IEEE 802.3 NEA Ad hoc
29 Oct 2020

IEEE 802.3 Call for Interest
CFI Consensus Presentation

“Beyond 400 Gb/s Ethernet“
OBJECTIVE FOR THE MEETING

- To measure the interest in starting a study group to address “Beyond 400 Gb/s Ethernet”
- 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 on the call may speak / vote
- RESPECT... give it, get it
Contributors

- John D’Ambrosia, Futurewei, U.S. Subsidiary of Huawei
- Matt Brown, Huawei Canada
- Joel Goergen, Cisco
- Mark Gustlin, Cisco
- Cedric Lam, Google
- Mike Li, Intel
- Ilya Lyubomirsky, Inphi
- Osa Mok, Innolight
- Gary Nicholl, Cisco
- Shawn Nicholl, Xilinx
- Mark Nowell, Cisco
- David Piehler, Dell Technologies
- Ted Sprague, Infinera
- Rob Stone, Facebook
- Jim Theodoras, HG Genuine
- Nathan Tracy, TE Connectivity
- Xinyuan Wang, Huawei
- George Zimmerman, CME Consulting

Also

- IEEE 802.3 2020 Ethernet Bandwidth Assessment
- IEEE 802.3 NEA Ad hoc
Today’s Panel

- **Speakers**
  - John D’Ambrosia, Futurewei (U.S. Subsidiary of Huawei)
  - Ray Nering, Cisco
  - Adam Healey, Broadcom

- **Additional Panelists**
  - Cedric Lam, Google
  - Rob Stone, Facebook
AGENDA

- Introduction
- Presentations
  - Market Pressures for Beyond 400 GbE
  - The Technical Roadmap to Beyond 400 GbE
  - Beyond 400 GbE - Why Now?
- Straw Polls
- Future Work
THE SCOPE OF ETHERNET TODAY

Our Scope

Scenario #1
Point-to-Point Ethernet Networks
80 km over DWDM Systems
Point-to-Point Ethernet Networks

Scenario #2
IEEE defined Ethernet
X,000 km
ITU-T defined "Core OTN Transport" carrying Ethernet traffic
IEEE defined Ethernet

OUR SCOPE

IEEE defined Ethernet
"Core OTN Transport" carrying Ethernet traffic
IEEE defined Ethernet

OUR SCOPE

IEEE defined Ethernet
"Core OTN Transport" carrying Ethernet traffic
IEEE defined Ethernet
MARKET PRESSURES FOR BEYOND 400 GbE

Presented by Ray Nering
THE SONG REMAINS THE SAME

- 2020 Ethernet Bandwidth Assessment (BWA) documented latest analysis of industry bandwidth needs and driving factors

\[
\text{Increased } \# \text{ of users} \times \text{Increased access methods and rates} \times \text{Increased services} = \text{Bandwidth Explosion}
\]

- 2020 Ethernet BWA
  - Reference slides in Appendix: Backup Slides
The 2020 Ethernet Bandwidth Assessment

Data Relative to 2017 Value

- Mobile Consumption / Subscription (China)
- Data Center Capacity Shipped
- Global CDN
- Mobile
- IP Video
- VR / AR
- Peering
- Global IP

2017 - 2025
DATA CENTERS CONTINUE AS A PRIMARY DRIVER

DC Traffic Continues to Grow Rapidly (Regular Servers)

Note – “Dip” in measured traffic related to monitoring issues

Courtesy - Cedric Lam, Google
Actual network deployment of higher capacity switches is driven by traffic demands as well as operational considerations:
- Cost
- Power
- Network Architecture (e.g. Radix)

Deployment can occur quite quickly after availability

Key observation: Network needs are driving switch capacity developments

Courtesy of:
Rob Stone, Facebook
Cedric Lam, Google
Mark Nowell, Cisco
Hyperscale Ethernet Deployment – Port Speed

Key observation:
Network capacity needs are driving increased max port speeds.
Beyond 400 GbE port speed is required to support continued bandwidth demand.

 Courtesy of: Rob Stone, Facebook Cedric Lam, Google Mark Nowell, Cisco
EXAMPLE EMERGING APPLICATION – 5G BACKHAUL

# of Networks Deployed

<table>
<thead>
<tr>
<th>Region</th>
<th>LTE</th>
<th>LTE Advanced</th>
<th>5G</th>
</tr>
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<tbody>
<tr>
<td>Africa</td>
<td>145</td>
<td>42</td>
<td>4</td>
</tr>
<tr>
<td>Asia &amp; Pacific</td>
<td>162</td>
<td>74</td>
<td>29</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>93</td>
<td>59</td>
<td>14</td>
</tr>
<tr>
<td>Latin America &amp; Caribbean</td>
<td>127</td>
<td>50</td>
<td>8</td>
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<tr>
<td>Middle East</td>
<td>44</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>U S &amp; Canada</td>
<td>20</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Western Europe</td>
<td>88</td>
<td>70</td>
<td>31</td>
</tr>
<tr>
<td>Global Totals</td>
<td>683</td>
<td>335</td>
<td>105</td>
</tr>
</tbody>
</table>

Source: as of 8/14/2020, https://www.5gamericas.org/resources/deployments/

Omdia projects 91 million global 5G connections by end of 2020

<table>
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<tr>
<th>Generation</th>
<th># of Quarters to ≈17.8 million Connections</th>
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<tbody>
<tr>
<td>5G</td>
<td>4</td>
</tr>
<tr>
<td>4G</td>
<td>10</td>
</tr>
<tr>
<td>3G</td>
<td>11</td>
</tr>
<tr>
<td>2G</td>
<td>14</td>
</tr>
</tbody>
</table>

Source: https://www.5gamericas.org/5gs-year-one-fast-start-and-healthy-growth/
ARTIFICIAL INTELLIGENCE & COMPUTE

- **First Era (Before 2012)**
  - Moore’s Law – 2-year doubling
  - Uncommon to use GPUs for machine learning

- **Modern Era (2012 and later)**
  - 2012 – 2014: most results used 1-8 GPUs rated at 1-2 TFLOPS
  - 2014 – 2016: large-scale results used 10-100 GPUs rated at 5-10 TFLOPS
  - 2016 – 2017: greater algorithmic parallelism (huge batch sizes, architecture search, expert iteration), specialized hardware (TPUs), faster interconnects

MORE OF THE SAME…..

- More users
- More and faster 5G mobile
- More video & higher resolution
- More and faster devices
- More data
- More applications
- More networked science
- Artificial Intelligence & ML
- Beyond 100 GbE servers
COVID-19 TRENDS, APRIL 2020

Source - Inphi blog post 'Bandwidth in the Age of COVID-19' posted 22nd April 2020 by Ford Tamer, President and CEO, Inphi Corporation <https://www.inphi.com/blog/>
SUMMARY

- Bandwidth growth continues and underlying factors indicate further bandwidth growth
  - Video (recorded and live) and mobile!
  - Increasing delta between “peak” and “average”
- New applications fueling bandwidth growth
- In today’s COVID-19 world
  - Connectivity has been critical!
  - “Instantaneous” growth in multiple application spaces
  - Moving to telepresence, i.e. streaming video
- “Up and to the right” continues
THE TECHNICAL TOOLBOX TO BEYOND 400 GbE

Presented by Adam Healey
## The Entire Ethernet Family Needs Considered

<table>
<thead>
<tr>
<th>Next Speed?</th>
<th>Reach</th>
<th>Medium</th>
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</thead>
<tbody>
<tr>
<td>&gt; 400 GbE</td>
<td>80 km</td>
<td>DWDM SMF</td>
</tr>
<tr>
<td>Router</td>
<td>&gt; 400 GbE</td>
<td>500 m to 40 km</td>
</tr>
<tr>
<td>Leaf/Spine</td>
<td>&gt; 400 GbE</td>
<td>50 m to 500 m</td>
</tr>
<tr>
<td>TOR / MOR / Leaf</td>
<td>&gt; 400 GbE</td>
<td></td>
</tr>
<tr>
<td>Server</td>
<td>&gt; 100 GbE</td>
<td>&lt; 30 m</td>
</tr>
</tbody>
</table>
THE CHALLENGES TO BEYOND 400 GBE

Electrical Functions
- Increase interface channel count?
- Increase interface rate?
- Increase interface modulation order?

Optical Functions
- Increase interface channel count?
- Increase interface rate?
- Increase interface modulation order?

Media
- Increase interface channel count?
- Increase fiber count?
- Increase lambda count?
- Breakout?

Forward Error Correction
- AUI Specific?
- PHY Specific?
- Multiple variants? Architecture impact?

RECONCILIATION
- MII
- PCS
- FEC
- PMA
- PMD

PHY
- AUI
- PMA
- MDI

MEDIUM

MAC
The options below are very feasible in near term technology (as an example, actual rate(s) are TBD)

<table>
<thead>
<tr>
<th>MAC Rate</th>
<th>Technology Node</th>
<th>Device Type</th>
<th>Bus Width</th>
<th>Clock Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 Gb/s</td>
<td>5 nm</td>
<td>ASIC</td>
<td>1024 b</td>
<td>800 MHz</td>
</tr>
<tr>
<td></td>
<td>5 nm</td>
<td>ASIC</td>
<td>512 b</td>
<td>1.6 GHz</td>
</tr>
<tr>
<td></td>
<td>7 nm</td>
<td>FPGA</td>
<td>1536 b</td>
<td>533 MHz</td>
</tr>
<tr>
<td>1.6 Tb/s</td>
<td>5 nm</td>
<td>ASIC</td>
<td>2048 b</td>
<td>800 MHz</td>
</tr>
<tr>
<td></td>
<td>5 nm</td>
<td>ASIC</td>
<td>1024 b</td>
<td>1.6 GHz</td>
</tr>
<tr>
<td></td>
<td>5 nm (or equiv)</td>
<td>FPGA</td>
<td>3072 b</td>
<td>533 MHz</td>
</tr>
</tbody>
</table>

Source – Mark Gustlin, Cisco; Mike Li, Intel; Shawn Nicholl, Xilinx
PCS/FEC

- Previous PCS concepts could be re-used
  - 64b/66b, transcoding, scrambling, AMs

- Will likely want a new stronger FEC for 200 Gb/s lane (if the project chooses to define 200 Gb/s per lane)
  - Multiple FEC options for direct detect, coherent light and longer reach coherent?
  - Still support end to end FEC for some options?
  - Optimize gain, latency, power and implementation burden for chosen FECs
    - While minimizing the overall number of FEC options
CMOS Roadmap

Comparision of Lane Data Rate and Node Label Timelines

- The upper data (blue) shows evolution of electrical lane data rate over time.
- The lower data (red) shows the evolution of node label over time.
- Current designs for 100 Gb/s per lane are in 7 nm and are moving to 5 nm.
- 3 nm and 2.1 nm will be available when 200 Gb/s per lane is standardized.
- The node label (halving every 3.4 years) is progressing faster than the electrical lane rate (doubling every 3.9 years).

Source – Matt Brown, Huawei Canada
DSP Architecture Advances

Reported implementations:
- “A 400 Gb/s Transceiver for PAM-4 Optical Direct-Detect Applications in 16nm FinFET,” ISSCC, 2019
- “A 460mW 112 Gb/s DSP-Based Transceiver with 38 dB Loss Compensation for Next-Generation Data Center in 7nm FinFET Technology,” ISSCC, 2020
- "FPGA Investigation on Error-Floor Performance of a Concatenated Staircase and Hamming Code for 400G-ZR Forward Error Correction," OFC, 2018
Beyond 400 GbE - Leveraging 100 Gb/s Signaling

Rate per Lane (Gb/s)

Interface Width (# of Lanes)

10 GbE  25 GbE  50 GbE  40 GbE  200 GbE  400 GbE  800 GbE  16 TbE

Rate per Lane (Gb/s)

1 10 25 50 100 200 400
Industry Efforts - 100 Gb/s Signaling

- **IEEE 802.3**
  - **Standards –**
    - IEEE P802.3bs – 400GBASE-DR4 (4 x 100 Gb/s)
    - IEEE P802.3cd – 100GBASE-DR (1 X 100 Gb/s)
  - **In Development**
    - IEEE P802.3ck 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Task Force
    - IEEE P802.3cu 100 Gb/s and 400 Gb/s over SMF at 100 Gb/s per Wavelength Task Force
    - IEEE P802.3db 100 Gb/s, 200 Gb/s, and 400 Gb/s Short Reach Fiber Task Force
    - IEEE P802.3ct 100 Gb/s over DWDM Systems Task Force

- **Other Industry Efforts**
  - INCITS T11 (Fibre Channel) FC-PI-8, 128GFC (112 Gb/s electrical and optical interface specifications)
  - OIF Common Electrical Interface 112 Gb/s Efforts
  - 100G Lambda MSA (100 Gb/s optical interfaces specifications)
800 Gb/s Industry Activities

- **Ethernet Technology Consortium**
  - [https://ethernettechnologyconsortium.org/](https://ethernettechnologyconsortium.org/)
  - “The 800 GbE specification introduces a new media access control (MAC) and Physical Coding Sublayer (PCS)”

- **QSFP-DD800 MSA**
  - [http://www.qsfp-dd800.net/](http://www.qsfp-dd800.net/)
  - Rev 1.0 released Mar 6 2020

- **OSFP**

- **800G Pluggable MSA**
  - [https://www.800gmsa.com/](https://www.800gmsa.com/)
  - 800G PSM8 specification (Draft 1.0) - Specification covering cost effective 8x100G transmission over at least 100m

Source – Nathan Tracy, TE Connectivity
OSFP Form Factor

Targeting 2km:
- 8 x 100 GbE with MPO-16
- 2 x 400 GbE with CS connector

OIF CEI-112G-VSR interface

0~70degC 18W, 10~60C 17W

7nm DSP inside

Source – Osa Mok, Innolight
Beyond 400 GbE - Leveraging 200 Gb/s Signaling

- 10 GbE
- 25 GbE
- 50 GbE
- 40 GbE
- 100 GbE
- 200 GbE
- 400 GbE
- 800 GbE
- 1.6 TbE

Interface Width (# of Lanes) vs. Rate per Lane (Gb/s)
Potential for Technology Reuse

Reuse of signaling rate technologies developed for higher Ethernet rates enables existing lower speed Ethernet rate specifications (AUI, -KR, -CR, -SR, -DR, -FR, -LR, -ER)

- 32 - 400 Gb/s capacity ports
- Can be configured to support 32 - 400 GbE ports
- Can be configured to support 128 - 100 GbE ports

“It has been my experience at Google that we have used optical and copper modules to support different configurations of a given port, including applications that require the maximum capacity of the single port.”

Cedric Lam, Google
Beyond 100 Gb/s Research is Underway

- Net 212.5 Gbit/s Transmission in O-band With a SiP MZM, One Driver and Linear Equalization, Maxime Jacques1, Zhenping Xing1, Alireza Samani1, Xueyang Li1, Eslam El-Fiky1, Samiul Alam1, Olivier Carpentier1, Ping-Chiek Koh2, David Plant1; 1McGill Univ., Canada; 2Lumentum, USA. OFC-2020, Post deadline paper Th4A.3
Industry Efforts Targeting Signaling Beyond 100 Gb/s

- **IEEE 802.3**
  - IEEE P802.3cw 400 Gb/s over DWDM Systems

- **ITU-T**
  - Recommendation ITU-T G.698.2, to include 200 Gb/s and 400 Gb/s application codes

- **OIF**
  - 400ZR
  - CEI 224G Development Project
800 Gb/s Single Wavelength Transmission

The Future of Coherent is emerging ....

- Successful trial of 800 Gb/s single-wave transmission over 950 km - https://bit.ly/2Wdkh8e

Potentially applicable to Duplex SMF and DWDM systems!
SUMMARY

- Path to Beyond 400 GbE exists
- Leverage 100 Gb/s building blocks
- 800 GbE building blocks and example available now
- Plausible implementations for today and next generation
- 800 Gb/s over a single wavelength for duplex SMF and DWDM systems is emerging now
BEYOND 400 GbE
WHY NOW?

Presented by
John D’Ambrosia
CONSIDERING THE NEXT ETHERNET RATE STANDARD

Data Relative to 2017 Value

- Mobile Consumption / Subscription (China)
- Global CDN
- IP Video
- Mobile
- VR / AR
- Data Center Capacity Shipped
- Peering
- Global IP

This is only an estimate of standard completion

Source: https://bit.ly/802d3bwa2
### The Work Needs to Begin...

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<td>&gt; 400 GbE</td>
<td>500 m to 40 km</td>
<td>Duplex SMF</td>
</tr>
<tr>
<td>&gt; 400 GbE</td>
<td>50 m to 500 m</td>
<td>MMF / SMF (duplex or parallel)</td>
</tr>
<tr>
<td>&gt; 100 GbE</td>
<td>&lt; 30 m</td>
<td>MMF Twin Axial</td>
</tr>
</tbody>
</table>

**Diagram:**
- **DCI**
- **Router**
- **Leaf/Spine**
- **TOR / MOR / Leaf**
- **Server**
SUMMARY

- Bandwidth –
  - Underlying factors all indicate continued growth
  - Exponential growth continues!
- New bandwidth generating applications constantly being introduced
  - Mobile (5G) / Video
  - Artificial Intelligence
  - Virtual / Augmented Reality
- Today’s world stressing the need for connectivity and bandwidth
- Last two “Higher Speed” efforts (from CFI to standard ratification)
  - 40 / 100 GbE – 3 years, 11 months
  - 200 / 400 GbE – 4 years, 9 months
- There is some time between standard ratification and product introduction
  - The bandwidth problem will only continue to grow
- We need to begin the process to study the problem!
- Big questions to consider
  - Next speed or speeds?
  - What physical layer specifications?
Proposed Study Group Chartering Motion

Approve the formation of a Beyond 400 Gb/s Ethernet Study Group to consider development of a Project Authorization Request (PAR) and Criteria for Standards Development (CSD) responses for:

1. Beyond 400 Gb/s Ethernet;

2. Physical Layers specifications for existing Ethernet rates based on any signaling rate used for (1).
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<tr>
<th>John Abbott</th>
<th>Corning Incorporated</th>
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<td>Marvell</td>
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Supporters (Page 3 of 3)

Rick Rabinovich Keysight Technologies
Sridhar Ramesh Maxlinear
Adee Ran Intel
Olindo Savi Hubbell
Steve Sekel Keysight Technologies
Steve Shellhammer QualComm
Kapil Shrikhande Innovium
Priyank Shukla Synopsys
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Rob Stone Facebook
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Winston Way Neophotonics
Markus Weber Acacia Communications
Yangling Wen Futurewei
Tom Williams Acacia Communications
James Withey Fluke
Chongjin Xie Alibaba
Shuto Yamamoto NTT
Zhiwei Yang ZTE
James Young Commscope
Xu Yu Huawei
Hua Zhang Hisense Broadband
Bo Zhang Inphi
Wenyu Zhao CAICT
Xiang Zhou Google
Yan Zhuang Huawei
George Zimmerman CME Consulting
Pavel Zivny Tektronix
STRAW POLLS
Call-for-interest

- Should a Study Group be formed for “Beyond 400 Gb/s Ethernet”
  - YES
  - No
  - Abstain

- Call Count
Participation

- I would participate in the “Beyond 400 Gb/s Ethernet” Study Group in IEEE 802.3
- Tally:

I believe my affiliation would support my participation in the “Beyond 400 Gb/s Ethernet” Study Group in IEEE 802.3
- Tally: (Results to be processed after call)
Future work

- Ask 802.3 WG for approval
- If approved, request formation of “Beyond 400 Gb/s Ethernet” Study Group by 802 EC
- If approved,
  - Creation of Study Group page /reflector
  - First Study Group meeting [teleconference?] anticipated for Jan 21 Interim
THANK YOU!
APPENDIX: BACKUP SLIDES
LINK AGGREGATION WILL NOT SUFFICE

• Problem: Need to scale the Network (density & cost)
• Temporary Solution: Link Aggregation
• Pros:
  • Addresses bandwidth requirements between releases of faster links
• Cons:
  • Non-deterministic performance
  • Fastest flow limited to individual link speed
  • Growth in operational & management issues
• Other bonding mechanisms, e.g. FlexE, fixes performance limitations but not density issues
• Faster links address these issues and they will be LAGGed or bonded!

Courtesy, David Ofelt, Juniper.
Increased processing capability will require bigger pipes!

Source: Top500.ORG - https://www.top500.org/statistics/sublist/
### WORLD INTERNET USAGE

<table>
<thead>
<tr>
<th>Total World</th>
<th>As of 3/31/19 ¹</th>
<th>As of 12/31/19 ³</th>
<th>Increase</th>
<th>As of 7/20/20 ²</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>7,716,223,209</td>
<td>7,796,615,710</td>
<td>80,392,501</td>
<td>7,796,949,710</td>
<td>80,726,501</td>
</tr>
<tr>
<td>Internet Users</td>
<td>4,383,810,342</td>
<td>4,574,150,134</td>
<td>190,339,792</td>
<td>4,833,521,806</td>
<td>449,711,464</td>
</tr>
<tr>
<td>Internet Penetration</td>
<td>57%</td>
<td>59%</td>
<td>2%</td>
<td>62%</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Top 20 Countries</th>
<th>As of 3/31/19 ¹</th>
<th>As of 12/31/19 ³</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>5,187,499,066</td>
<td>5,233,377,837</td>
<td>45,878,771</td>
</tr>
<tr>
<td>Internet Users</td>
<td>3,117,533,898</td>
<td>3,241,273,512</td>
<td>123,739,614</td>
</tr>
<tr>
<td>Internet Penetration</td>
<td>60%</td>
<td>62%</td>
<td>2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rest of World</th>
<th>As of 3/31/19 ¹</th>
<th>As of 12/31/19 ³</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>2,565,984,143</td>
<td>2,563,237,873</td>
<td>-2,746,270</td>
</tr>
<tr>
<td>Internet Users</td>
<td>1,229,027,955</td>
<td>1,332,876,622</td>
<td>103,848,667</td>
</tr>
<tr>
<td>Internet Penetration</td>
<td>48%</td>
<td>52%</td>
<td>4%</td>
</tr>
</tbody>
</table>

**Observations**

- Only 8 countries had at least 80% connectivity
- ≈ 450 million users increase
- 5% increase in Total World Internet Penetration since Mar 31 2019

1. IEEE 802.3 BWA, PART II
2. HTTPS://WWW.INTERNETWORLDSTATS.COM/STATS.HTM
3. HTTPS://WWW.INTERNETWORLDSTATS.COM/TOP20.HTM
Number of connected devices per capita is growing
The average traffic per user is growing at a much faster rate

# Global Device Connection Growth (Average)

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>2017</th>
<th>2022</th>
<th>CAGR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North America</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mb/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Broadband</td>
<td>2017</td>
<td>43.2</td>
<td>94.2</td>
<td>16.9%</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2017</td>
<td>37.1</td>
<td>83.8</td>
<td>17.7%</td>
</tr>
<tr>
<td>Cellular</td>
<td>2017</td>
<td>16.3</td>
<td>42.0</td>
<td>20.8%</td>
</tr>
<tr>
<td><strong>Western Europe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mb/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Broadband</td>
<td>2017</td>
<td>37.9</td>
<td>76.0</td>
<td>14.9%</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2017</td>
<td>25.0</td>
<td>49.5</td>
<td>14.6%</td>
</tr>
<tr>
<td>Cellular</td>
<td>2017</td>
<td>16.0</td>
<td>50.5</td>
<td>25.8%</td>
</tr>
<tr>
<td><strong>Central &amp; Eastern Europe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mb/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Broadband</td>
<td>2017</td>
<td>32.8</td>
<td>46.7</td>
<td>7.3%</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2017</td>
<td>19.5</td>
<td>32.8</td>
<td>11.0%</td>
</tr>
<tr>
<td>Cellular</td>
<td>2017</td>
<td>10.1</td>
<td>26.2</td>
<td>21.0%</td>
</tr>
<tr>
<td><strong>Latin America</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mb/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Broadband</td>
<td>2017</td>
<td>11.7</td>
<td>28.1</td>
<td>19.2%</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2017</td>
<td>9.0</td>
<td>16.8</td>
<td>13.3%</td>
</tr>
<tr>
<td>Cellular</td>
<td>2017</td>
<td>4.9</td>
<td>17.7</td>
<td>29.3%</td>
</tr>
<tr>
<td><strong>Middle East &amp; Africa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mb/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Broadband</td>
<td>2017</td>
<td>7.8</td>
<td>20.2</td>
<td>21.0%</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2017</td>
<td>6.2</td>
<td>11.2</td>
<td>12.6%</td>
</tr>
<tr>
<td>Cellular</td>
<td>2017</td>
<td>4.4</td>
<td>15.3</td>
<td>28.3%</td>
</tr>
<tr>
<td><strong>Asia Pacific</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(Mb/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Broadband</td>
<td>2017</td>
<td>46.2</td>
<td>98.8</td>
<td>16.4%</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2017</td>
<td>26.7</td>
<td>63.3</td>
<td>18.8%</td>
</tr>
<tr>
<td>Cellular</td>
<td>2017</td>
<td>10.6</td>
<td>28.8</td>
<td>22.1%</td>
</tr>
</tbody>
</table>

GLOBAL INTERNET TRAFFIC
BUSY-HOUR VS AVERAGE HOUR

Growth in the adoption of HD and UHD dominate IP video traffic

DATA CENTER CAPACITY CONTINUES TO GROW

Enterprise / Cloud Server Unit Shipments*

Switch Capacity Shipments in Eb/s**

* Percent of annual server shipments categorized by speed of the attached controllers and adapters
** Annual port capacity shipped on Data Center Ethernet Switches measured in exabits per second
Global mobile traffic is exponential and may even be underestimated.