400 G:
Physics, Economics, & Business

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400G Study Group

Agenda

- Intro and Background
- Broad Market Potential
  - Technical Feasibility
  - Distinct Identity
  - Compatibility
- Economic Feasibility
  - Technical Feasibility
  - Distinct Identity
  - Compatibility
- Closing Summary Assessment

The rate at which data can be transmitted down optic fibers is approaching a limit because of nonlinear optical effects. Multiplexing allows data to be encoded in different modes of light such as polarization, wavelength, amplitude, and phase and to be sent down the fibers in parallel. Optical angular momentum (OAM) can provide another degree of freedom whereby the photons are given a well-defined twist or helicity. Researchers now report that they were able to transmit high-bandwidth data using OAM modes in long lengths of optical fibers, thus providing a possible route to get yet more capacity through optic fiber networks.

400 G Study Group Abstract:

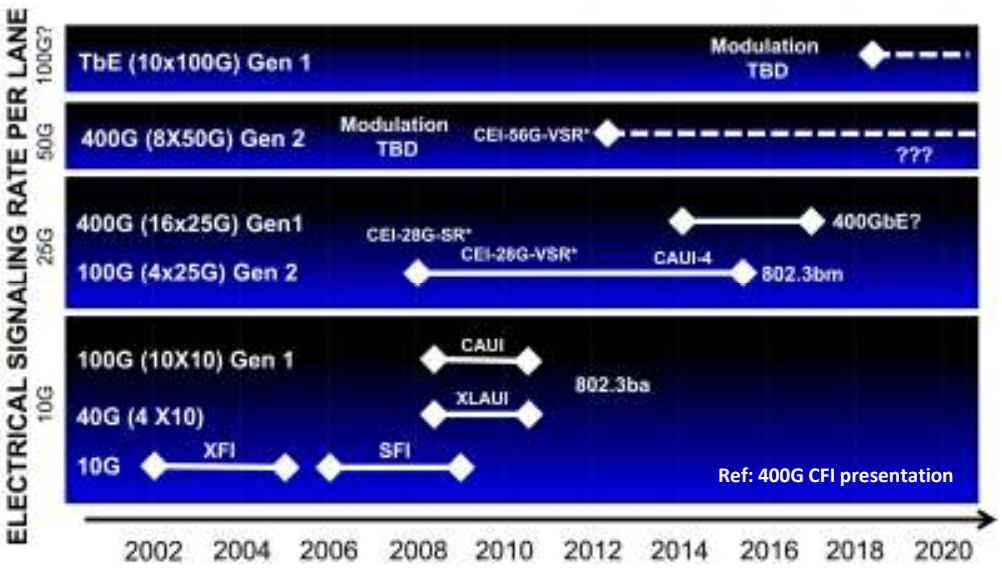
As stories about eavesdropping make news more often these days, the world is becoming more aware that computing and the internet is changing how businesses operate, governments function, and people live. Big data is a newer, less visible transformative trend as there is considerable *information* floating around these days, and it is being put to astonishing new uses. Big data is distinct from the Internet. While the web makes it much easier to collect and share data, big data is about more than just communication. Big data is based on the premise that we can learn more from a large body of information, things we could not comprehend when we used only smaller amounts.

In the 3rd century BC, the Library of Alexandria was believed to house the sum of human knowledge. Today, there is enough information in the world to give every person alive 320x as much as historians believed was stored in Alexandria's collection (1,200 EB). If all this information were placed on CDs, one could form five pillars reaching to the moon.

The explosion of data is relatively new. In 2000, only 25% of all the world's *stored* information was digital. With the rapid growth of *digital* data (2x • 36 months) we are quickly evolving with less than 2% of all stored information being non-digital. Given this colossal scale-up, it is a challenge to appreciate big data solely in terms of size. Big data is also characterized by the ability to render insight into aspects of the world that have never been quantified before. Location has been *datafied* using GPS systems. Words are datafied by mining centuries' worth of books. Friendships and "likes" are datafied, via Facebook. Big data helps answer *what*, not *why*. So, what is the connectivity demand as an opportunity in terms of value/Joule/bit/time?

Why & How & When

Technical developments related to Tb channel links continue to evolve with the economic practicality being incomplete. Prototype development and experimental efforts show that technology enhancements will allow 400 Gb Ethernet to be deployed in the very near-term, primarily for HPC applications. In particular, advances in key technical approaches (bits-per-symbol, symbols-per-second, Joules-per-bit, etc.) show that the evolution to Tb/sec speeds includes realizing fundamental technical opportunities. Propagation, bandwidth, latency, hop, etc., physics (i.e., latency=((⟦Propdelay⟧ + ⟦Packetsize⟧))/BW) indicates that latency is an important physical limit and the implications of 400 GbE physics may be only an economic opportunity. So, *can it be done* ➔ *can it be done at right value* (i.e., power, performance, cost, density).



Courtesy, Atsushi Takai, Oclaro

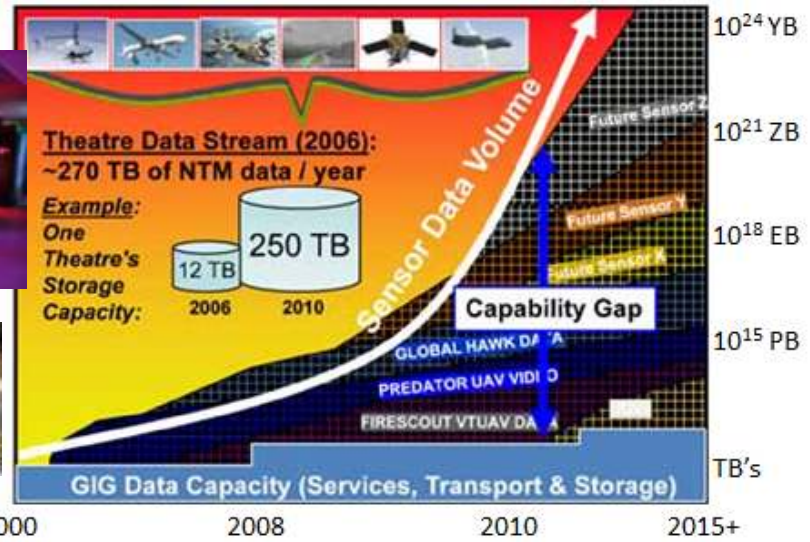
Why & How

more new recent

Big Brain Proje

…

BigBrain pushes the limits of today's technology; no SW for multiple brains as single model w/20 um resolution; a 1 um model → 20 to 22 PB; no computer capable



Surveillance platforms such as the Global Hawk system are capable of producing 10's to 100's of TB over a period of hours. Pete Rustan (MIT/Lincoln Laboratory) advisory council review, heard that for DOD and IC today (2008) "70 % of the data we collect is falling on the floor."

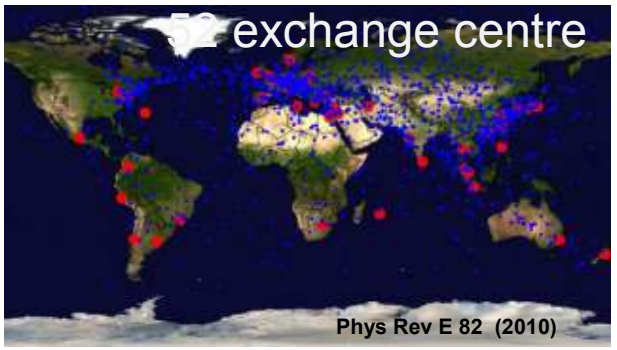
- Earth: 5.1×10^{14} m^2
- Earth: allocating 1B/sqm, 0.5 PB
- Earth w/1 m^2 resolution/sec, 1.8 EB/hour
- Continuously (month/year), 1.3 ZB/16 ZB
- Earth at 1 m^2 resolution/sec for 100 years, 1.6 YB

HEP: hundreds of PB (est ~10^{17} B) in 2015
LHC: global network 100 PB annually

Source: JASON presentations (2008)

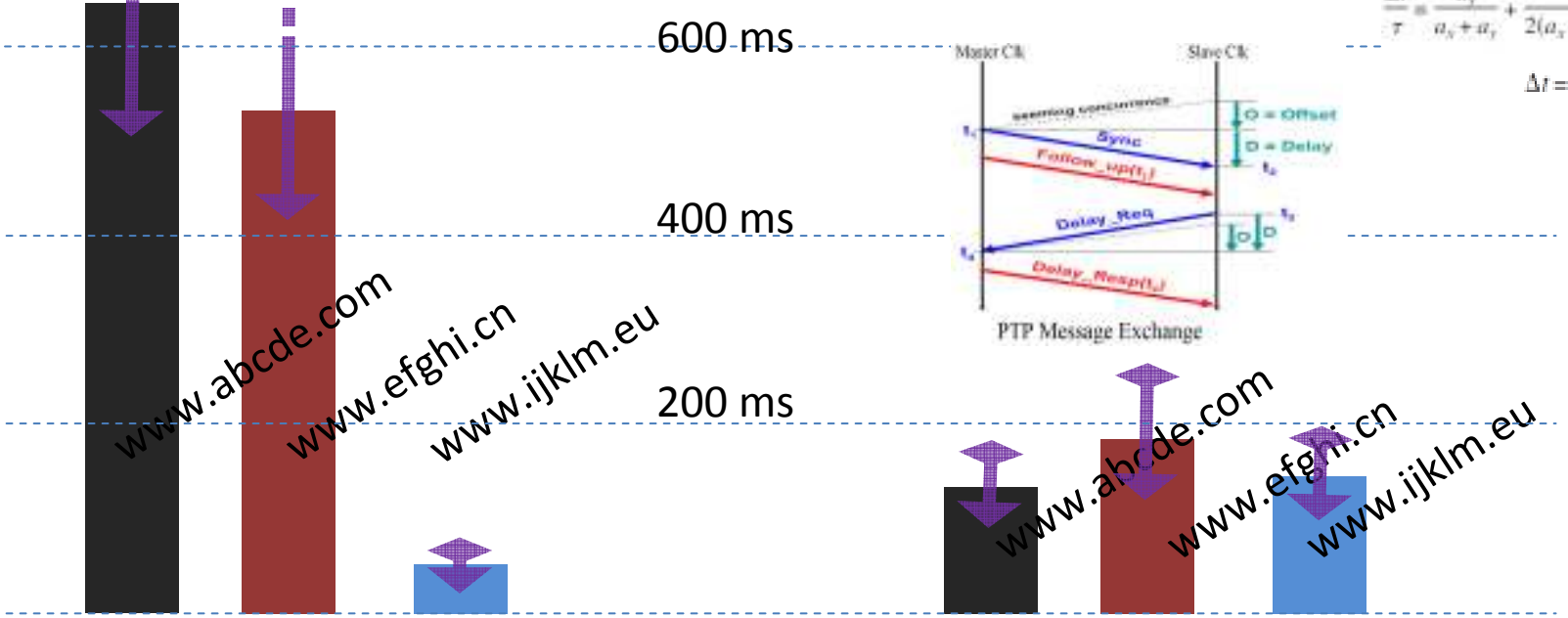
Network Latency Experimentally

- *value of a microsecond* and *latency arms race* (new businesses)
- Fundamental network latency; refractive property of the fibre
- BW is *outsourced*; borrowed from the network infrastructure
- Latency as resource access opportunity
- 4.76 usecs/km, 100km ≈ 500 usecs; nearly 269,813+ km/sec
- 40G ➔ 100G: connect core routers, high capacity demanding users (HPC); optimize CAPEX and OPEX
- Better economics vs yesterday's high-end transmission capacity



$$\frac{\Delta t}{\tau} = \frac{a_y}{a_x + a_y} + \frac{1}{2(a_x + a_y)\tau} \ln\left[- \frac{\hat{X} + 2a_x X}{\hat{Y} + 2a_y Y} \right]$$

$$\Delta t = \pi a_y / (a_x + a_y)$$

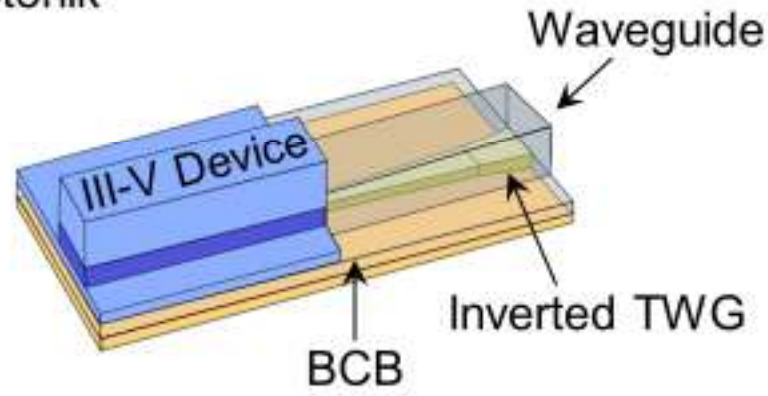


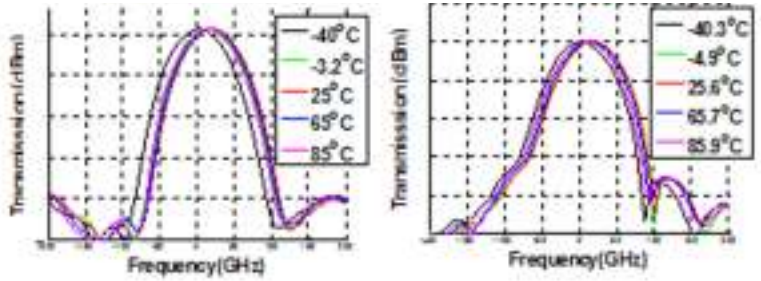
http://www.slac.stanford.edu/comp/net/wan-mon/tutorial.html
http://psas.pdx.edu/news/2013-01-27/

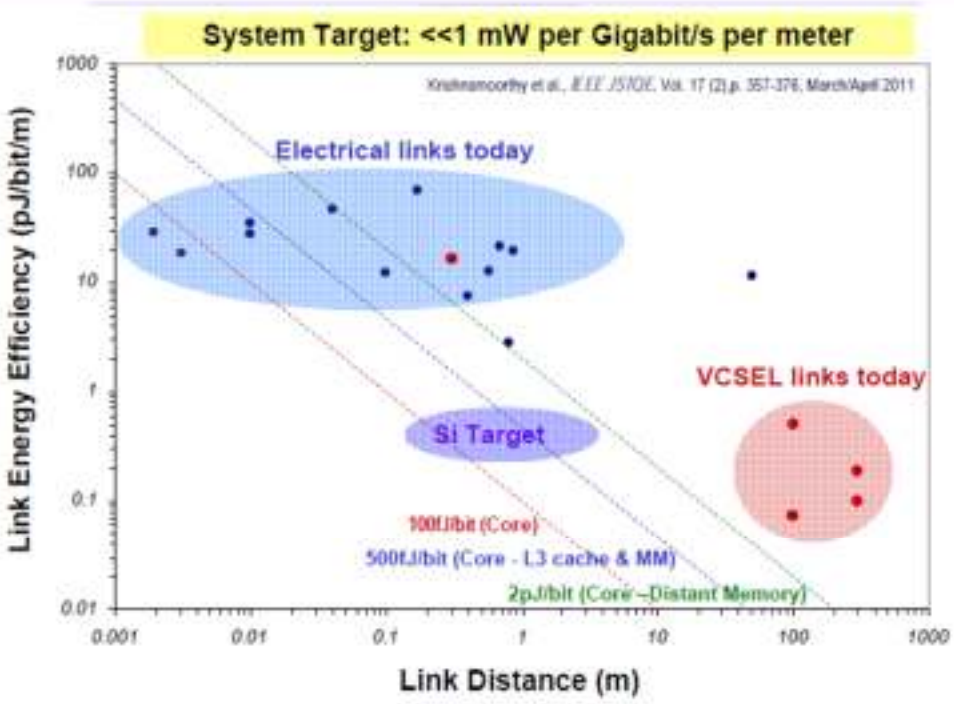
http://www.verizonenterprise.com/about/network/latency/

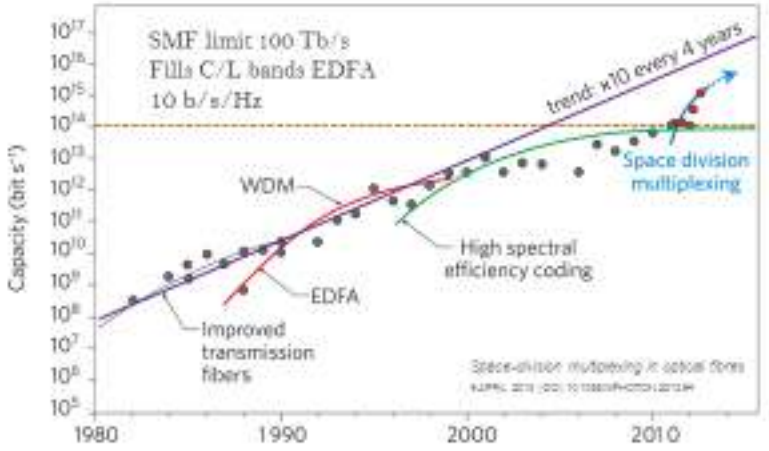
400 GbE: Technical vs Practical Opportunity

Photonic News:
Budget cuts impact photonics
予算がインパクトフォトニクスをカット
Budget réduit l'impact photonique
Tagli di bilancio impatto fotonica
Budgetkürzungen Auswirkungen Photonik

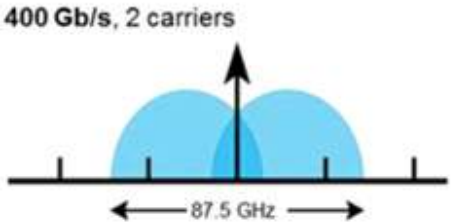


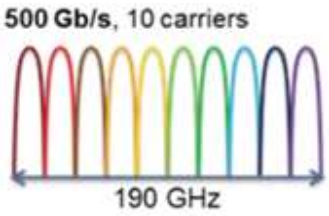


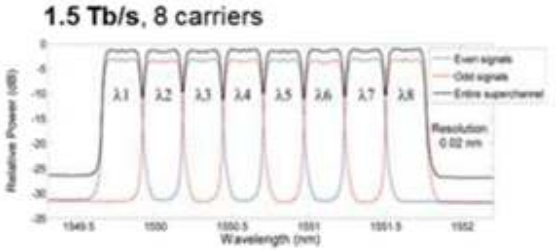




High-performance Stds Summary







distance

Distance	Standards	Modulation/Signaling	
X,000 km Continental	OIF, OTN, ITU, Engineered	Complex optical	DP-QPSK/ DP-16QAM
10 to 40 km	Ethernet	NRZ Single-Mode	100GBASE-L/E-R4
100 m to 2km	Ethernet	NRZ MM and SM	100GBASE-SR4
10 m	Ethernet	NRZ over cable or el.<->opt. cable	100GBSE-CR4
Backplane < 1m	Ethernet, OIF CEI	NRZ, PAM4	100GBASE-KR4, KP4, CEI LR
Interconnect module to chip, chip to chip	OIF CEI Ethernet	NRZ	VSR CAUI4

100G

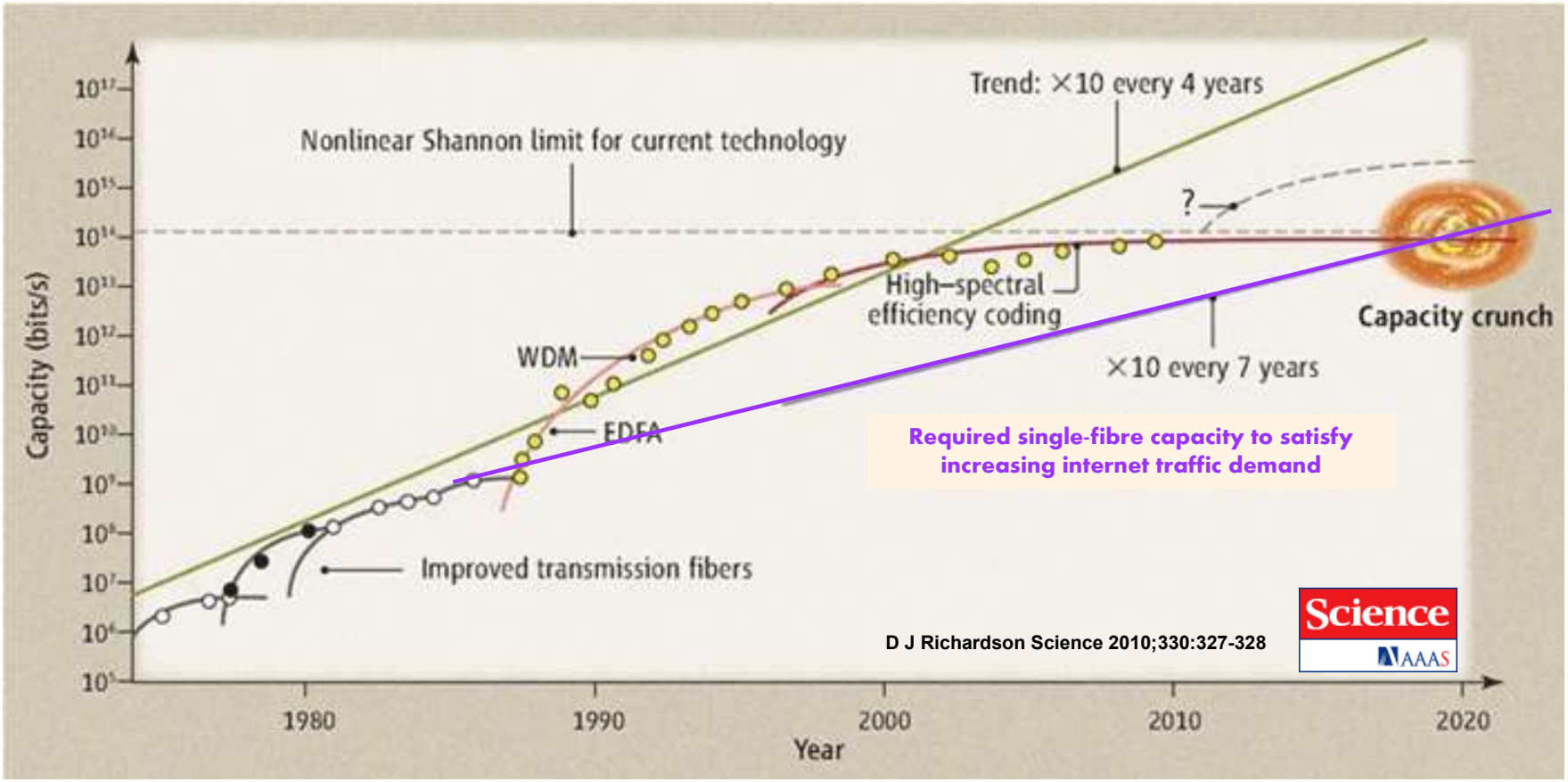
- Carriers: key issue “cost ratio" or cost of the higher-BW to well-established lower-BW
- Carriers: ratio will reach 6:1 over the next two years (maybe 7:1)
  10:1 too expensive
- 100GE line purchased similar value to 6 x 10GbE
- More attractive for 100GE “cost ratio”

Ethernet Services

	2013	2014	2015	2016	CAGR
100 GbE	750%	312%	93%	67%	157%
40 GbE	150%	25%	8%	-7%	26%
Total	270%	157%	71%	54%	90%

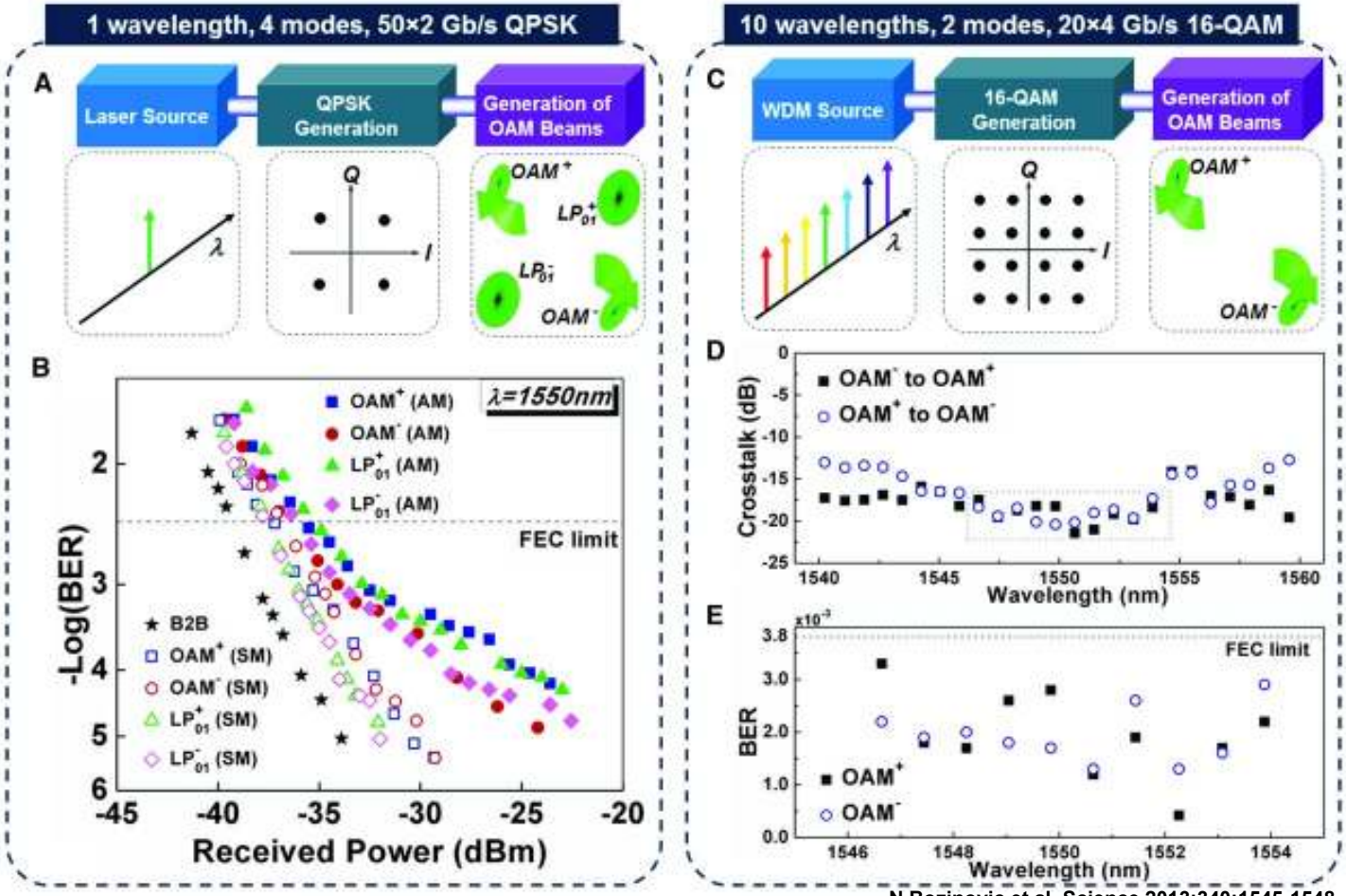
Ref: Heavyreading

and on the data flows …



Data transmission capacity of single- fibre transmission vs year (40% increase)
NL Shannon limit for the existing technology and spectral efficiency
Breakthroughs: LL SM fibre, EDFA, WDM, DSP-based coherent detection
Not really a red brick wall; value/J/b/s/Hz valuable metric

Data-transmission experiments



N Bozinovic et al. Science 2013;340:1545-1548

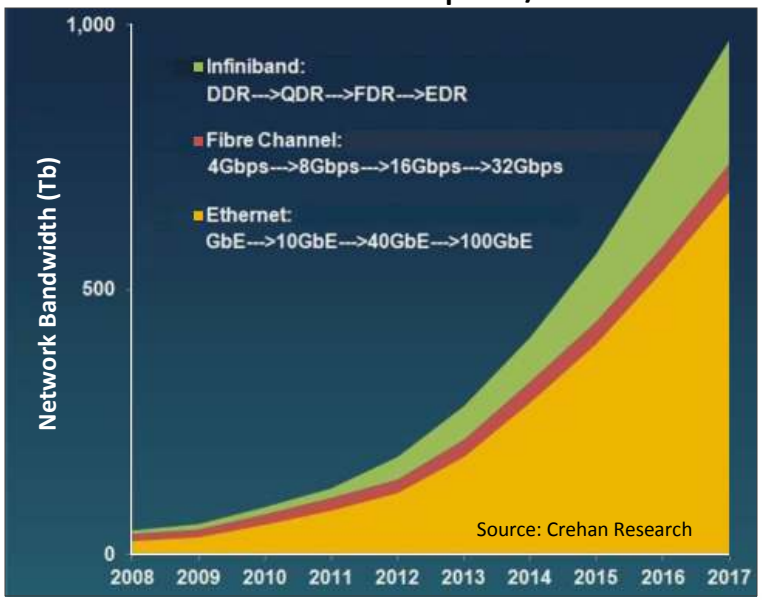
A) 50 × 2 Gbaud QPSK signal via single wavelength (4-modes, vortex fibre)
B) BER as a function of power (single vs all channels)
C) 20 x 4 Gbaud 16 QAM via 10 wavelengths (2-modes, vortex fibre)
D) X-talk vs wavelength
E) BER as a function of wavelength in WDM

Science
AAAS

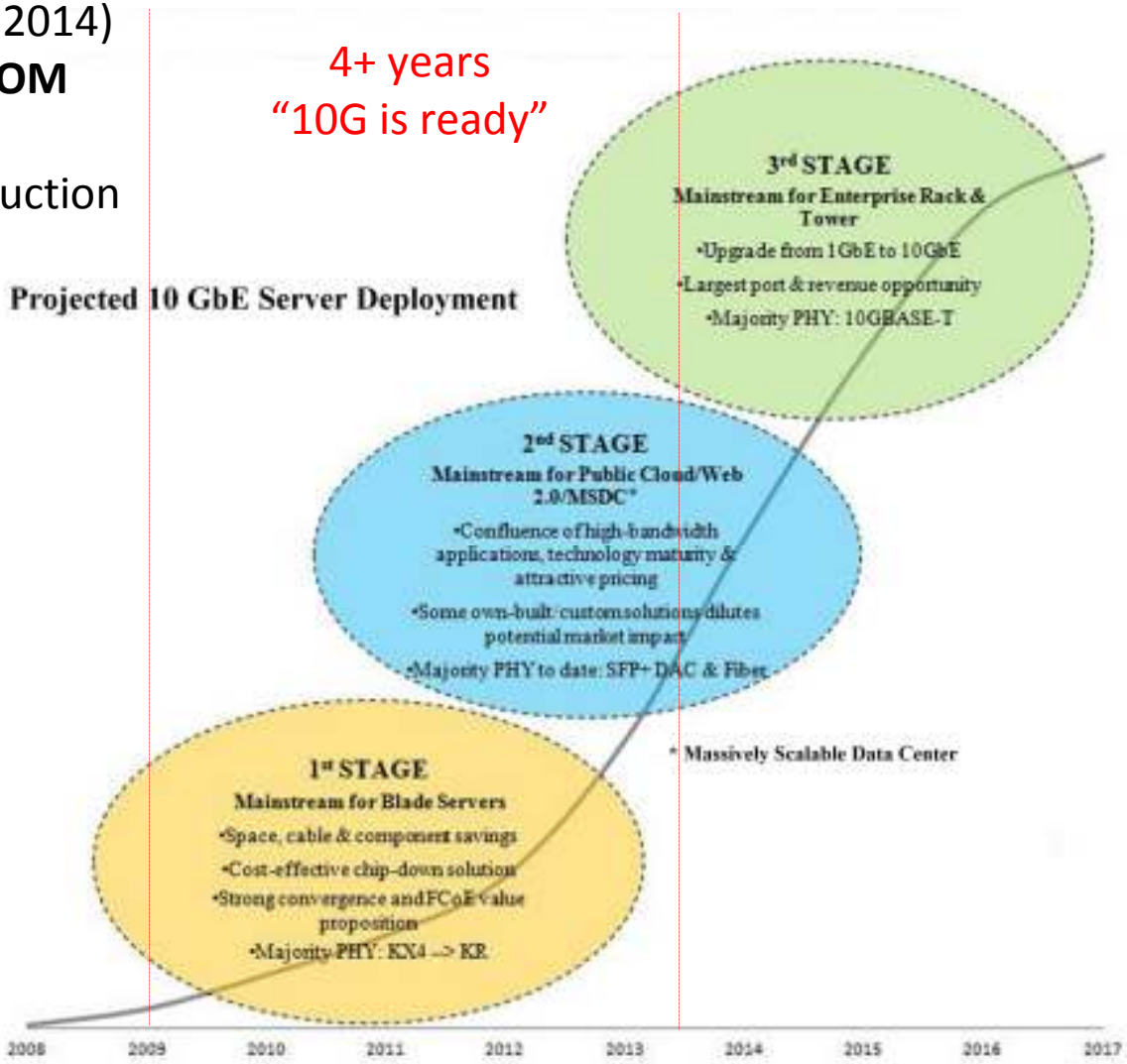
10 GbE Adoption

- 10 GbE is 60% of total bandwidth (2014)
- 10 GbE **server-class adapter and LOM** shipments > 1 GbE (Q214)
- PHY vendor (2009), ready for production
- Not a 400G scenario at this time

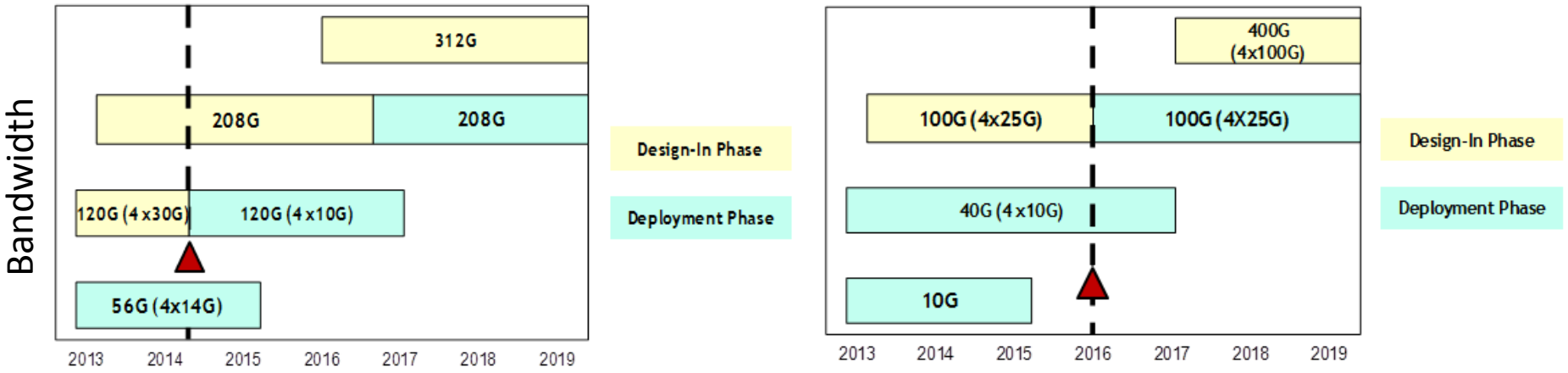
Server-class Adapter/LOM



4+ years
"10G is ready"



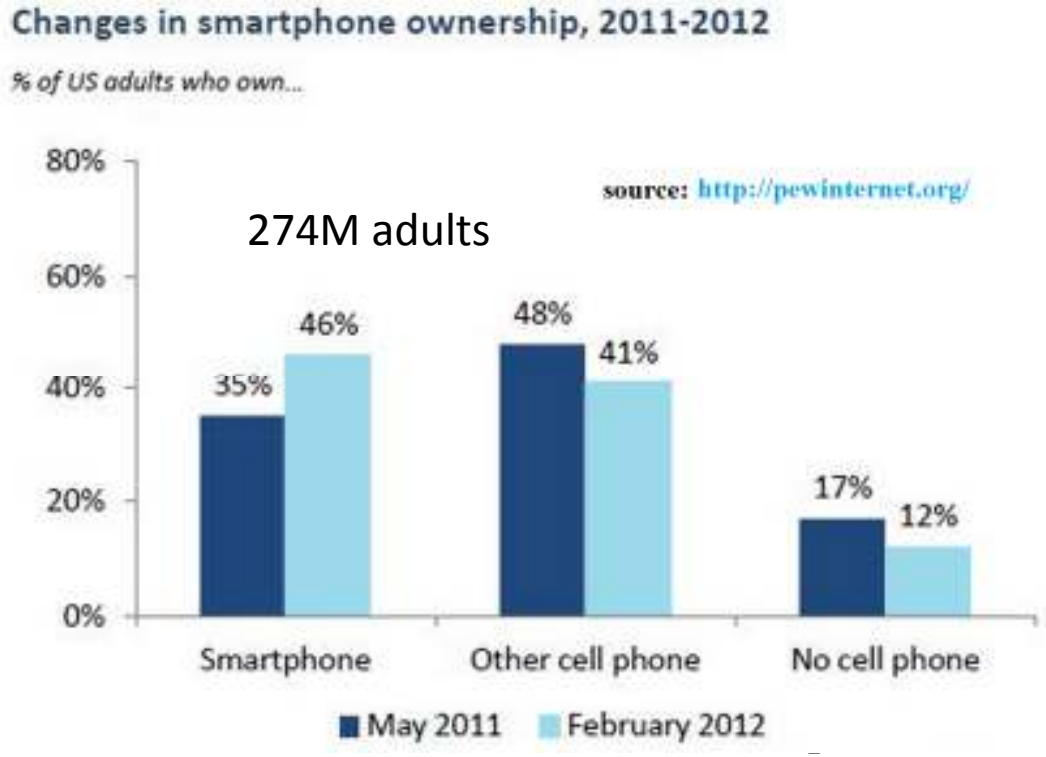
Photonic Network Trends



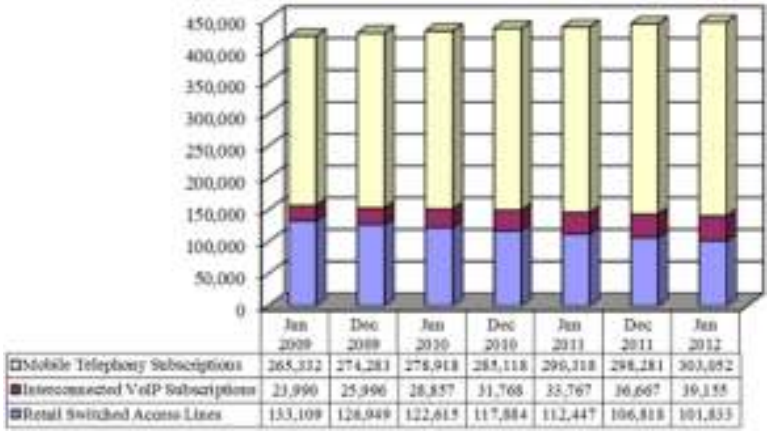
- 100G adoption in the Data Center (2018) – research consensus
- 40G transmitter requiring 100G bandwidth (2015) – research consensus
- FCC: continued growth in VoIP and mobile connectivity (6/2013)
- Continued decline in traditional wired telephone services
- Retail local telephone service customers are served by two wireline technologies; switched access lines/VoIP and by wireless
- 102M switched access lines users; 39M VoIP subscriptions; 303M mobile subscriptions in US

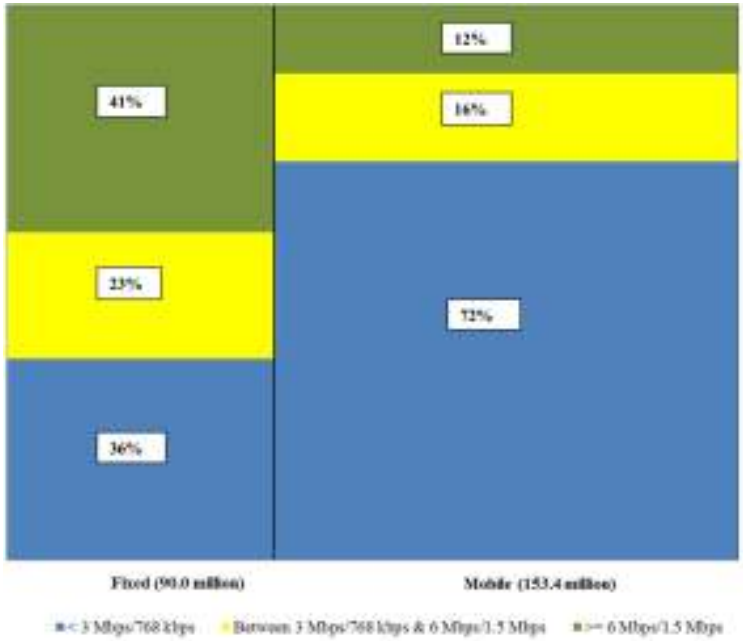
FCC Form 477 Program

- VoIP subscriptions CAGR +18% (2009 – 2012)
- Mobile subscriptions CAGR +5% (2009 – 2012)



ias0612_maps.pdf





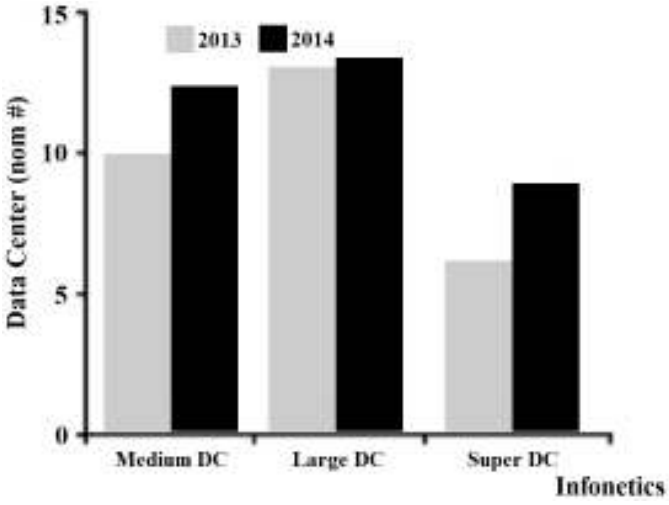
Ethernet Market

- Global Ethernet equipment (carrier) -3% in 2012; IP edge router spend + (2012)
- Carrier Ethernet equipment ports 95M+ WW (2017)
- Operator investment anticipated FC/FCoE
- 10 GbE connections growing the most
- WAN connection expected to double (2012 vs 2014)
- Global Ethernet switch market $5B+ (4Q12)
- Global Ethernet switch market $20B+ (2012)
- 10 GbE switch is primary revenue growth opportunity
- Shipments grew 66% in 2012; 40 GbE up 10x in 2012
- L2-3 Ethernet Switch market ➔ 6% CAGR (2016)
- 40/100 GbE market research ➔ 16% growth
- 2015+, 40/100 GbE switch growth opportunity

L2 L3 Ethernet Switch Market Revenue (LAN)

Source: Dell'Oro

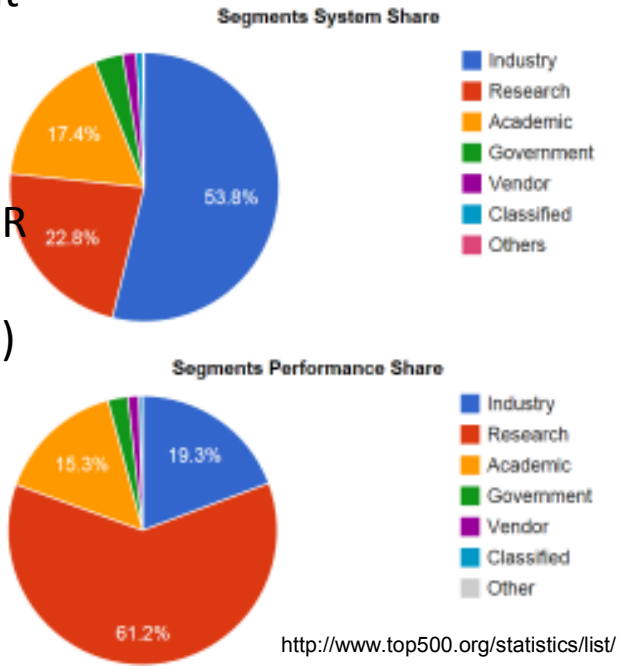
Dell'Oro
Infonetics
Chrehan
just my consensus



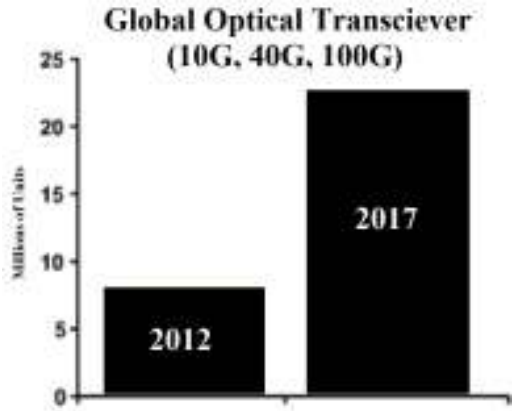
Years Deployed

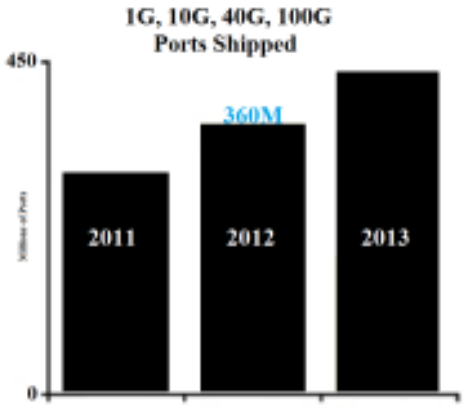
Economics: …/40G/100G

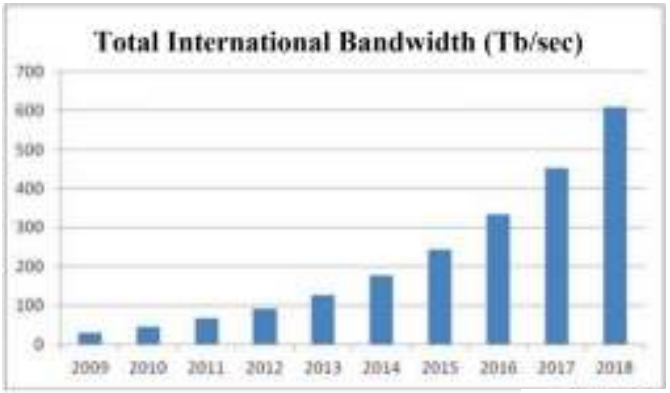
- Global Optical Network Hardware (GONH) market to grow at a CAGR of 3.9% (2011–2015)
- GONH BW demand growing (approx. 33%) CAGR
- 1Q12 vs. 1Q13 GONH $\$_{total}$ -5%, driven by cuts to SONET/SDH spending (-30%); WDM +10% (Y2Y) ; WDM CAGR 12% (2012 – 2017)
- Global optical transceiver market (10/40/100G) +10% (2012)
- 40G QSFP(LR/SR) 3x growth in 2013 (Infonetics)
- Tunable XFP shipments 2x+ growth in 2012
- Overall 40G coherent modules declining vs 100G coherent deployments up
- Tunable XFPs growth opportunity; 36% CAGR
- 40/100GbE: *Demand Will Hinge on Lower Expense*



http://www.top500.org/statistics/list/







Infonetics (2012)

Dell'Oro Group Forecast

Optical Transport Market

- The Dell'Oro Group forecasts that the global optical transport market will grow to 10% CAGR in 2017
- 2012 SONET/SDH sales -20%, while WDM equipment sales was unchanged
- Dell'Oro expects optical transport growth across all the main regions, with no one region dominating. The market research company does foresee greater growth in Europe given the prolonged underspend of recent years
- European operators are planning broadband access investment such as fibre-to-the-cabinet/ VDSL vectoring as well as fibre-to-the-home
- 40Gb and 1100 Gb optical transport will be the main WDM growth areas through 2017
- 40Gb demand to grow through 2017, probably tapering off due 100 Gb demand
- 100Gb continues to exceed Dell'Oro's forecast, predicting 100 Gb wavelength shipments to grow at a 75% CAGR over the next five years; 60% of the WDM capacity shipments by 2017
- Service providers will accept gradual evolution (10G/40G/100G/ …) vs 10G/100G

Source: Dell'Oro (January 2013)
http://www.delloro.com/news/total-wavelength-division-multiplexer-wdm-market-to-reach-13-billion-in-2017-according-to-delloro-group

Data Centers

Range International Information Hub (2016); Langfang, China; 6.3M sqft; commercial computing

Switch SuperNAP data campus; Las Vegas; 2.2M sqft

NSA; 1M+ sqft (2013)

QTS Metro Data Center (Atlanta); 970k sqft and Tulip Data City in Bangalore, India ("largest in Asia")

Telecom hub by Lakeside Technology (Chicago); 1.1M sqft

In Closing …

IDC forecasts that worldwide spending on public IT cloud services is expected to grow at a 26% compound annual growth rate in three years with segments like Virtual Private Cloud growing at greater than 50% CAGR. So, what does the IEEE 400G do *!?!*

No PMD for volumes; high-end focus