiers, 40km ‘grey’ direct-detect interfaces are expected to have continued traction
• Up in the tiers, 80km/ "-ZR" without external EDFAs expected to become popular (coherent being the most natural fit)
• DWDM may come into the picture, even in lower tiers, to solve specific network design challenges (fiber exhaust problems, “router optical bypass”, ...)

Courtesy of Antonio Tartaglia, Ericsson
Mobile Backhaul Demand for Beyond 10km
Not all geographies are the same

Present status and forecast

• According to our survey, long distance module is a mandatory requirement for us

| Statistics for 10GE & 100GE Modules used in PTN, as of June, 2016 |
|-----------------|--------|--------|--------|
| Transmission Distance | <2km | 10km | 40km | 80km |
| 10GE distribution | 0.28% | 44.46% | 44.05% | 11.20% |
| 100GE distribution (more than 15k modules) | 0 | 56.43% | 34.59% | 8.97% |

• According to the increase of LTE traffic, as LTE backhaul network, PTN will face 4~5 times traffic in 2017 or 2018.
• Then we will have to use 400GE interface in the same scenario and take the same percentage with 100GE and 10GE.
• In 2018~2019, we expected the requirement for 400GE ER modules will be more than 10K.


Mobile Networks Bandwidth Trends

- Previous B10k CFI focused on Chinese Mobile Backhaul market requirements. 50 Gb/s & 200 Gb/s clearly identified as requirements
- Different geographies are seeing different growths on the bandwidth drivers indicating 100 Gb/s needed

Annual Shipments for 40km+ Applications

- For 100 GbE, 40km, LightCounting projects a market that will roughly triple in value from 2017 to 2021.
- SONET 40-80km shipments represent another half-million units in 2016. SONET is transitioning to Ethernet.
- 1 / 2.5 / 10 Gb/s DWDM / CWDM 40km & 80km optics will exceed 1M units this year and growing.
- Totals are for merchant supplier shipments. Captive supply could add another half-million units.

Data courtesy of LightCounting
Optical Module Volumes: 40km and Beyond 40km

LightCounting forecast for optical modules for Ethernet and non-Ethernet applications

- Totals are for merchant supplier shipments
- The market for 40km and >40km optical modules continues to grow
- The >40km market space for both 10Gb and 100Gb is significant and growing faster than the 40km

Data courtesy of LightCounting
Summary

• New markets coming to Ethernet where > 10km is important
  • Cable/MSO networks migrating architectures towards Ethernet
    • No Ethernet solution exists for 100 Gb/s 40-80km (service for ~ 600M homes)
  • Emerging applications to drive future traffic over mobile networks
  • Drivers for Mobile Traffic differ in different regions of the world. Network topologies are similar, timing around deployment of rates will follow capacity demands
  • Direct detect, coherent and DWDM all potential solutions the market is looking for

• Established Ethernet market shows use case for >10 km
  • 3 Million units (GbE to 100GbE, SONET, DWDM/CWDM) for 40km and beyond shipped annually
  • Bandwidth growth throughout ecosystem
  • “Geographically challenged” applications exist throughout Ecosystem
  • > 40km forecasts growing faster than 40 km
Technical Feasibility
100GbE Beyond 10km Optical PHY
The SMF Optical Landscape *

The graph illustrates the optical landscape with lane rates on the x-axis and reach in kilometers on the y-axis. The following optical technologies are represented:

- **Direct-Detect**
  - 10G-ZR
  - 10G-ER
  - 40G-ER4
  - CWDM4
  - 10G-LR
  - 10G-ER4
  - 4WDM-20
  - 4WDM-40

- **Coherent**
  - ITU-T (G.698.2)**
  - 400ZR
  - 100G-DR
  - 400G-DR4
  - 200G-FR4
  - 50G-FR
  - 50G-LR
  - 200G-LR4
  - 40G-LR4

- **400ZR**

**Leverages**

**Includes Standards and Efforts in development**

**https://www.slideshare.net/ITU/itut-study-group-15-introduction.**

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* - Includes Standards and Efforts in development

An Ethernet Overview of the Problem

Approaches to Longer Reach
- Stronger FEC
- Improved Tx / Rx
- APD
- DSP
- Coherent
- Other (SOA, ....)
Impact of Use of APD (2\(\lambda@51.5625\) Gb/s PAM4)

![Graphs showing BER performance with PIN and APD ROSA for different distances.](image)

**Data:** PRBS31

Used actual chip implementation with real-time Rx DSP with 10+ taps FFE embedded inside the silicon

**Source:** Frank Chang, Inphi, “OFC 2016: Link Performance Investigation of Industry First 100G PAM4 IC Chipset with Real-time DSP for Data Center Connectivity “, OFC’16 Th1G.2
Targeting >10km with Coherent Technology

Assumptions

- Modulation Format
  - 100G – QPSK @ ~30Gbaud
  - 200G – 16QAM @ ~30Gbaud
  - 400G – 16QAM @ ~60Gbaud
- Tx and Rx power levels achievable with high yield and multiple optical technologies
- Note – Longer reach, i.e., higher link budgets, can be supported by transmit SOA/EDFA or with additional amplification

* - http://www.ieee802.org/3/ba/public/tools/Fibre_characteristics_V_3_0.xls

Source: Tom Williams, Acacia
100 Gb/s Coherent Standards Activity

Coherent technology has been under development for greater than 10 yrs with initial market deployments since 2008.
Significant industry standardization efforts at both ITU and OIF

**ITU:**

**OIF:**
OIF-HBPMQ-TX-01.0 – Implementation Agreement for High Bandwidth Integrated Polarization Multiplexed Quadrature Modulators (*December 2016*)
OIF-PMQ-MTX-01.0 – Implementation Agreement for Integrated Polarization Multiplexed Quadrature Modulated Transmitters for Metro Applications (*September 2015*)
OIF-PMQ-TX-01.2 – Implementation Agreement for Integrated Polarization Multiplexed Quadrature Modulated Transmitters (*May 2015*)
OIF-DPC-MRX-02.0 – Implementation Agreement for Integrated Dual Polarization Micro-Intradyne Coherent Receivers (*June 2017*)
OIF-DPC-RX-01.2 – Implementation Agreement for Integrated Dual Polarization Intradyne Coherent Receivers (*November 2013*)
OIF-CFP2-ACO-01.0 – Implementation Agreement for Analogue Coherent Optics Module (*January 2016*)
Implementation Cost Considerations

Implementation costs need to be studied –
- Inclusion of components
- Number of components
- Operation rate of components
- Specifications of components

Source: Tom Williams, Acacia
Technical Feasibility of Beyond 10km 100 Gb/s Optical PHYs

• Growing evidence of different ways to support reaches beyond 10km for 100GbE
  • PAM4 (Direct Detect) test data for 40km provided
  • Higher Power EML Transmitters, APDs, Advanced DSP, FEC
  • Commercial 80km solutions shipping today (amplified solution over DWDM)
• Coherent Optics & DWDM Optics
  • Shipping today
  • Industry development efforts that may be leveraged.
    • ITU-T (ITU-T G.698.2)

• Same technology options already under consideration in Beyond 10k Study Group
• Technologies are always evolving toward narrower lane widths – both electrically and optically.
  • Enable reductions in cost, power etc
  • Aligns with host SerDes roadmap

Real challenge – determining the right solution for the right reach / rate!
Why Now?
Why Now?

• Opportunity to align with the Beyond 10km Study Group effort underway for 50GbE, 200GbE, and 400GbE

• Existing 100 GbE solution for 40km (100GBASE-ER4) does not fully address the market
  • No Ethernet PHY solution for up to 80km nor compatible with a DWDM deployment
  • Newer technologies available to potentially cost reduce even 40 km solution

• New markets with 100 GbE focus – example MSO

• Numerous applications for > 10km Optical PHYs
  • Everywhere - ≈3M units shipped annually addressing 40+km
  • Not same volumes as Data Center – but relevant to overall ecosystem
  • 100 GbE is the latest rate growing into this space
Supporters

Frank Chang  Inphi
Hai-Feng Liu  Intel
Kohichi Tamura  Oclaro
Ryan Yu  Molex
Scott Sommers  Molex
Curtis Knittle  CableLabs
Steve Swanson  Corning
David Ofelt  Juniper Networks
Scott Schube  Intel
Kohichi Tamura  Oclaro
Thananya Baldwin  Ixia
Jeffrey Maki  Juniper Networks
Kenneth Jackson  Sumitomo Electric
Mark Nowell  Cisco
Jerry Pepper  Ixia
Kent Lusted  Intel
Isono Hideki  Fujitsu
Patricia Bower  SocioNext
Vipul Bhatt  Finisar
David Lewis  Lumentum
Rajesh Radhamohan  Maxlinear
Sridhar Ramesh  Maxlinear
Samuel Liu  Nokia
Keisuke Kojima  Mitsubishi Electric
Gary Nicholl  Cisco
Tomoo Takahara  Fujitsu Laboratories
Justin Abbot  Lumentum
Matt Brown  MACOM
Atul Gupta  MACOM
Chris Collins  MACOM
Brad Booth  Microsoft
Akinori Hayakawa  Fujitsu
Antonio Tartaglia  Ericsson
Matt Traverso  Cisco
Marek Hajduzenia  Charter Communications
Dave Chalupksy  Intel
Tom Williams  Acacia
Fabio Cavaliere  Ericsson
Tony Zortea  MultiPHY
Ilya Lyubomirsky  Inphi
Chan-Chih (David) Chen  Applied Optoelectronics
Eugene Dai  Cox Communications
James H. Chien  ZTE
Ted Sprague  Infinera
Fernando Villarruel  Cisco
Mark Gustlin  Xilinx
Karen Liu  Kaim
Oded Wertheim  Mellanox
Mizuki Shirao  Mitsubishi Electric
Yonatan Malkiman  Mellanox
Ryan Tucker  Charter Communications
David Malicoat  Senko
Alexander Umnov  Corning
John Johnson  Broadcom
Winston Way  NeoPhotonics
Shawn Esser  Finisar
Tom Palkert  Molex
Paul Brooks  Viavi
Tad Hofmeister  Google
Jörg-Peter Elber  ADVA
Phil Miguelez  Comcast
Christophe Metivier  Arista
Scott Kipp  Brocade
Dale Murray  LightCounting
Bharat Tailor  Semtech
Rita Horner  Synopsis
Robert Coenen  InterOptic
Keith Conroy  Acacia
Matt Schmitt  CableLabs
Eric Maniloff  Ciena
Ed Ulrichs  Source Photonics
Atul Srivastava  NEL America
Mark Kimber  Semtech
Anand Anandakumar  Maxlinear
Piers Dawe  Mellanox
Mabud Choudhury  OFS Optics
Jacky Chang  HP Enterprise
Straw Polls
Straw Poll 1: Call-For-Interest

• Should a Study Group be formed to consider Beyond 10km Optical PHYs for 100GbE?

Y: 103  N: 0  A: 24

Room Count: 124
Straw Poll 2: Scope

• If this CFI is successful on Thursday, I would support expanding the scope of the existing Beyond 10km Study Group to include 100GbE.

Y: 106    N: 0    A: 14

Room Count: 124
Participation

• I would participate in the “Beyond 10km Optical PHYs for 100GbE” Study Group in IEEE 802.3.
  Tally: 66

• My company would support participation in the “Beyond 10km Optical PHYs for 100GbE” Study Group in IEEE 802.3.
  Tally: 39
Future Work

• Look for indication from current Beyond 10k Study group that if this CFI is successful, that there is interest in expanding it’s scope to include 100 Gb/s

• Ask 802.3 Working Group on Thursday to form a Beyond 10km 100 GbE Optical PHYs Study Group

• Let 802.3 Working Group determine how this will go forward if successful

• If approved, on Friday
  • 802 EC
Backup
Distributed Access Architecture – more details

Number of 100G optical units is derived from the node analysis in the Infonetics Study with these assumptions:
- ~12 nodes are aggregated onto a single 100 Gb/s distribution link
- Each link has 2 endpoints
- Each node is connected to the aggregation point @ 10 Gb/s
  - Current node bandwidth is @ 1-3 Gb/s
  - 10 Gb/s provides future headroom
- Redundancy is not included in numbers as this isn’t a universal architecture amongst MSO’s

Digital Access Architecture
Optical Units, Early years

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