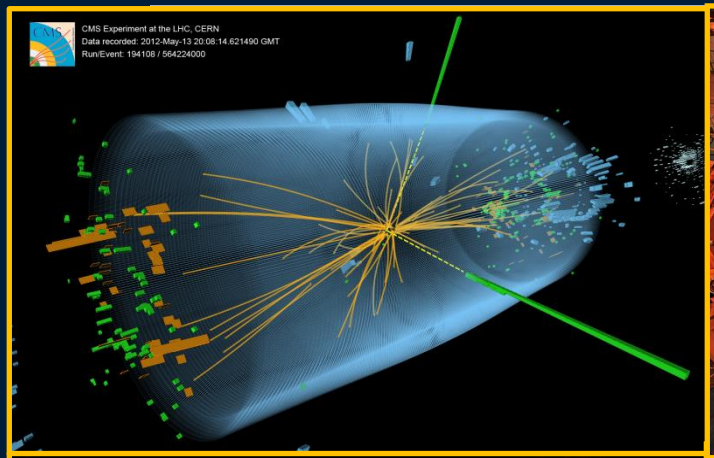
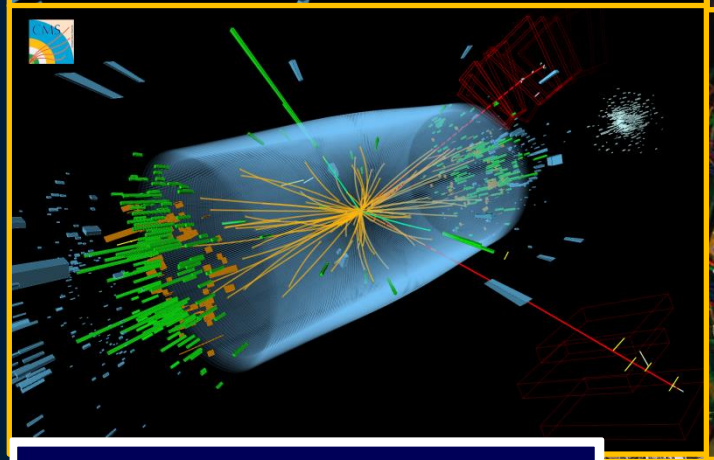
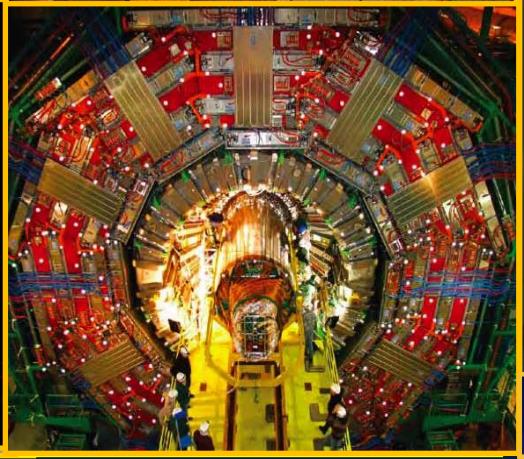
Networking for HEP in the LHC Era:
Global-Scale Developments for Data Intensive Science







- ***LHC Run1:***
  Discovery of a New Boson
- ***LHC Run2: New Physics***
  Beyond the Standard Model

Gateway to a New Era

50 Vertices, 14 Jets, 2 TeV

Harvey B Newman, Caltech

International School of Physics
“Enrico Fermi”: Lecture 3

Networking for HEP in the LHC Era: Global-Scale Developments for Data Intensive Science

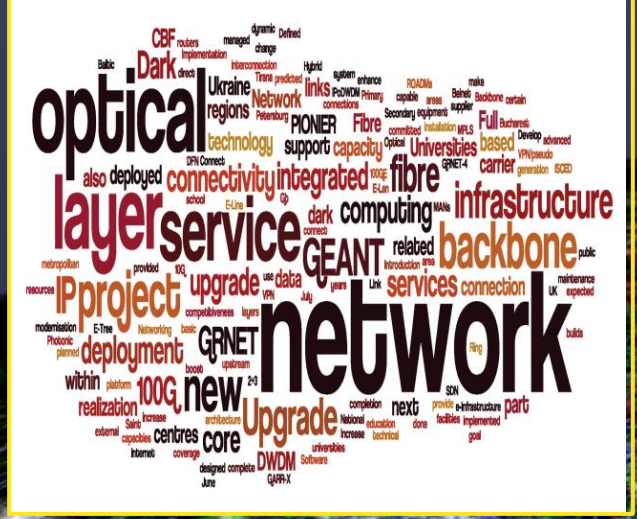
- Internet World Trends: Usage, Penetration, Traffic Growth and Qualitative Changes
- ICFA SCIC: A World View of Networks, Trends and Developments; Working to Close the Digital Divide
- SCIC Monitoring WG: Quantifying the Digital Divide
- Closing the Divide Dark with Fiber Networks
- Digital Divide: Model Cases and Problem Areas
- Conclusions

Internet World Trends in 2014

Users, Penetration and Broadband Global Traffic Evolution

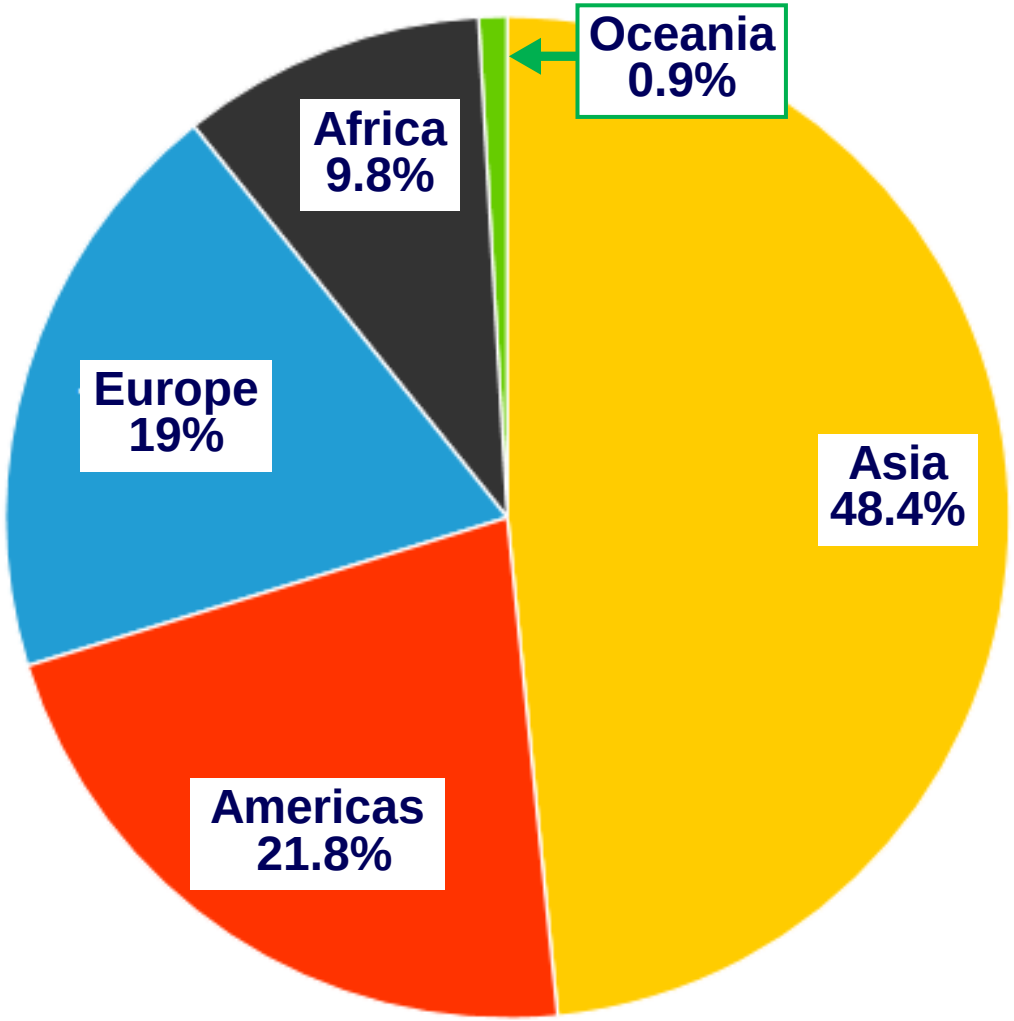
The first node in the web

Sailing the Internet



World Internet Use: Penetration by Region Revolutionary Changes 2014

- Explosion of bandwidth use: ~50 Exabytes/month
- Rise of broadband
- Rise of Video + Mobile Traffic: ~33 Exabytes/month Per mo. (66%) in 2014
- Web 2.0: Billions of Web Pages, embedded apps.; transition to a mobile world
  - Facebook, Skype, iPhone vs. Android; Twitter; Google
- Rising Dominance of CDNs
- Billions of Devices: the Internet of Things (IoT) *to* the Internet of Everything (IoE)
- *Optical fiber network advances:* Raw capacity largely unused

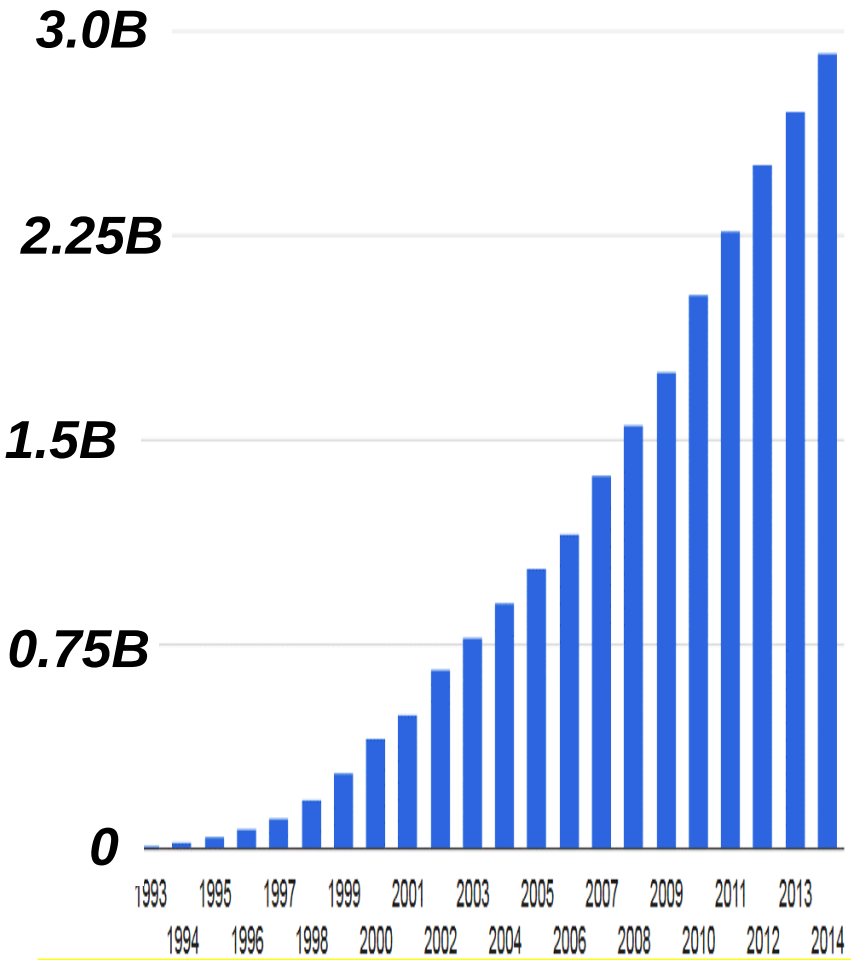


http://www.internetlivestats.com/

2.94 Billion Internet Users; 650M+ in China

Penetration 40% [14% in 2004; 1% in 1995]; + 8%/Year

Internet Users in the World

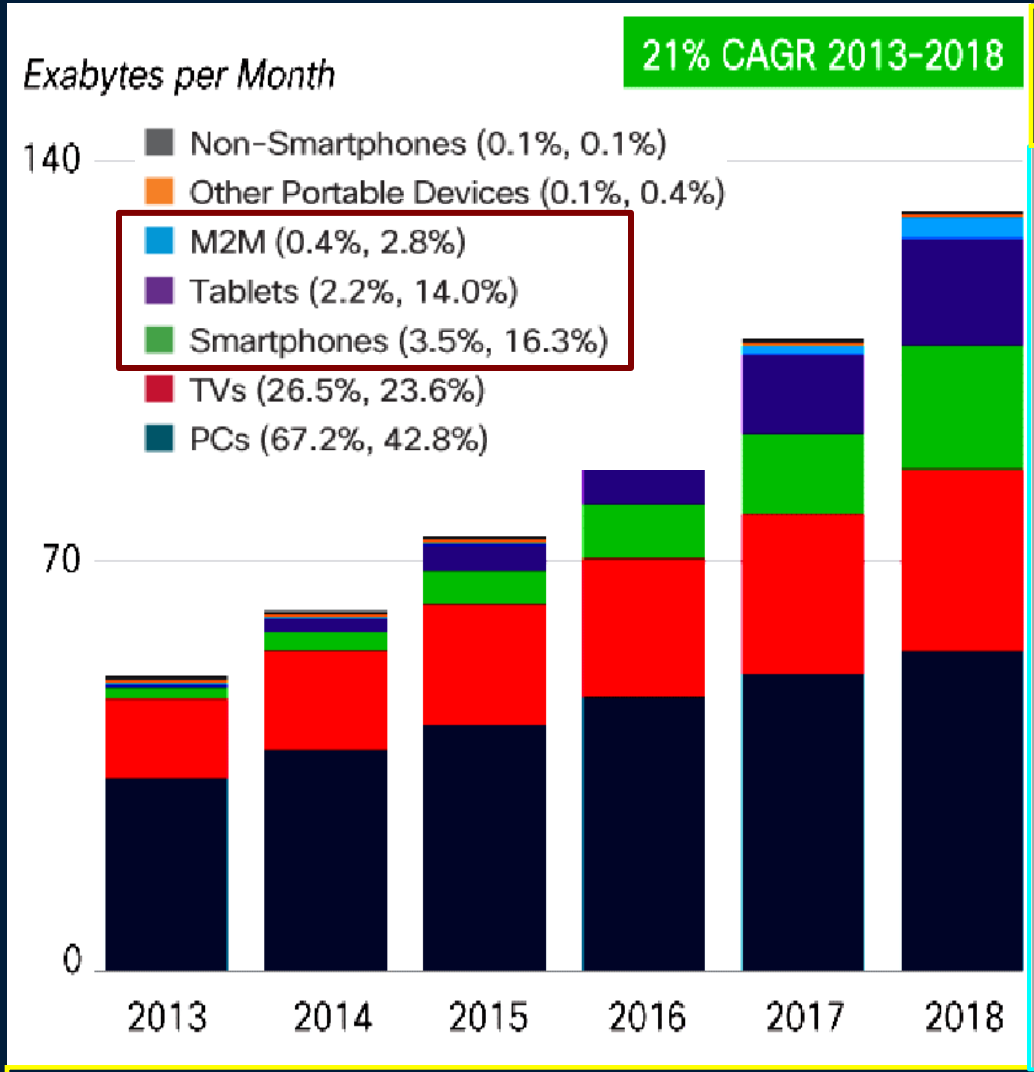


1st Billion in 2005; 2nd in 2010
3 Billion by the End of 2014

Year (July 1)	Internet Users	Users Growth	World Population	Population Growth	Penetration (% of Pop. with Internet)
2014*	**2,925,249,355**	7.9%	7,243,784,121	1.14%	**40.4%**
2013	**2,712,239,573**	8.0%	7,162,119,430	1.16%	**37.9%**
2012	**2,511,615,523**	10.5%	7,080,072,420	1.17%	**35.5%**
2011	**2,272,463,038**	11.7%	6,997,998,760	1.18%	**32.5%**
2010	**2,034,259,368**	16.1%	6,916,183,480	1.19%	**29.4%**
2009	**1,752,333,178**	12.2%	6,834,721,930	1.20%	**25.6%**
2008	**1,562,067,594**	13.8%	6,753,649,230	1.21%	**23.1%**
2007	**1,373,040,542**	18.6%	6,673,105,940	1.21%	**20.6%**
2006	**1,157,500,065**	12.4%	6,593,227,980	1.21%	**17.6%**
2005	**1,029,717,906**	13.1%	6,514,094,610	1.22%	**15.8%**
2004	**910,060,180**	16.9%	6,435,705,600	1.22%	**14.1%**
2003	**778,555,680**	17.5%	6,357,991,750	1.23%	**12.2%**
2002	**662,663,600**	32.4%	6,280,853,820	1.24%	**10.6%**
2001	**500,609,240**	21.1%	6,204,147,030	1.25%	**8.1%**
2000	**413,425,190**	47.2%	6,127,700,430	1.26%	**6.7%**
1999	**280,866,670**	49.4%	6,051,478,010	1.27%	**4.6%**
1998	**188,023,930**	55.7%	5,975,303,660	1.30%	**3.1%**
1997	**120,758,310**	56.0%	5,898,688,340	1.33%	**2.0%**
1996	**77,433,860**	72.7%	5,821,016,750	1.38%	**1.3%**

http://www.internetlivestats.com/

Global IP Traffic: 132 Exabytes/Month by 2018. The Rise of Mobile and Video



Global IP Traffic: Historical Context

Year	Global Internet Traffic
1992	100 GB per Day
1997	100 GB per Hour
2002	100 GBps
2007	2000 GBps
2013	28,875 GBps
2018	50,000 GBps

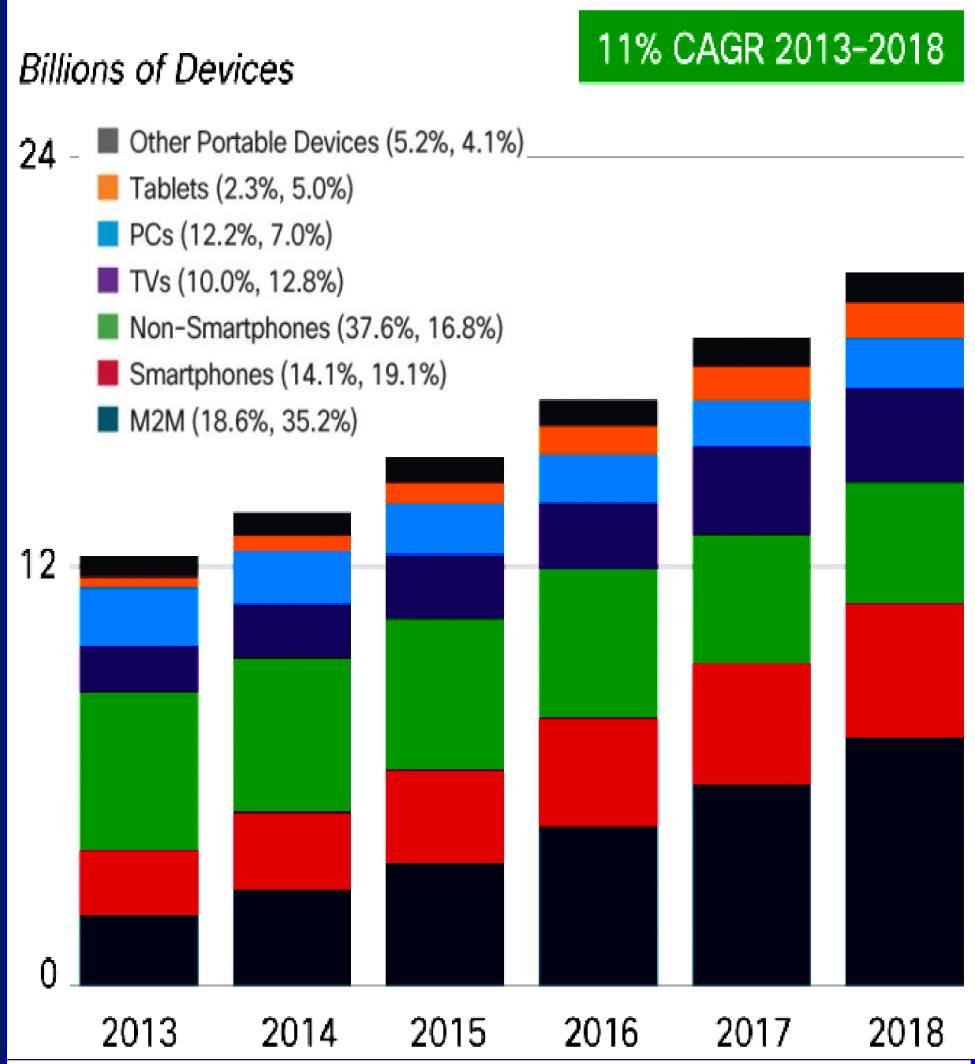
Cisco Visual Network Index 2014:
The Zettabyte Era: Trends and Analysis

Cisco VNI Global IP Traffic Outlook
The Zettabyte Era: Trends and Analysis

- Annual global IP traffic will reach 1.1 Zettabytes (ZB) in 2016; 1.6 ZB by 2018
  - ❒ Global IP traffic has increased 5X over the past 5 years, and will increase 3X over the next 5 years, equivalent to a CAGR of 21% [slowing growth]
- Busy-hour Internet traffic will increase 3.4X between 2013 & 2018, to 1.0 petabit/s while average Internet traffic will increase 2.8X to 0.3 Pbps.
- Metro traffic will surpass long-haul traffic in 2015, and account for 62% of total IP traffic by 2018.
  - ❒ Due in part to the increasing role of content delivery networks, which bypass long-haul links and deliver traffic to metro & regional backbones.
  - ❒ 55% of all Internet traffic will cross CDNs by 2018 globally, up from 36% in 2013.
- The Non-PC share of total IP traffic will grow to 57% by 2018.
  - ❒ CAGR of Traffic Sources: PC-originated 10%; TVs 35%; *Tablets 74%; Smartphones 64%; M2M (machine to Machine) 84%*
- Traffic from wireless and mobile devices will exceed traffic from wired devices by 2016.

Rise of the Internet of Things

20 Billion Devices by 2018



From the Internet of Things to the Internet of Everything; Not If but When

Number of Device Connections *Per Person*	2013	2018
Asia Pacific	1.41	2.24
Central and Eastern Europe	2.10	3.39
Latin America	1.75	2.58
Middle East and Africa	0.92	1.28
North America	5.34	9.26
Western Europe	3.89	6.52
Global	1.73	2.73

Source: Cisco VNI, 2014

ICFA SCIC: A World View of Networks, Trends and Developments

Monitoring and Closing the Digital Divide

Assisting with Advanced Network Infrastructure and Development and Methods in World Regions

ICFA and International Networking

- **ICFA Statement on Communications in Int'l HEP Collaborations of October 17, 1996**

  See *http://www.fnal.gov/directorate/icfa/icfa_communicaes.html*

"ICFA urges that all countries and institutions wishing to participate even more effectively and fully in international HEP Collaborations should:

- ***Review their operating methods to ensure they are fully adapted to remote participation***
- ***Strive to provide the necessary communications facilities and adequate international bandwidth"***

ICFA Standing Committee on Interregional Connectivity (SCIC)

- Created by ICFA in July 1998 in Vancouver ;
  Following ICFA-Network Task Force study group in 1997
- CHARGE:
- Make recommendations to ICFA concerning the connectivity between *the Americas*, Asia and Europe (and network requirements of HEP)
  - As part of the process of developing these recommendations, the committee should
    - Monitor traffic
    - Keep track of technology developments
    - Periodically review forecasts of future bandwidth needs, and
    - Provide early warning of potential problems
- Create subcommittees when necessary to meet the charge
- The chair of the committee should report to ICFA once per year, at its joint meeting with laboratory directors
- Representatives: Major labs, Europe, Asia, NA Users, S. America

SCIC in 2013-14

http://cern.ch/icfa-scic

2014 Reports: *LHC Networking Post-Discovery and the Outlook for Run2 and Beyond*

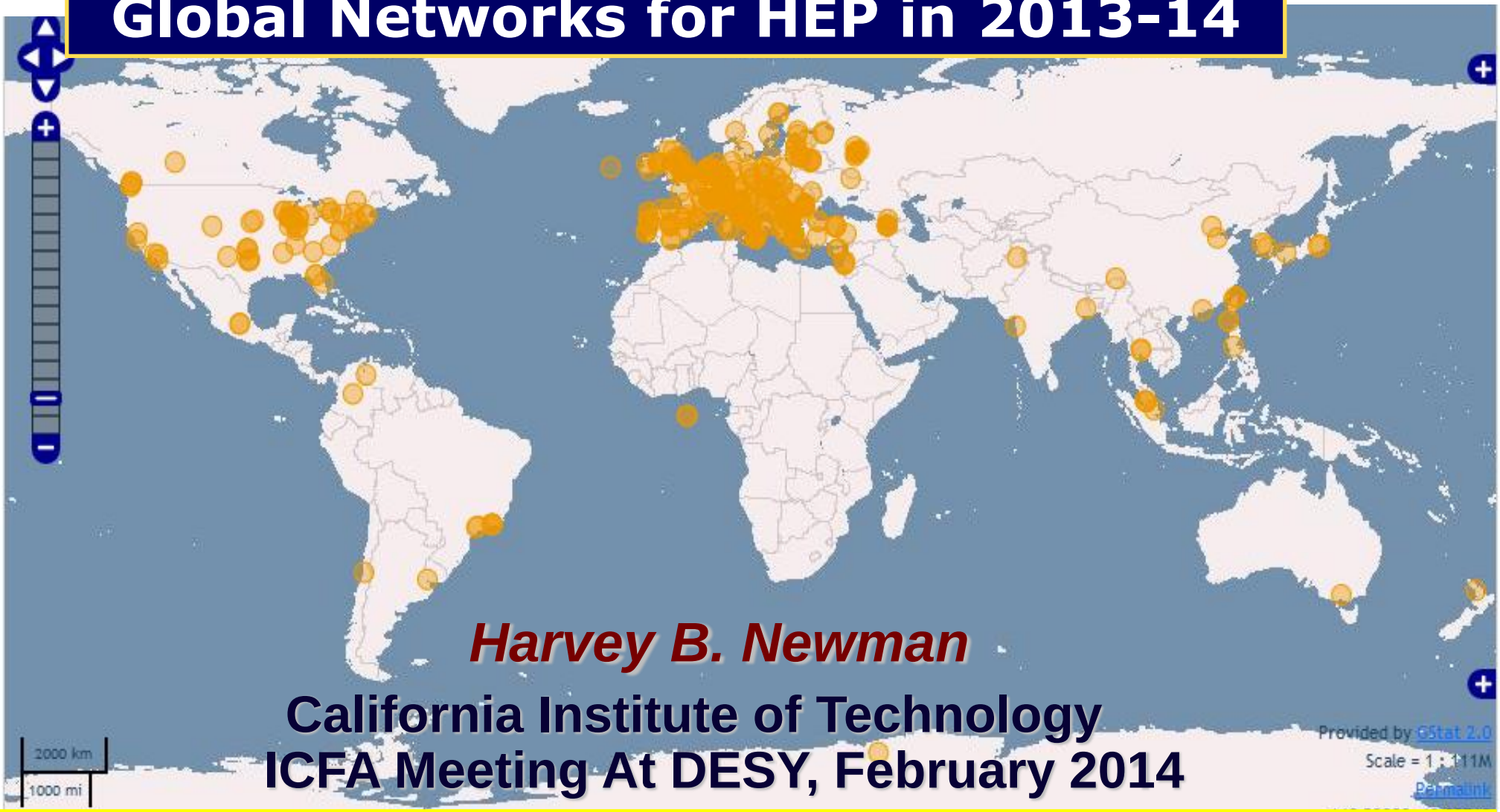
- ***Main Report*: "Networking for HEP"** [HN, A. Barczyk, A. Mughal et al.]
  - ➔ **Updates on the Digital Divide, World Network Status**
- ***30* New Annexes + A World Network Overview**
  Status and Plans of International, Nat'l & Regional Networks, HEP Labs, and Advanced Network Projects
- ***Monitoring Working Group Report*** [R. Cottrell, S. McKee, R. Khan]
- ***LHCONE (www.lhcone.net):*** **A New Global Architecture of Open Exchange Points supporting the new LHC Computing Models: *Focus on Tier1/2/3 Operations; Successful First Phase***

Also See:

- **TERENA *2013 Compendium* (www.terena.org): R&E Networks in Europe**
- **http://internetworldstats.com: Worldwide Internet Use**
- **Telegeography.com; Interactive Submarine Cable Map: http://submarinecablemap.com**

ICFA Standing Committee on Interregional Connectivity (SCIC)

Global Networks for HEP in 2013-14



Harvey B. Newman

California Institute of Technology

ICFA Meeting At DESY, February 2014

Presentation and Reports at http://icfa-scic.web.cern.ch/

2014 SCIC Full Presentation to ICFA: Topics

- **ICFA SCIC Reports, Work and Conclusions for 2014**
- **Networking for HEP in the LHC Era;** Evolution and Revolution in 2013-14
- **SCIC Monitoring Group: Mapping the Digital Divide:** Key Observations; Funding Issue; Mapping from the Sites
- **National, Continental and Transoceanic Network Infrastructures:** Many Transitions to 100G
- **LHC Computing:** View from the Tier1s **(LHCONE Workshop)**
- **Move to New LHC Computing Models:** LHCONE Ramps Up
- **Closing the Digital Divide:** Model Examples; Problem Areas
- **Innovative Network-Related Projects**
- **Advances in High Speed Data Transfers** for HEP
- **The Long View:** Challenges for Run 3 and HL LHC
- **Internet World Trends:** Users, Penetration; Traffic + Capacity
- **Optical Data Transmission:** the State of the Art

SCIC Work Areas

- *Closing the Digital Divide*
  - Monitoring the world's networks, with a focus on the Divide; work towards greater equality of scientific opportunity
  - Work on throughput improvements; problem solutions
  - Provide information and training on advanced methods
  - Encouraging the development of national advanced network infrastructures: through knowledge sharing, and joint work
- Advanced network technologies and systems
  - Track adv. network technologies and emerging standards
  - High throughput methods; + community engagement to apply the methods in many countries, for the LHC and other major programs (HEP, LIGO, AMS, et al.)
  - New network concepts and architectures: Creation and development; with many network partners
    - *LHCONE; SDN;* Integration of advanced network methods

World Summit on the Information Society (WSIS): Geneva 12/2003 and Tunis in 2005

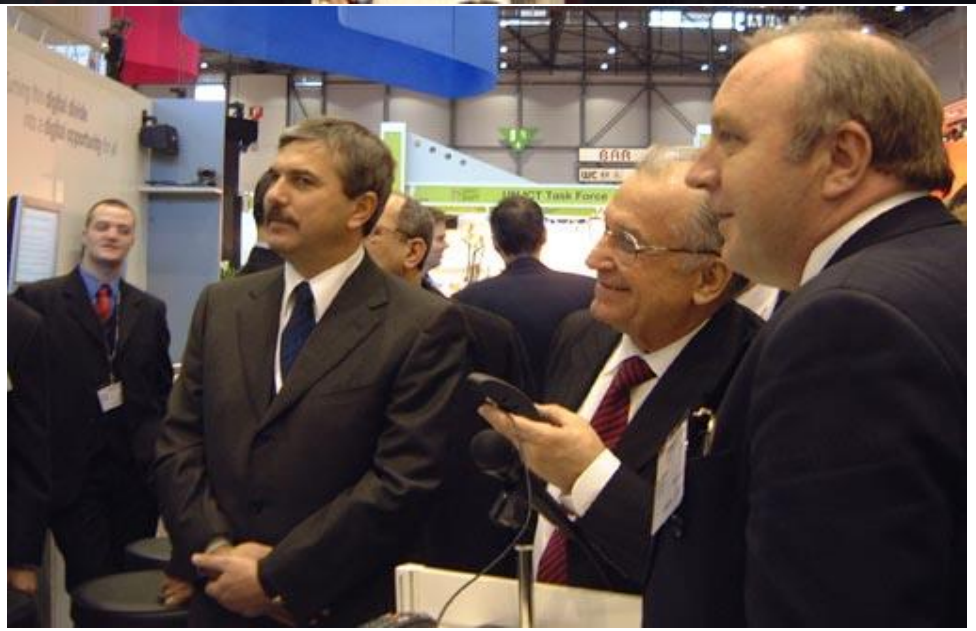
- *The UN General Assembly adopted in 2001 a resolution endorsing the organization of the World Summit on the Information Society (WSIS), to be convened under the patronage of the United Nations Secretary-General, Kofi Annan, with the ITU taking the lead role in its preparation along with UN organizations and the host countries.*
- ***GOAL: To Create an Information Society:***
  A Common Definition was adopted
  in the "Tokyo Declaration" of January 2003:
  "… One in which highly developed ICT networks, equitable and ubiquitous access to information, appropriate content in accessible formats and effective communication can help people achieve their potential"
- *The Summit offered a unique opportunity for the world community to discuss and give shape to the Information Society by bringing together governments, international organizations, private sector and civil society*
- *ICFA SCIC has been quite active in the WSIS, starting in Geneva (12/2003)*

Role of Sciences in Information Society. Palexpo, Geneva 2003

- **Demos at the CERN/Caltech RSIS Online Stand**
  - ➔ World Scale multisite multi-protocol videoconference with VRVS (Europe-US-Asia-South America)
  - ➔ Distance diagnosis and surgery using Robots with “haptic” feedback (Geneva-Canada)
  - ➔ Music Grid: live performance with bands at St. John’s, Canada and the Music Conservatory of Geneva on stage
  - ➔ Monitoring very large scale Grid farms with MonALISA
  - ➔ Advanced network and Grid-enabled analysis demonstrations

Role of Science in the Information Society. Palexpo, Geneva 2003

- CERN SIS Forum and
- CERN/Caltech Online Stand
- **Visitors:**
  - Kofi Annan, UN Sec'y General
  - John H. Marburger, Science Adviser to US President
  - Ion Iliescu, President of Romania; and Dan Nica, Minister of ICT
  - Jean-Paul Hubert, Ambassador of Canada to Switzerland
  - Carlo Lamprecht, President of the Economic Department of the Canton of Geneva
  - …



HEPGRID and Digital Divide Workshop
UERJ, Rio de Janeiro, Feb. 16-20 2004

NEWS:

Bulletin: ONE TWO

WELCOME BULLETIN

General Information

Registration

Travel Information

Hotel Registration

Tutorials

- C++
- Grid Technologies
- Grid-Enabled Analysis
- Networks
- Collaborative Systems

Theme: Global Collaborations, Grids and Their Relationship to the Digital Divide

ICFA, understanding the vital role of these issues for our field's future, commissioned the Standing Committee on Inter-regional Connectivity (SCIC) in 1998, to survey and monitor the state of the networks used by our field, and identify problems. For the past years the SCIC has focused on understanding and seeking the means of reducing or eliminating the Digital Divide, and proposed to ICFA that these issues, as they affect our field of High Energy Physics, be brought to our community for discussion. This led to ICFA's approval, in July 2003, of the Digital Divide and HEP Grid Workshop.

More Information:

http://www.uerj.br/lishep2004

SPONSORS

CLAF CNPQ FAPERJ UERJ

All Sessions and Tutorials Available Live Via VRVS

2ND International ICFA Workshop on HEP Networking, Grids, and Digital Divide Issues for Global e-Science

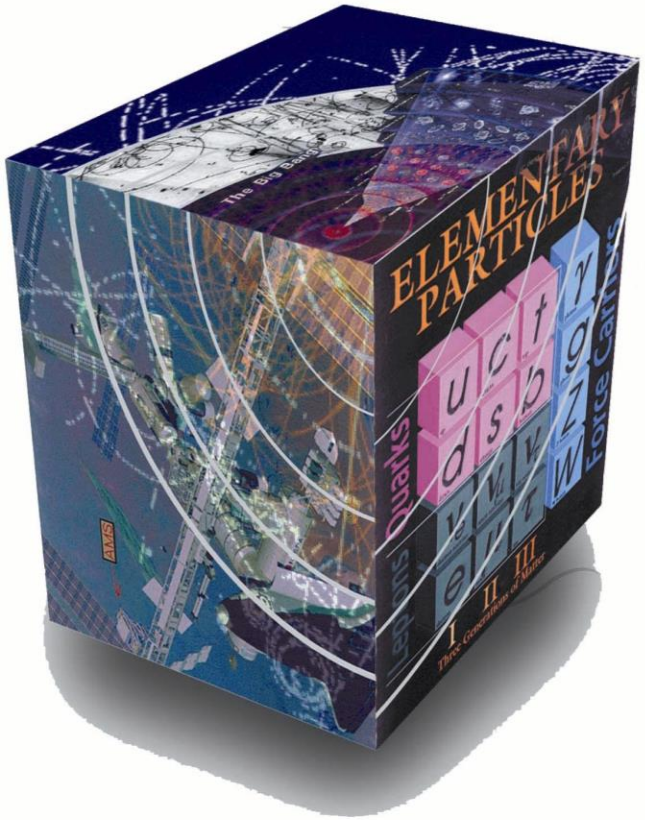
http://chep.knu.ac.kr/HEPDG2005

Workshop Missions

- Review the status and outlook, and focus on issues in data-intensive Grid computing, inter-regional connectivity and Grid enabled analysis for high energy physics
- Relate these to the key problem of

the Digital Divide

- Promote awareness of these issues in various regions, focusing on the Asia Pacific, Latin America, Russia, and Africa
- Develop approaches to eliminate the Divide and
- Help ensure that the basic requirements for global collaboration are met, related to all of these aspects



President of India Kalam Collaborating with US, CERN, Slovakia via VRVS/EVO at CHEP2006

Coincident with Data Transfers of ~500 Mbps

15 TBytes to/from India in 2 Days

Mumbai-Japan-US Links

INDIA

Chennai POP VSNL
LANDING STATIONS

VSNL MUX

TIC MUX

SINGAPORE LANDING STATION

TIC

Cable

JAPAN

JAPAN LAND STANDING

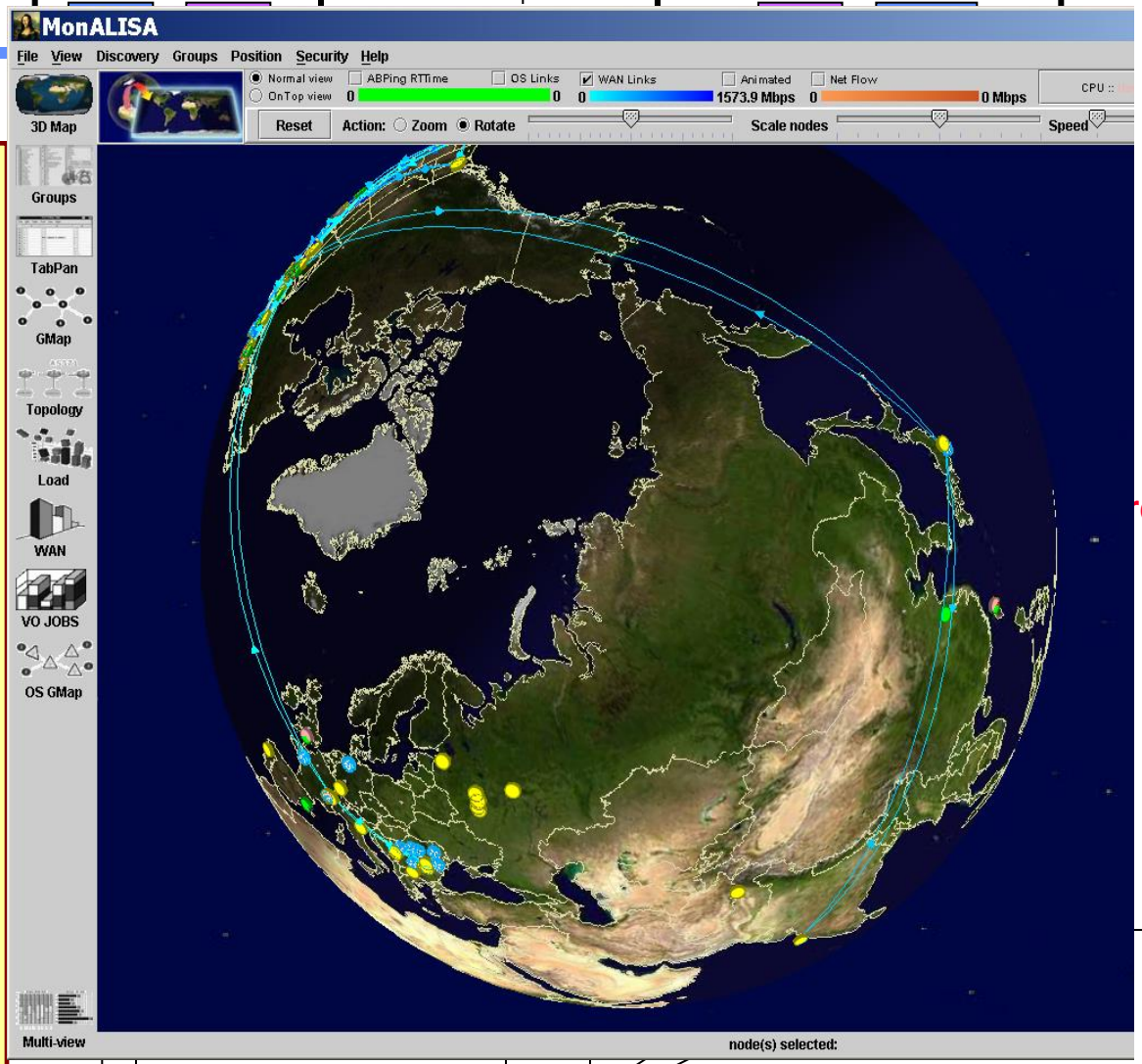
TIFR Link to Japan
+ Onward to US & Europe

Loaned Link from VSNL at CHEP06 (2006)

End to End Bandwidth
4 X 155 Mbps
on SeMeWe3 Cable

Goal was to Move to 10 Gbps on SeMeWe4

Helped spark planning for Next Generation R&E "Knowledge Network" in India



INTERFACE TYPES

STM 4

INTERFACE TYPES

OC-12

TIFR Mumbai, INDIA

NTT Otemachi Bldg, JAPAN

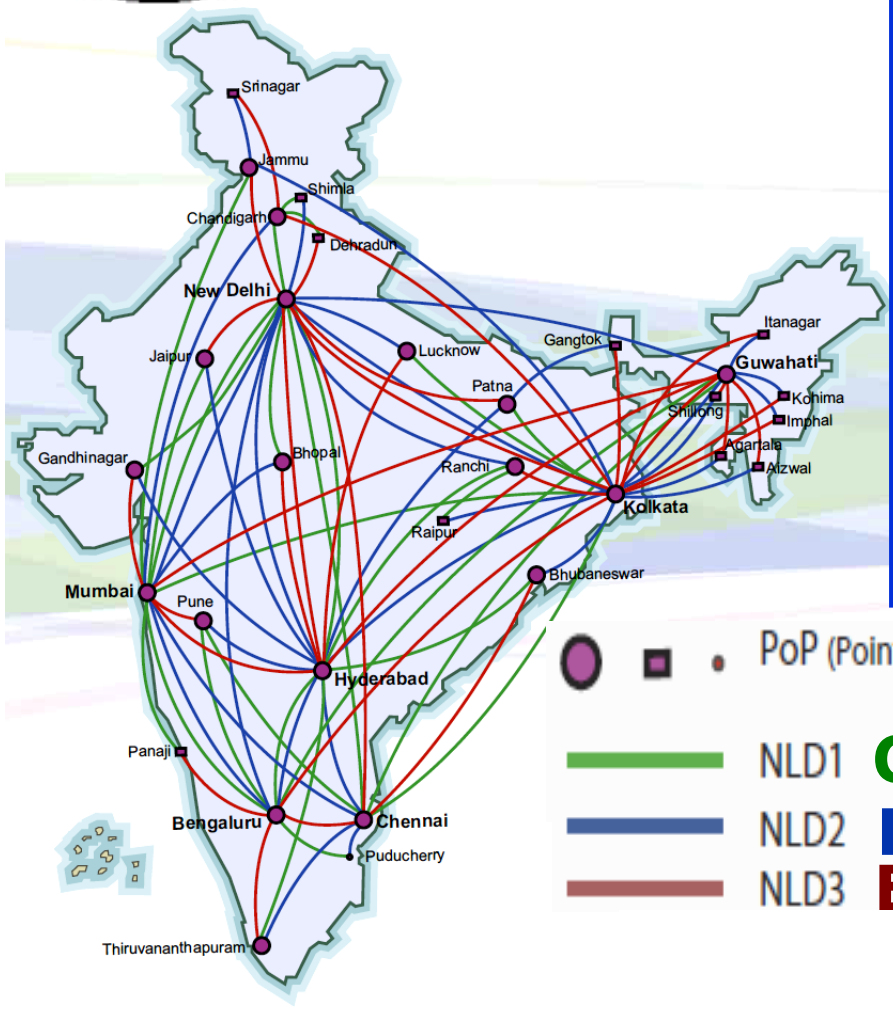
+ Onward to US, Europe ➡

India: Knowledge Commission Recommendation to Create a National "Knowledge Network": Approved by Prime Minister January 25, 2007

- *"Build a National Knowledge Network with gigabit capabilities to connect all universities, libraries, laboratories, hospitals and agricultural institutions to share data and resources across the country."*
- *5000 Institutions; 500-1000 in Phase 1 [Time estimate: 3-6 Months]*
- *Minimum connectivity at end nodes, 100 Mbps (to gigabit)*
- *Prioritization of nodes for implementation: institutions most likely to use the network from day one and demonstrate the benefits*
- *Phase 1: Start with existing commercial networks [Estimate $ 50-100M/Yr]*
- *"Slide" into hybrid network with inner core owned by the stakeholders*
- *Migrate core to N X 10 Gbps, providing gigabit connectivity [Estimate $ 250M Per Year]*
- *Advisory Committee (Including SCIC) worked with the Knowledge Commission, Internet2, the World Bank, et al. during the last months*
- *Will continue to provide advice on technology and implementation during 2007*
- *Ongoing price issue with 10 G int'l Link to TIFR (Mumbai)*

INDIA: *National Knowledge Network (NKN)* Initial Phase in 2014

P. S. Dhenke
S. V. Raghanvan



Themes

- Virtual Classrooms
- Remote Medical Diagnosis
- Collaborative Research
- Grid Computing

Multi-10G Core Backbone

Typically 1G at the Edge

855 Institutes Connected of 1500 Approved

Planned Connectivity to Internet2 at 10G

Intend to Eventually Connect 255,000 Villages

CHEP06 (Mumbai): *HEP Global Network (in-sg-jp-us-CERN) & Applications Demo to President of India helped kick off NKN*

Monitoring the World's Networks

SCIC Monitoring Group (R. Cottrell et al.)

Mapping the Digital Divide

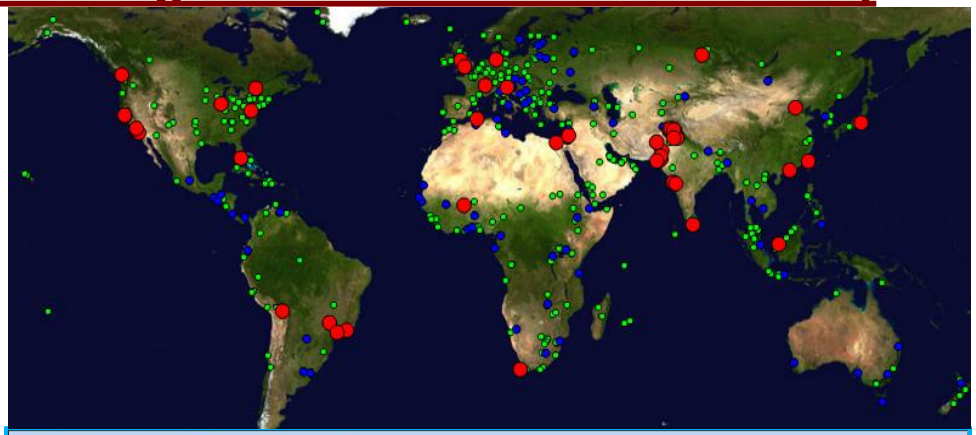
SCIC Monitoring WG
PingER (Also IEPM-BW)

R. Cottrell

IEPM Internet End-to-end Performance Monitoring

ICFA SCIC

Monitoring & Remote Nodes Dec2013)



- **Measurements from 1995 On**

  Reports link reliability & quality

- **Countries monitored**
  - → Contain 99% of world pop.
  - → 99.5% of World's Internet Users
- 950 remote sites monitored in 170 nations; 89 monitoring nodes;
- Strong Collaboration with ICTP Trieste and NUST/SEECS (Pakistan) and three Malaysian universities
- Excellent, Vital Work; Funding issue

Countries: N. America (3), Latin America (*19*), Europe (31), Balkans (*10*), Africa (49), Middle East (*16*), Central Asia (9), South Asia (*8*), East Asia (4), SE Asia (10), Russia (1), Oceania (5)

Throughput Trendlines from SLAC 1998 - 2014

IEPM Internet End-to-end Performance Monitoring

SLAC NATIONAL ACCELERATOR LABORATORY

Top 4

Europe, N. America, East Asia & Australasia

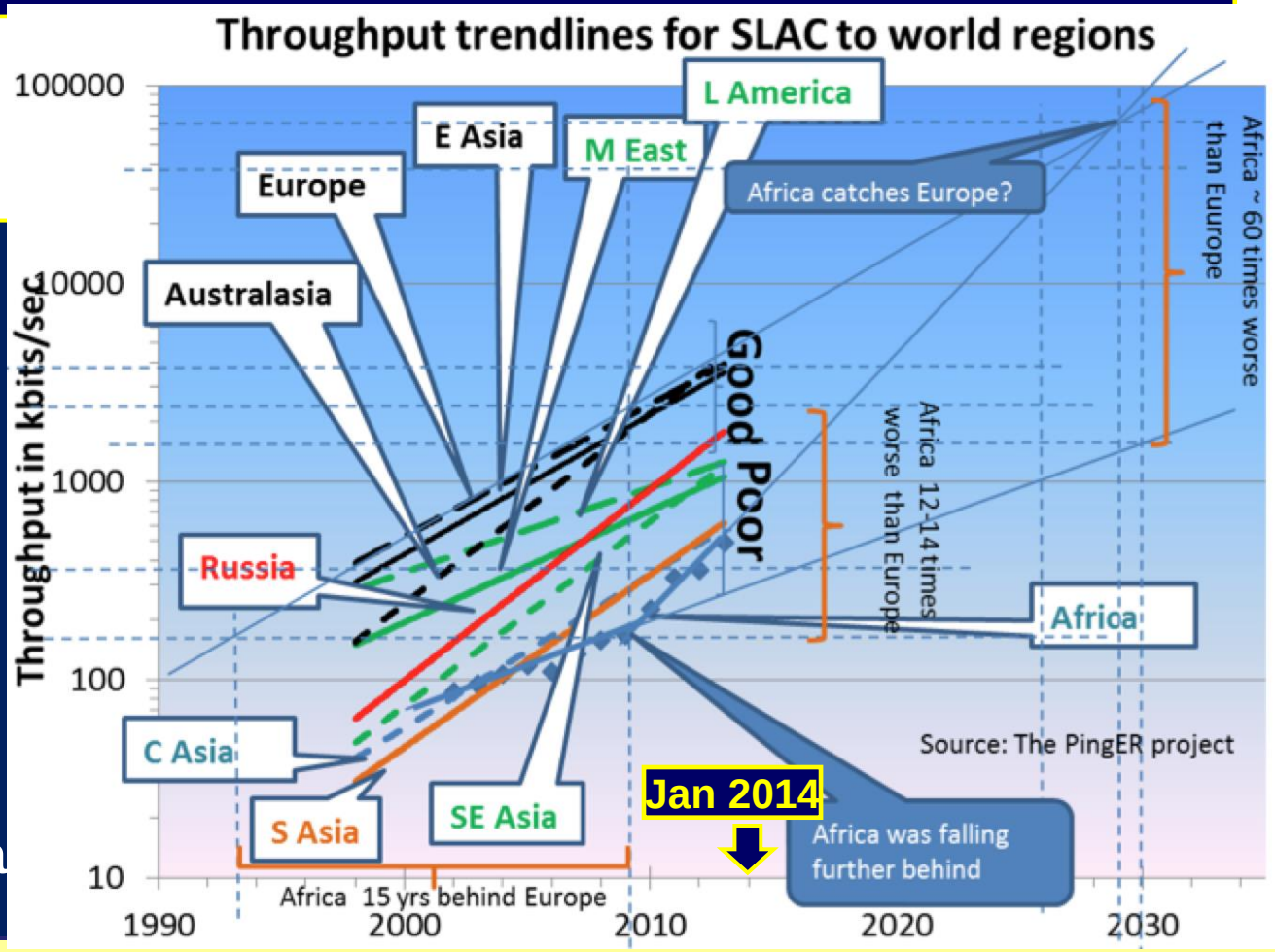
Behind Europe

5 Yrs: Russia, Latin America, Middle East

9 Yrs: Southeast Asia

12-14 Yrs: So+Central Asia

15 Years: Africa

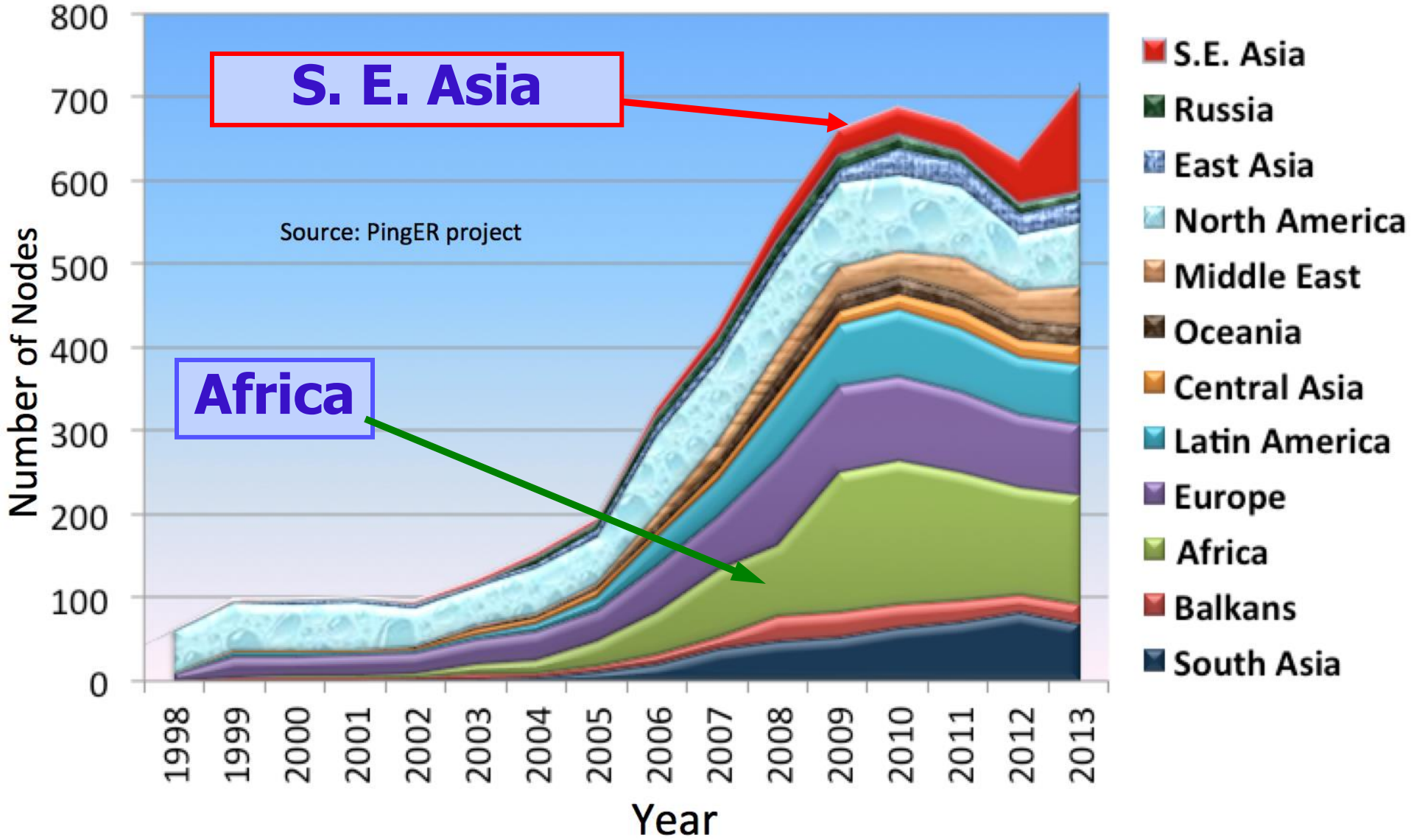


Derived TCP Throughput = 1460 Bytes*8bits/Byte/ (RTT * Sqrt(loss probability)); Matthis et al.

In 10 years: Russia and Latin America should catch up with top 4. Africa was falling farther behind; ***But new cables are making a difference since 2012***

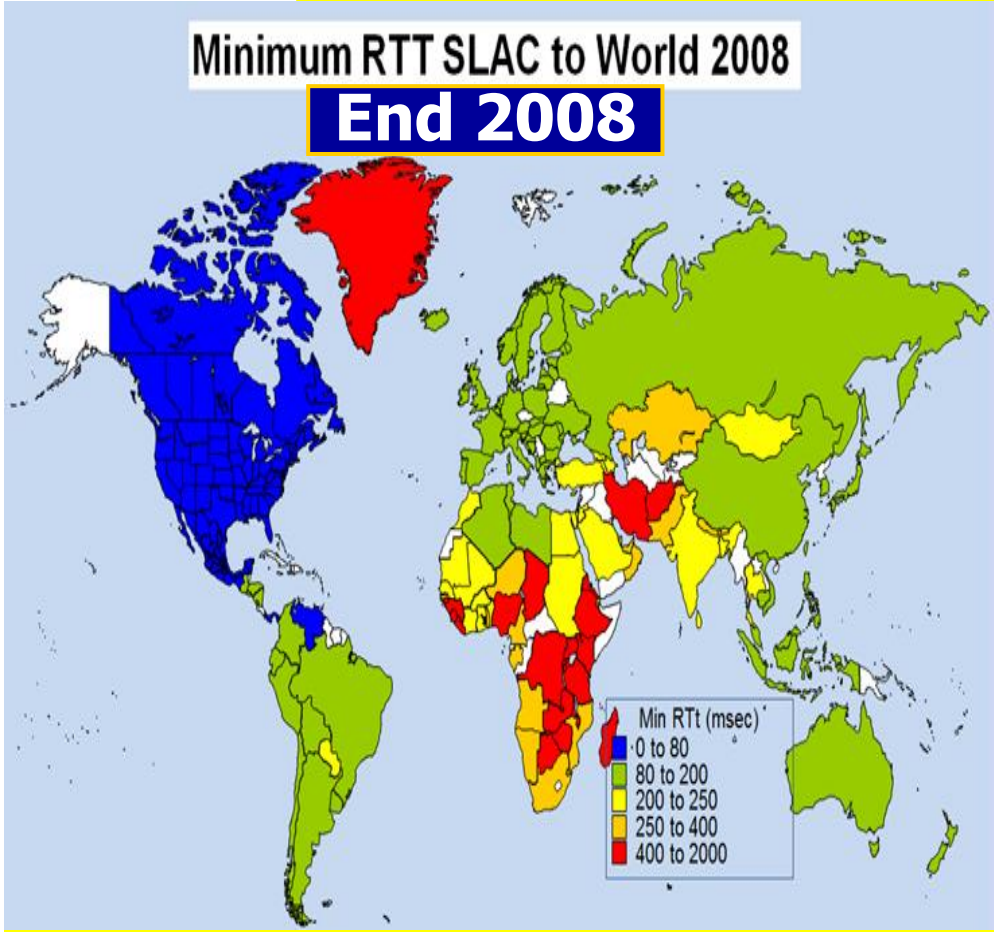
Number of Hosts Monitored By Region: 1998 - 2012

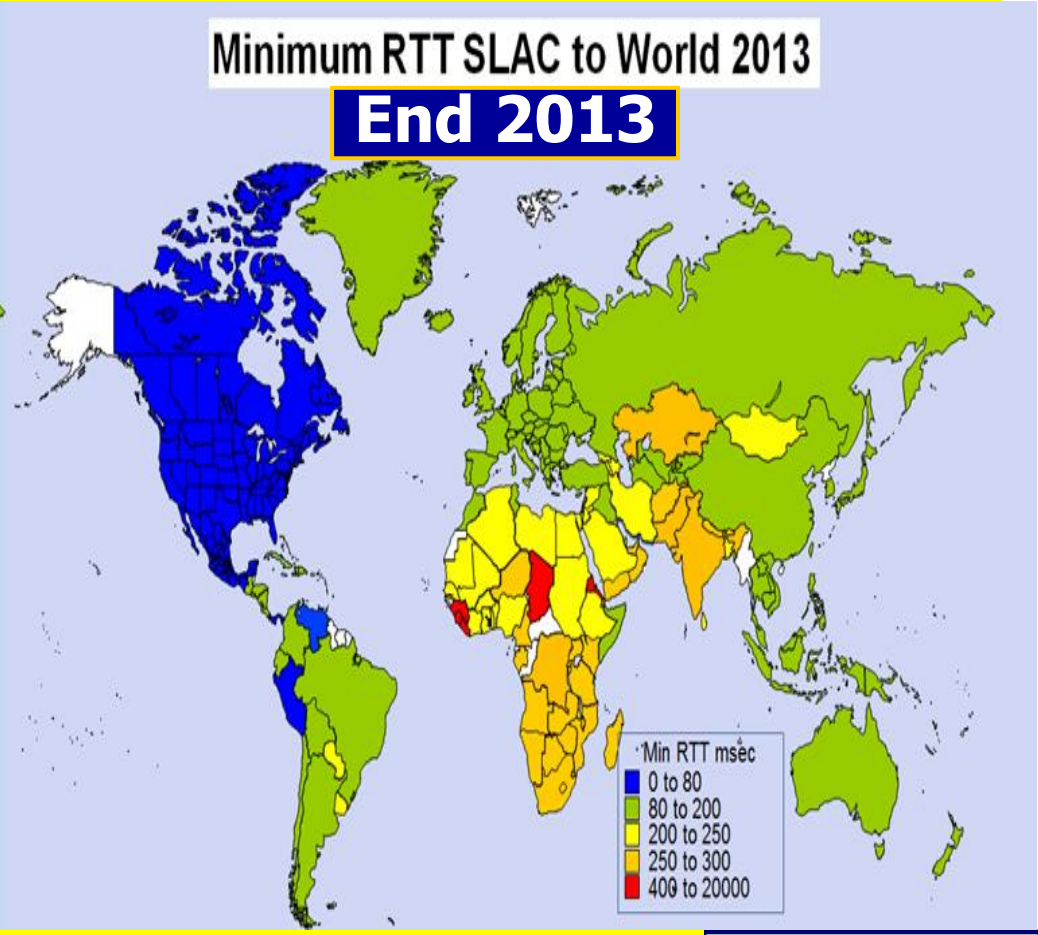
R. Cottrell



World Map: Minimum RTT from SLAC

Countries Still on Geosynchronous Satellite are in Red

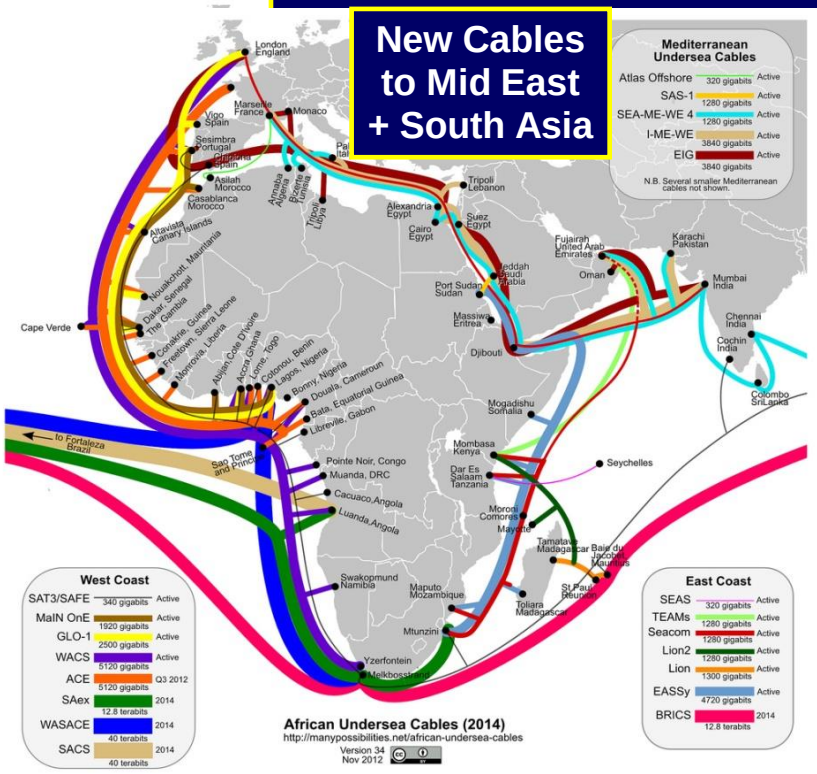




Note increased coverage, i.e. reduced white countries, e.g. Congo-Brazzaville, Central Africa Republic, Myanmar

R. Cottrell

New African Undersea Cables to Europe, India, Middle East



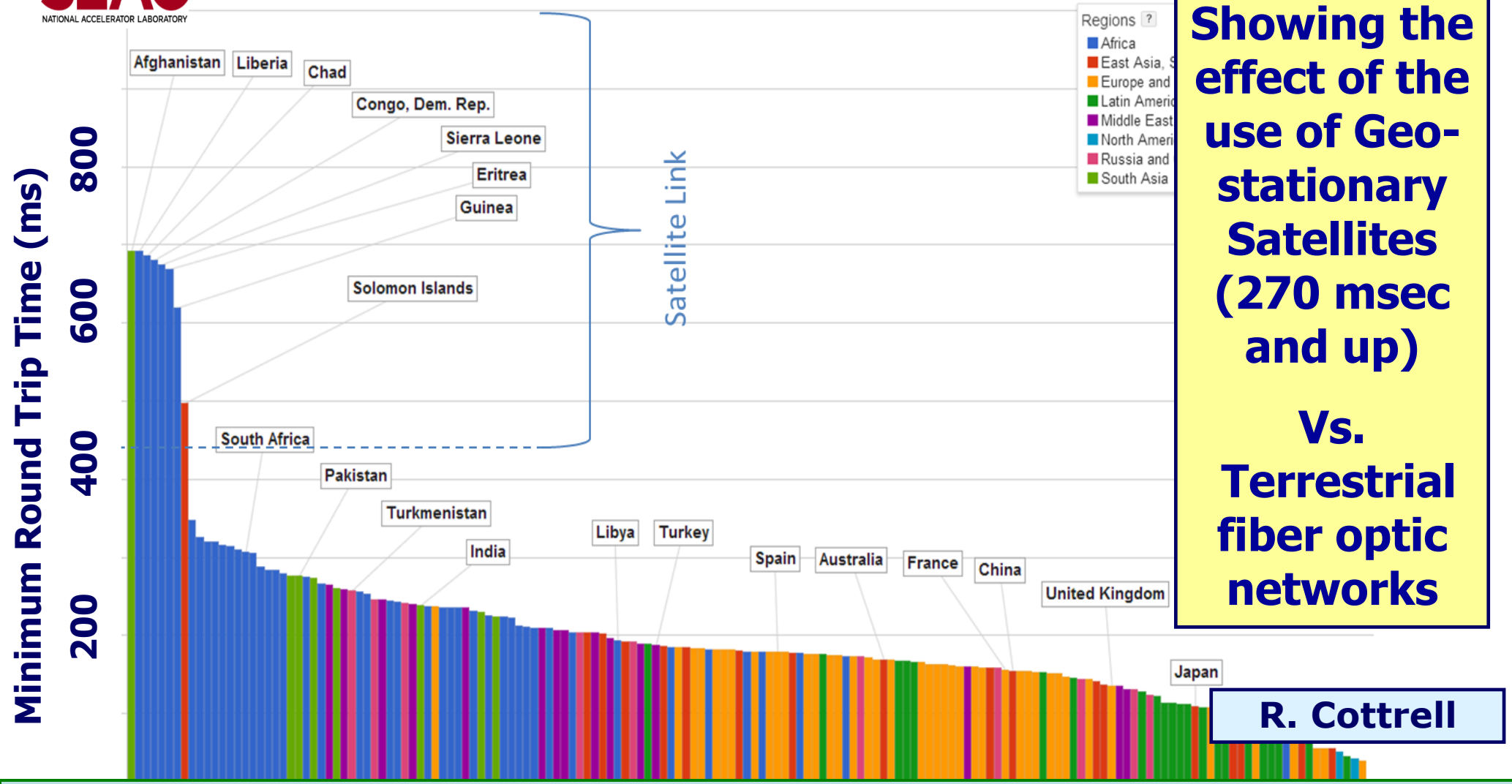
- Undersea cables continue to arrive at both African coasts (since 2009); 1000X Potential capacity
- Triggered by the 2010 World Cup.
- Multi-Terabits/sec max. capacity
- Seacom, EASSy, TEAMS, Lion, Lion2, MainOne, GLO1, WACS *in production*
  - *+ ACE, BRICS, SAex, WASACE, SACS by 2014*
- Connections to the African interior *spreading*
- Plus new Mediterranean Cables to Mideast+Gulf

http://manypossibilities.net/african-undersea-cables

More comprehensive map (with intra-Africa):
http://www.ubuntunet.net/sites/default/files/Intra-Africa_Fibre_Map_v6.pdf

Seacom	EASSy	TEAMs	MainOne	WACS	GLO1	ACE	SAex	WASACE	BRICS
$ 650M	$ 265M	$ 130M	$ 240 M	$ 600M	$ 800 M	$ 700M	$ 500M	?	?
13.7 kkm	10 kkm	4.5 kkm	7 kkm	14 kkm	9.5 kkm	14 kkm	9 kkm	9 kkm	34 kkm
1.28 Tbps	4.72 Tbps	1.28 Tbps	1.92 Tbps	5.12 Tbps	2.5 Tbps	5.12 Tbps	12.8 Tbps	40 Tbps	12.8 Tbps
Active 2009	Active 2010	Active 2009	Active 2010	Active 2012	Active 2010	2013	Q2 2013	2014	2014

Minimum Round Trip Time (RTT) From SLAC to Countries of the World
December 2013



Showing the effect of the use of Geo-stationary Satellites (270 msec and up)

Vs. Terrestrial fiber optic networks

R. Cottrell

Cuba now has terrestrial link, Africa & Afghanistan still satellite

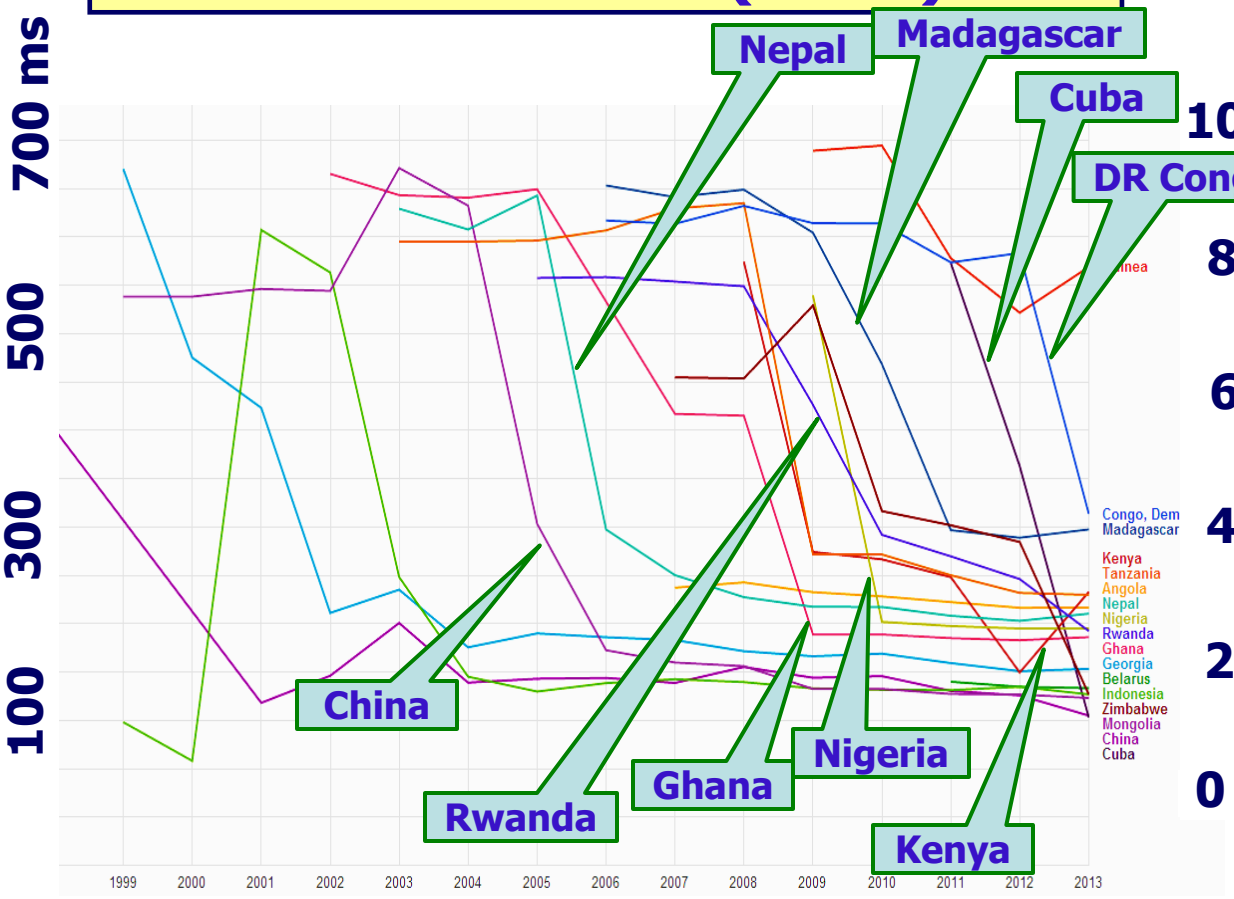
Round Trip Time (from SLAC) Drops

as African Nations Move from Geostationary Satellites to the New Undersea Cables

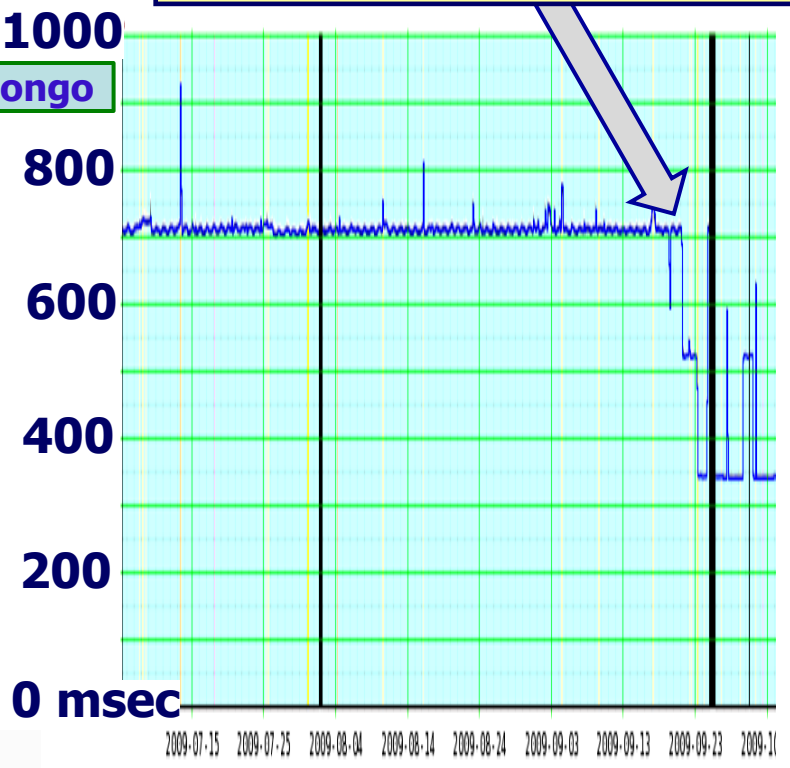
IEPM Internet End-to-end Performance Monitoring

SLAC NATIONAL ACCELERATOR LABORATORY

Minimum RTT (msec)



Rwanda: RTT shift from GEOS to Fiber



Dec 2013

R. Cottrell

Erice Declaration on Principles

for Cyber Stability and Cyber Peace

World Federation of Scientists (2009)

It is an unprecedented triumph of science that mankind, through the use of modern **ICTs, has the means to expand economic resources for all countries, enhance the intellectual capabilities of their citizens, and develop their culture and trust in other societies.**

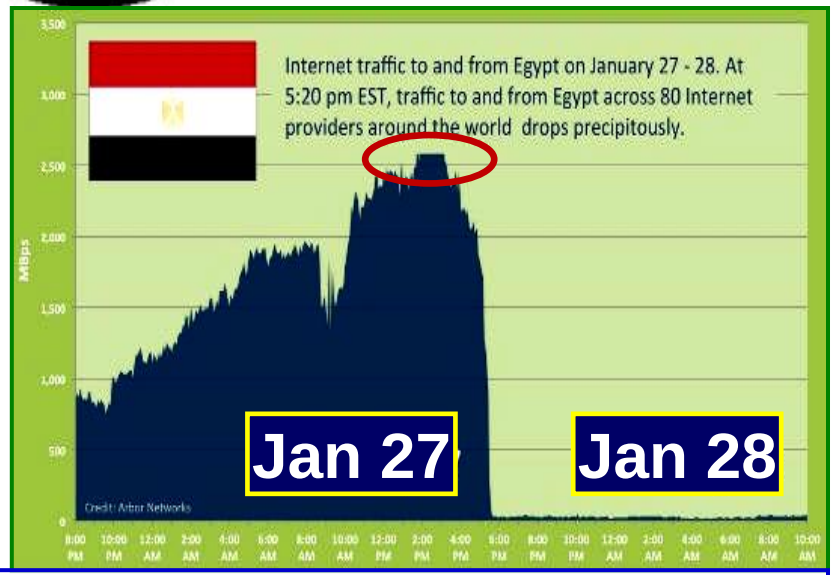
The Internet, like science itself, is fundamentally transnational and ubiquitous in character.

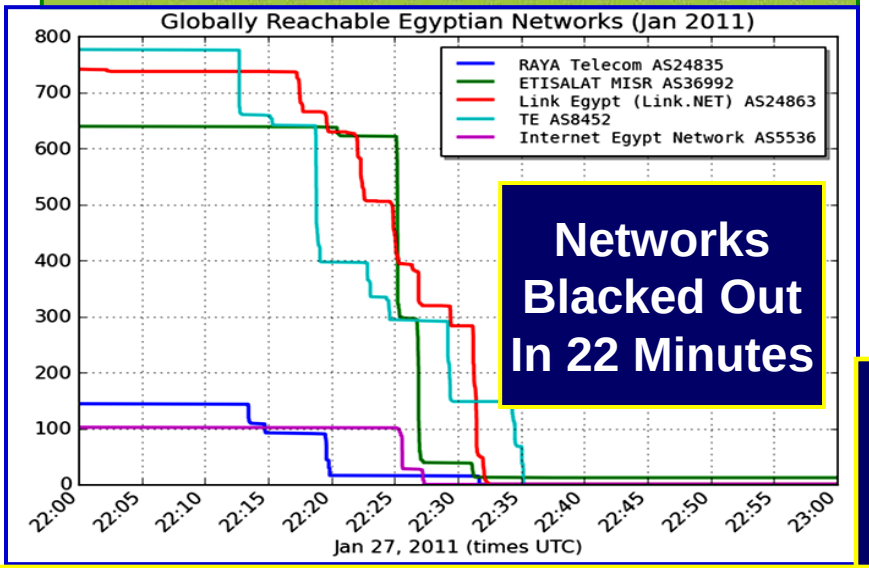
The Internet, and its attendant information tools, is the indispensable channel of scientific discourse… offering to all the benefits of open science, without secrecy and without borders.

In the 21st century, the Internet and other interconnected networks (cyberspace) have become critical to human well-being and the political independence and territorial integrity of nation states.

Information and communication systems and networks underpin national and economic security for all countries and serve as a central nervous system for response capabilities, business and gov't operations, human services, public health, and individual enrichment.

The Arab Spring: Egypt Shuts Down their Internet January 28 – February 2 2011



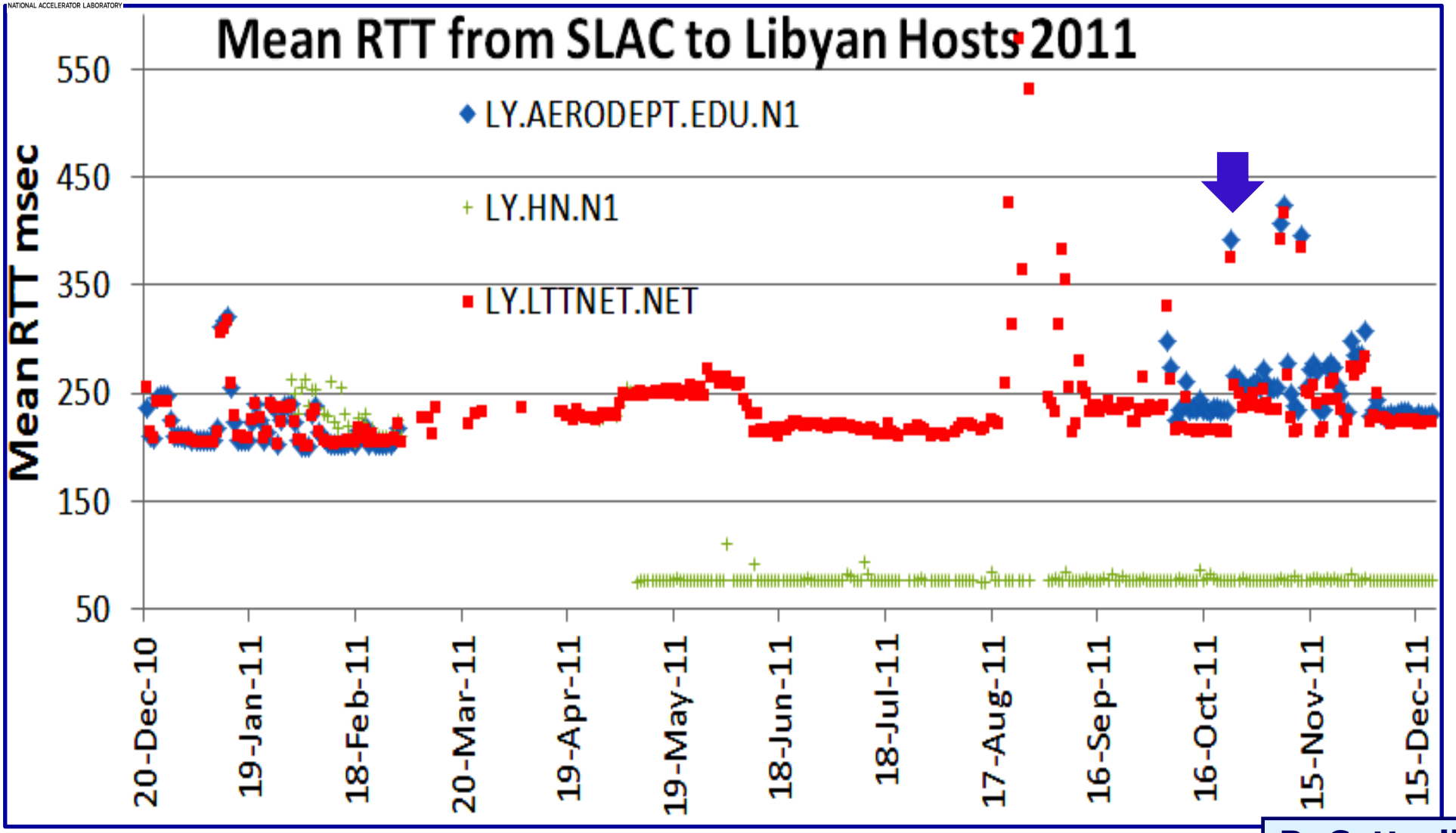


R. Cottrell

Note: US Discussion of an Internet "Kill Switch" to "Defend Against CyberAttacks"

Issue: Internet Connectivity as a Human Right: Erice Declaration

Arab Spring: Mean RTT & Packet Loss from SLAC to LIBYAN Hosts Dec. 2010 to Dec. 2011

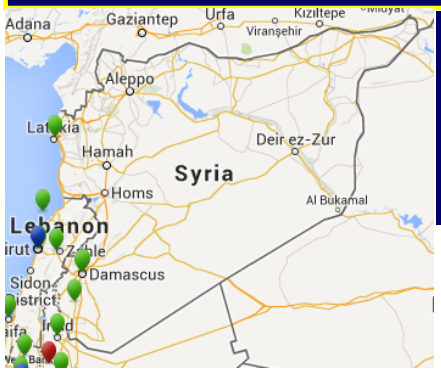


R. Cottrell

Syria went offline

Monitored: www.inet.sy, www.thawraonline.sy

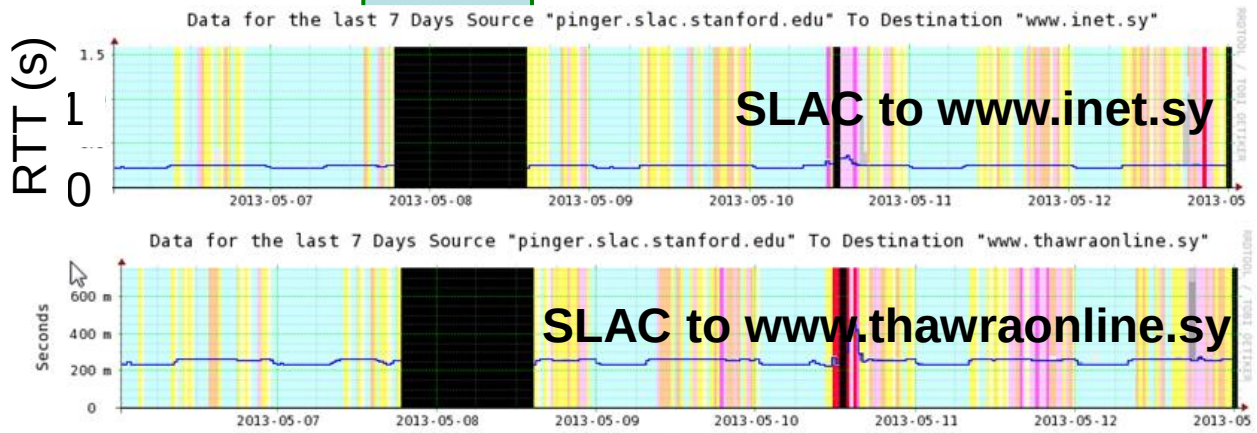
May 7-8 2013



PingER Measurements from SLAC to 2 hosts in Syria showed both not responding from 18:37 May 7, 2013 to 13:37 May 8, 2013

R. Cottrell

"Internet in Syria has been restored on Wednesday at 14:13 UTC. The country went offline on Tuesday at around 18:45 UTC as Internet connectivity was completely cut across the nation."
–The Next Web



May 7 May 8 May 9

Blue line = Avg RTT, Background color = Loss

No loss **<5% loss** **<10% loss**

<20% loss **<20% loss** **<50% loss**

To 100% loss, or no response, disconnected

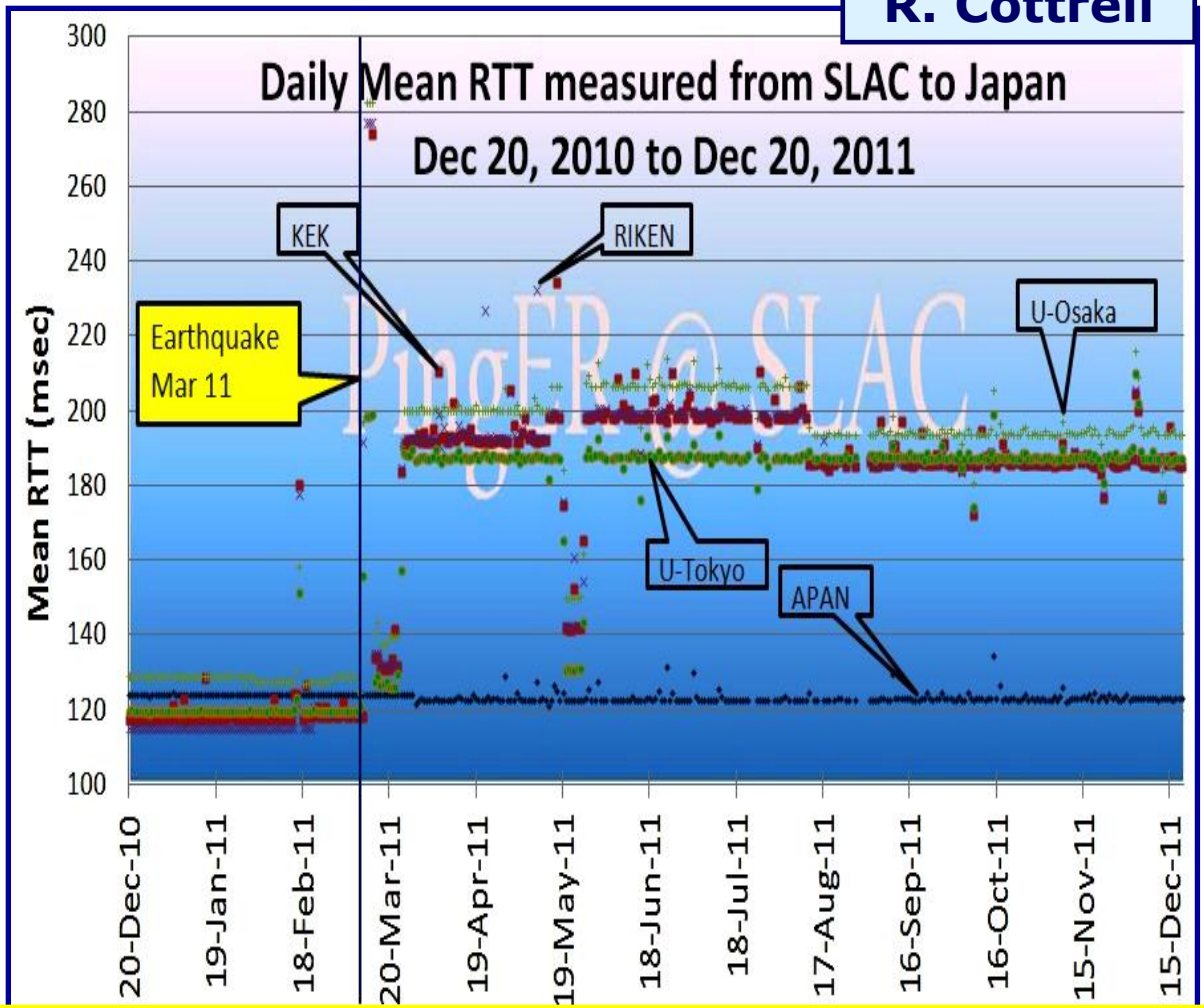
Impact of the Fukushima 9.0 Earthquake

Monitored: KEK, RIKEN, Tokyo, Osaka, Okinawa

IEPM Internet End-to-end Performance Monitoring
SLAC NATIONAL ACCELERATOR LABORATORY

Dec. 2010 Through Dec. 2011

R. Cottrell



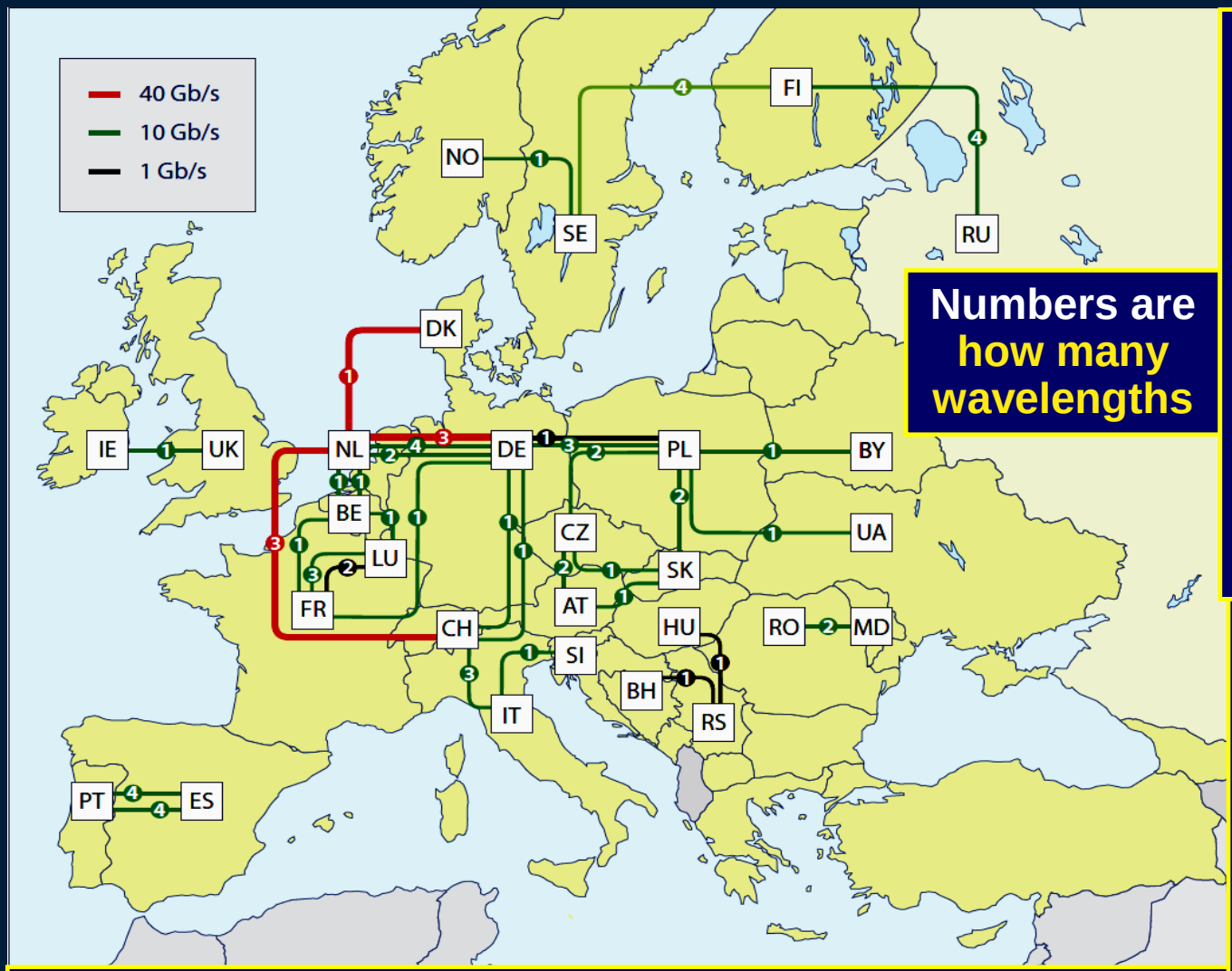
"The massive earthquake off the coast of Japan damaged several undersea cables, some of which (were) still awaiting repair. Despite these outages, communications between Japan and the rest of the world were largely unaffected, due to the large array of undersea cables linked to Japan.
'The earthquake temporarily knocked out approximately 30% of Japan's international capacity,'
–Telegeography Research

Connections to major labs and universities degraded for many months

Dark Fiber Networks

Closing the Digital Divide

Increasing Role of Cross Border Dark Fiber
in Europe, including Int'l N X 40G and 100G Links



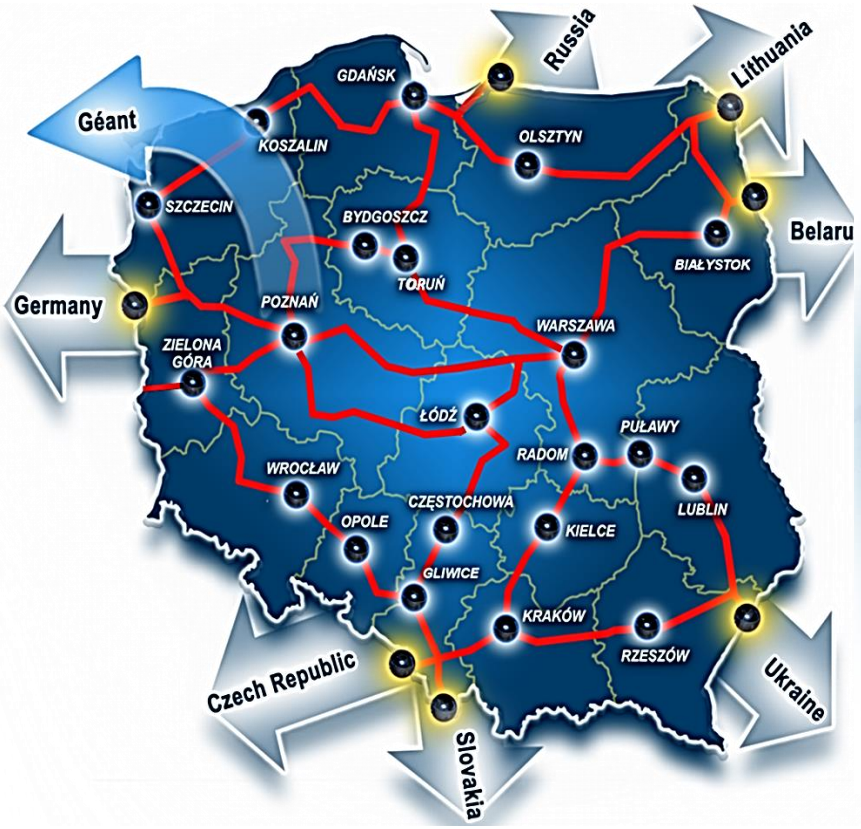
Numbers are how many wavelengths

Total 65 waves:
54 of 10G; 4 of 1G;
7 of 40G:
Amsterdam to CERN (3), to Hamburg (3) and to Copenhagen (1)
2 X 100G AMS-London Planned

Does Not Show
CERN-AMS 100G
CERN-Budapest 2 X 100G;
CERN-Poznan planned

TERENA Compendium 2013

PIONIER in Poland: Direct Connections to DFN, SURFnet, NORDunet



Marek Bazyly

Cross Border Dark Fiber Links (15 x 10G) to Russia, Ukraine, Lithuania, Belarus, Germany, Slovakia and Czech Republic

Direct connections to DFN (de), SURFnet (nl) and NORDUnet via a dark fiber to Hamburg

SLOVAK Academic Network January 2014: All 10 GE Switched Ethernet; Utilization ~25%

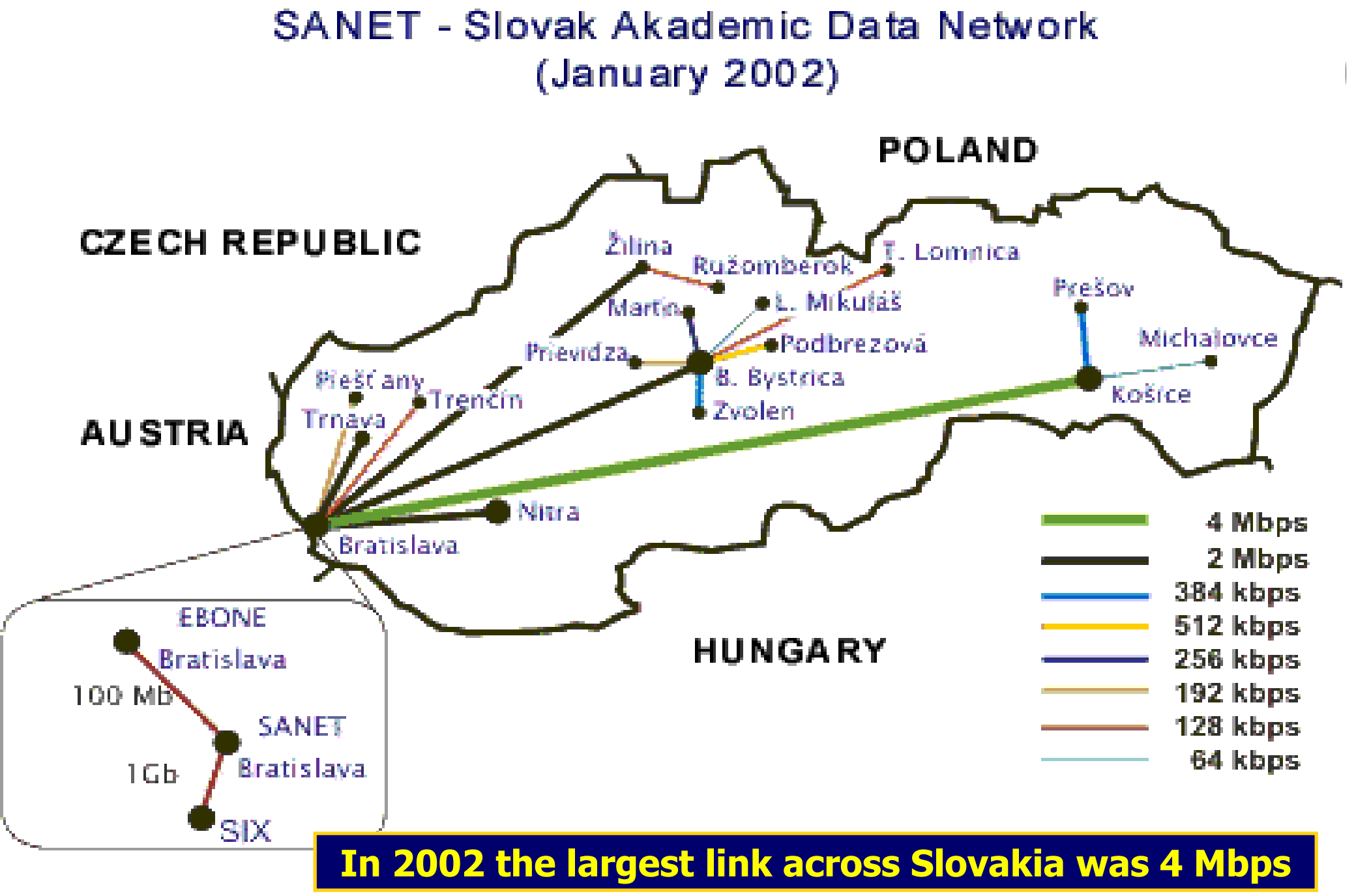
www.sanet.sk/en/index.shtm

In 2002 the largest link across Slovakia was 4 Mbps

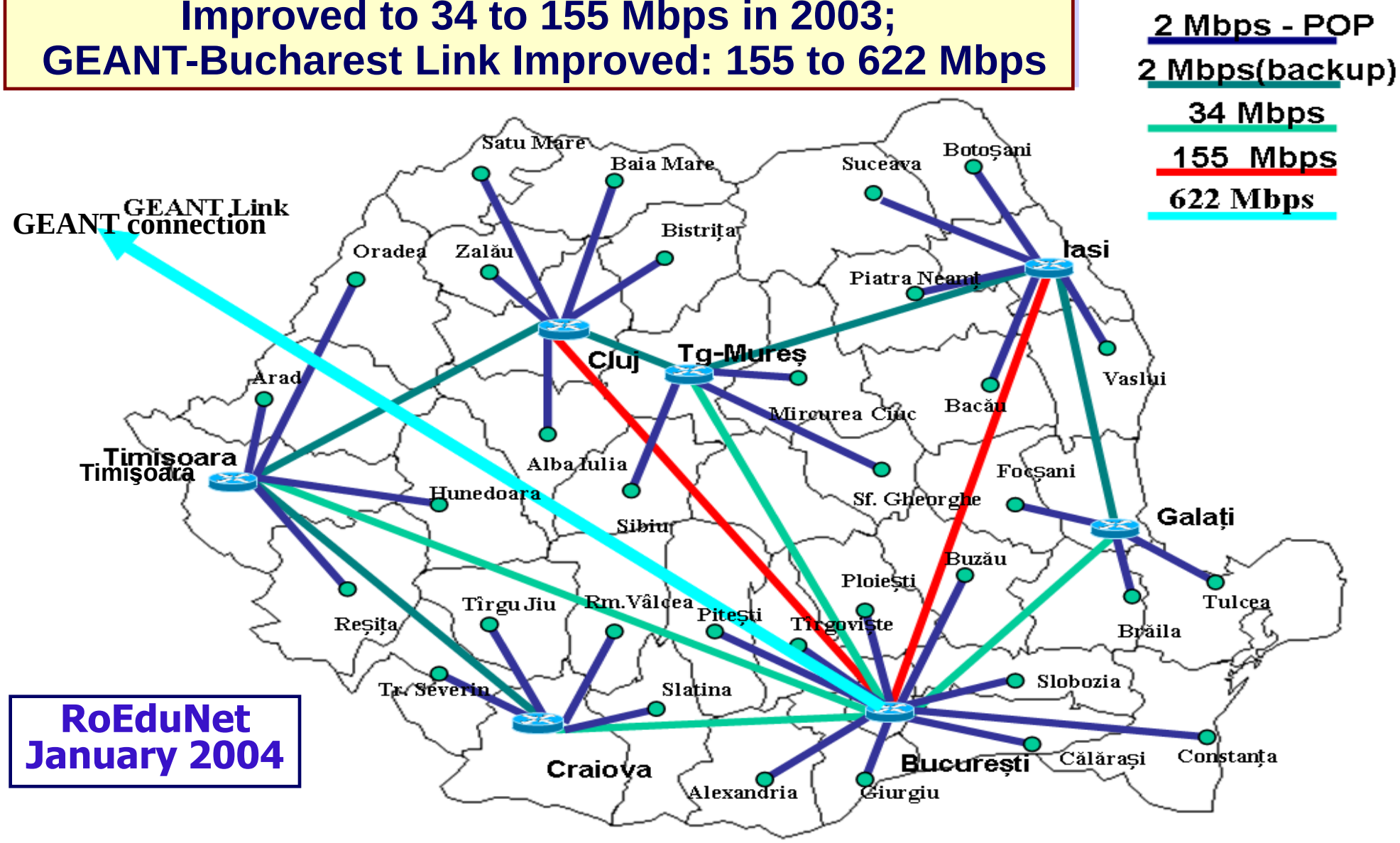
Now: SANET to Schools
1GE to 500 Schools In 54 Cities Progressing

Weis

- **2002-2004: 1G Backbone Installed; Cross Border Dark Fiber to Austria, Czech Republic, Poland.**
- **2006: 10 GbE Cross-Border Dark Fiber to Austria & Czech Republic; 8 X 10G over 224 km with Nothing In-Line Demonstrated**
- **2007-9: Transition Backbone to 10G Done; All CB Dark Fibers to 10G**
- **2013: Cross-Border Utilization ~30%**
- **2014: Planning for 100G backbone capacity**


SANET - Slovak Akademic Data Network
(January 2002)
POLAND
CZECH REPUBLIC
AUSTRIA
HUNGARY
Žilina
Ružomberok
T. Lomnica
Martin
L. Mikuláš
Prešov
Michalovce
Prievidza
Podbrezová
B. Bystrica
Piešťany
Trenčín
Trnava
Zvolen
Košice
Nitra
Bratislava
4 Mbps
2 Mbps
384 kbps
512 kbps
256 kbps
192 kbps
128 kbps
64 kbps
EBONE
Bratislava
100 Mb
SANET
Bratislava
1Gb
SIX
In 2002 the largest link across Slovakia was 4 Mbps

Romania: Inter-City Links of 2 to 6 Mbps in 2002 Improved to 34 to 155 Mbps in 2003; GEANT-Bucharest Link Improved: 155 to 622 Mbps



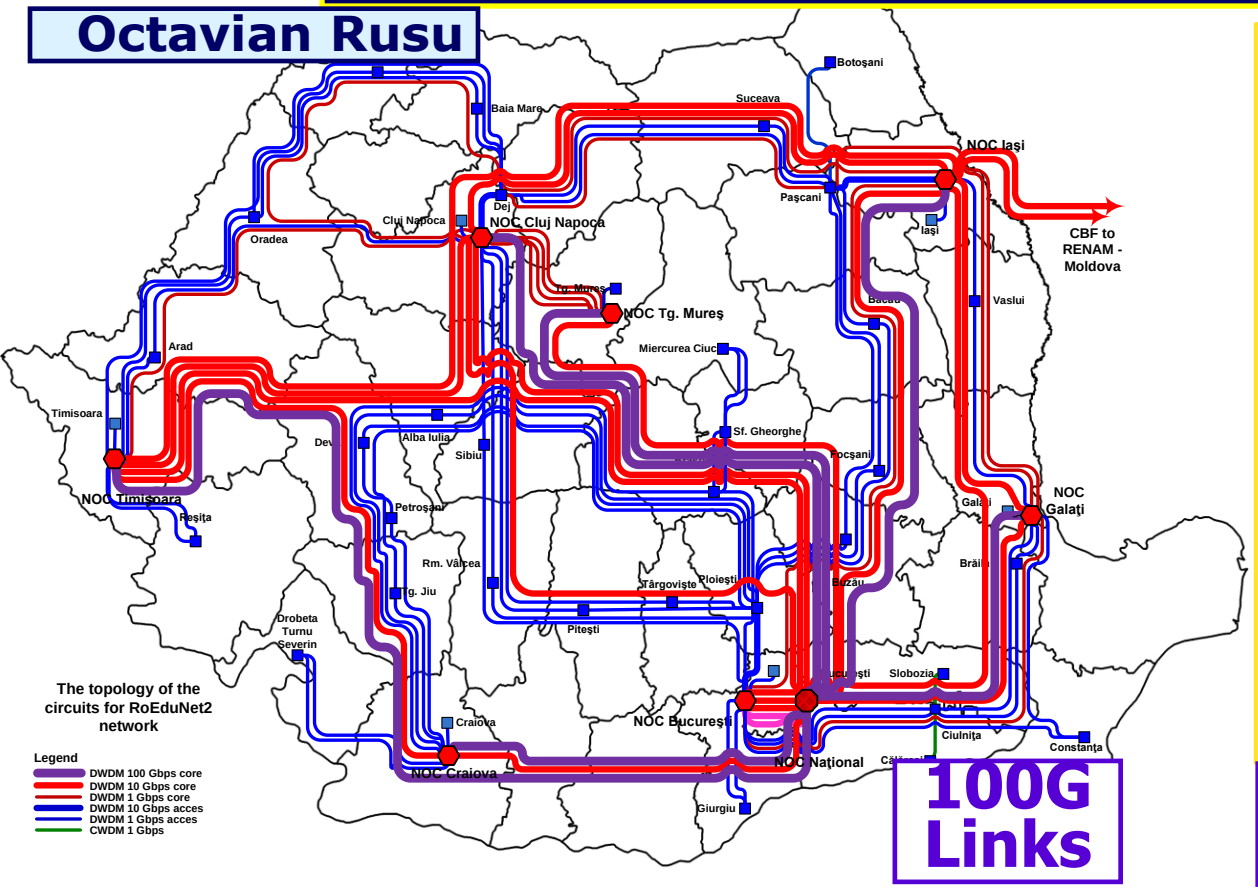
RoEduNet
January 2004

In 2002 the largest link across Romania was 6 Mbps

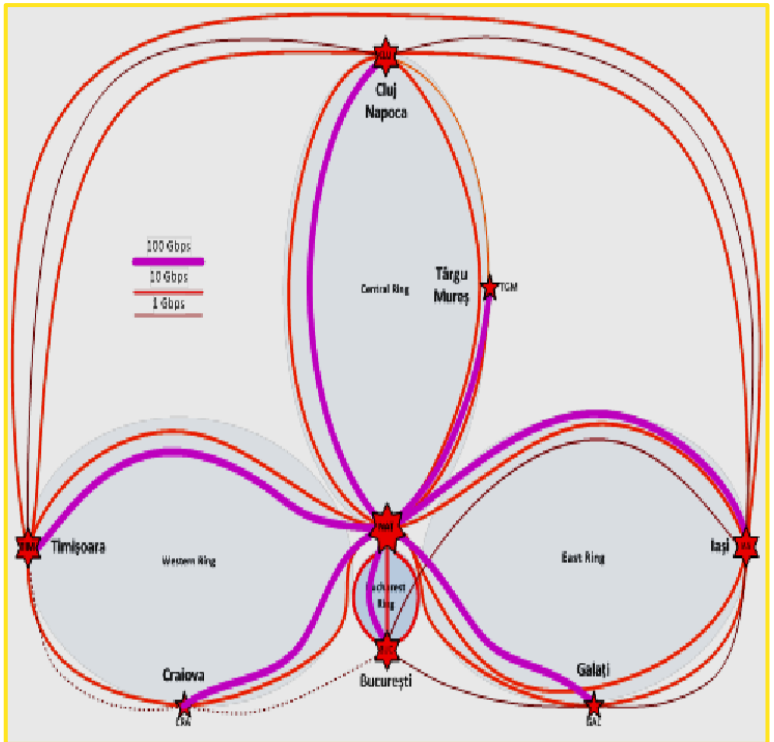
RoEduNet2 (ROMANIA): New 100G Core in 2013

100,000X Since 2002: Pan-European "Role of Science in the Information Society" Ministerial Meeting with HEP Bucharest

Octavian Rusu



100G Links



100G Rings on Fibers Linking Major Cities

5636 Km Dark Fiber

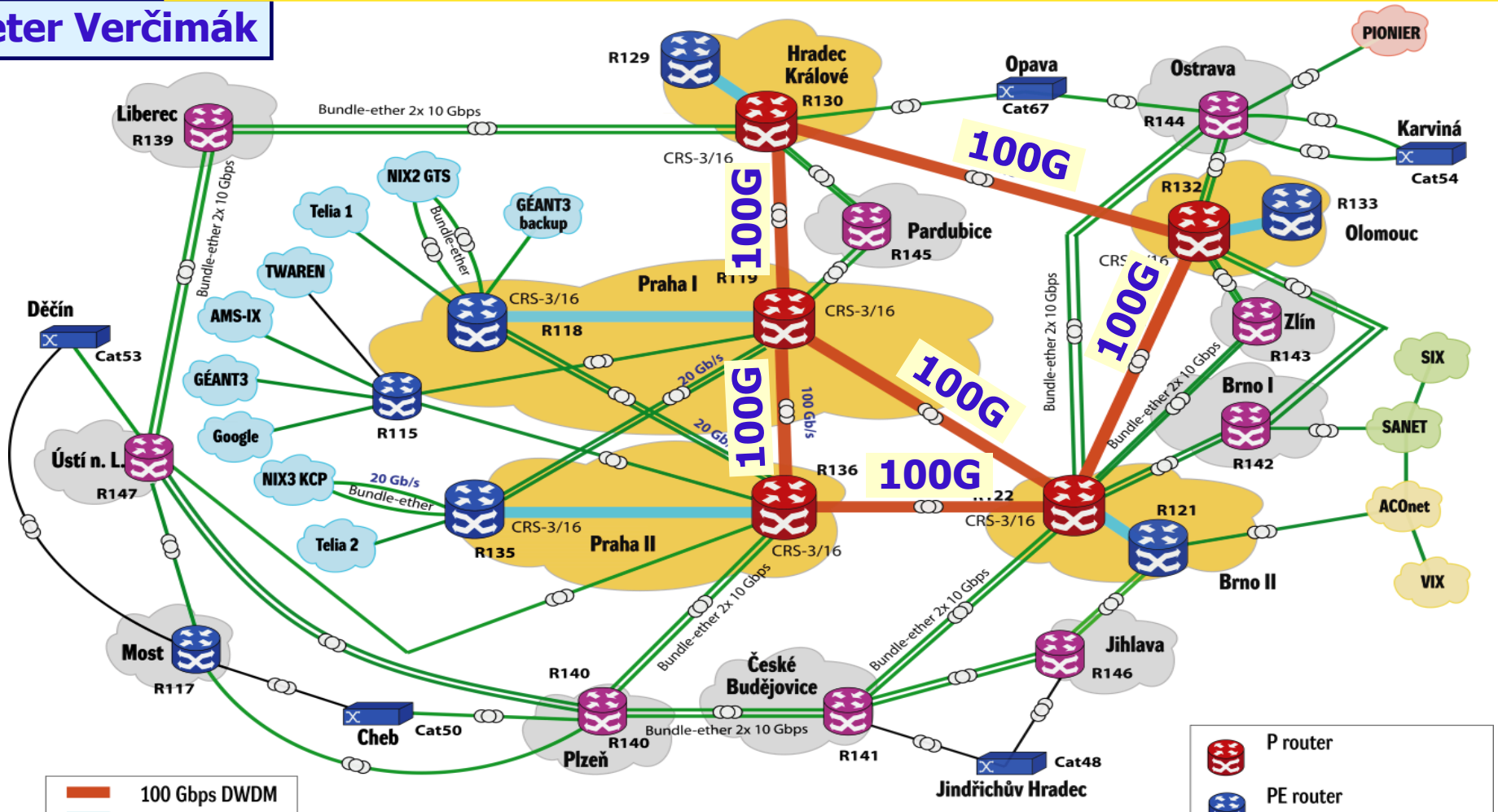
56 Optical Sites; 35 10GE + 54 10 X 1GE Links

2012: 1st 100GE Link; 2013: Core with 7 100G Waves

3 Rings each with 2 100G Waves + Bucharest Ring

CESNet2 Topology: Core Optical Network and Access Routers Upgraded to 100G

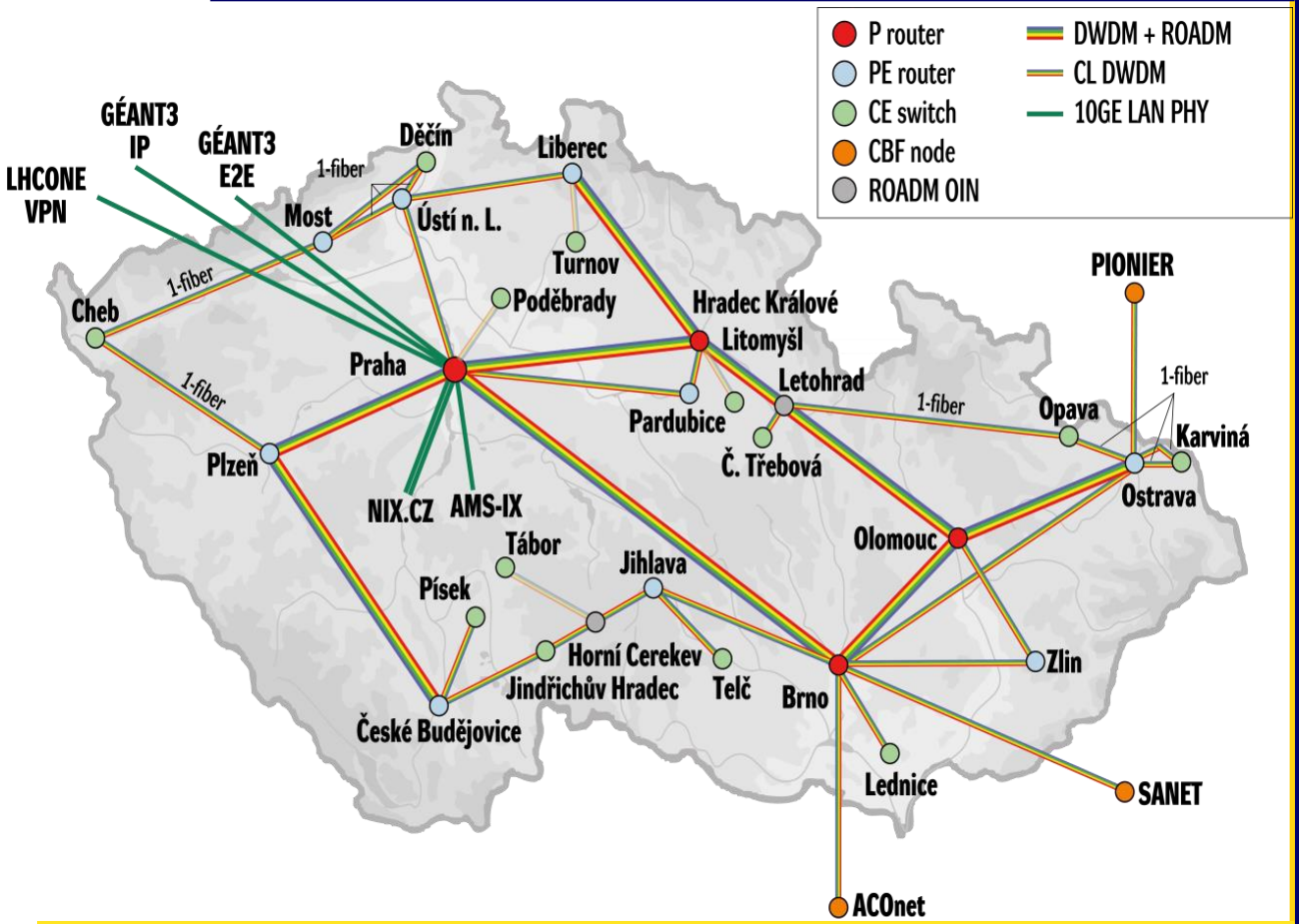
Peter Verčimák



6 Optical Core Nodes and 7 Access Routers at 100G

CESNet2 and CESNet EF: Advanced Digital and All Photonic Networks

Peter Verčimák (peter.vercimak@cesnet.cz



DWDM Optical Topology

5340 km
Leased Fiber
420 Km Dark Fiber
738 km Exp. Net Facility

All-Photonic Service:

λ Switching

Fixed Bandwidth with Fixed Delays

100G Core Network
built on top of this infrastructure begun in 2013

Closing the Digital Divide

Model Examples and Problem Areas

GLORIAD and GLORIAD-Taj 2013-14

Optical Ring Around the Earth

Partners: US, Netherlands, Russia, China, Korea, Denmark, Finland, Iceland, Norway, Sweden, India, Egypt, Singapore

New global monitoring **system focused more on the performance of individual user's end-to-end flows.** System based on deployment of open-source Argus software (www.qosient.com/argus), collecting and analyzing > 400M network utilization records/day.

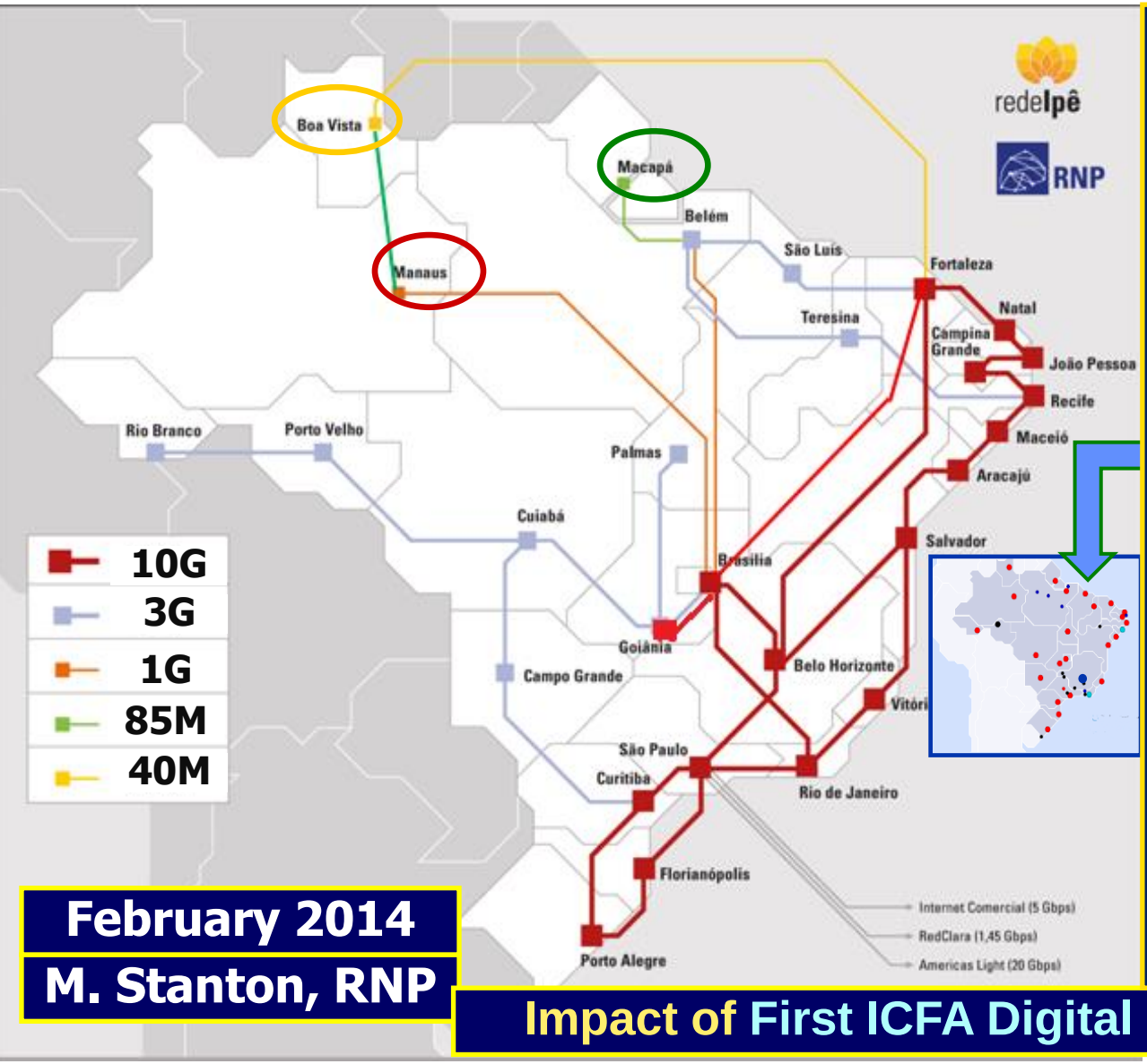
Hybrid technologies and network services serving the most diverse user group

Layer 1 "optical" lambda lightpaths for "big science" projects and experimental networking research,

Layer 2 "switched" Ethernet services especially well-suited for capacity building and reliability/redundancy

Layer 3 "routed" high-bandwidth service with peering capability based on the needs of the users.

Brazil in 2013-14: 6th Phase "Ipê" 10G Core Network



- 4000 km 10G Footprint (East+South) Completed; New 2 X 10G to Brasilia
- Completion of the optical fiber footprint: Manaus – Boa Vista at 100 Mbps + 40 Mbps backup
- Metro dark fiber nets for 1 or 10G Connections in 24 of 27 state capitals.
- Brasilia – Manaus Link to 1G: Amazon subfluvial link
- New 2nd fiber across Amazon reaches the northern capitals Macapa and Manaus
  - RNP expects to get multi-Gbps to these cities soon

February 2014

M. Stanton, RNP

Impact of First ICFA Digital Divide Wkshp in Rio in 2004

Aerial Crossing of the Amazon at Jurapari: 2100m span between 300m towers

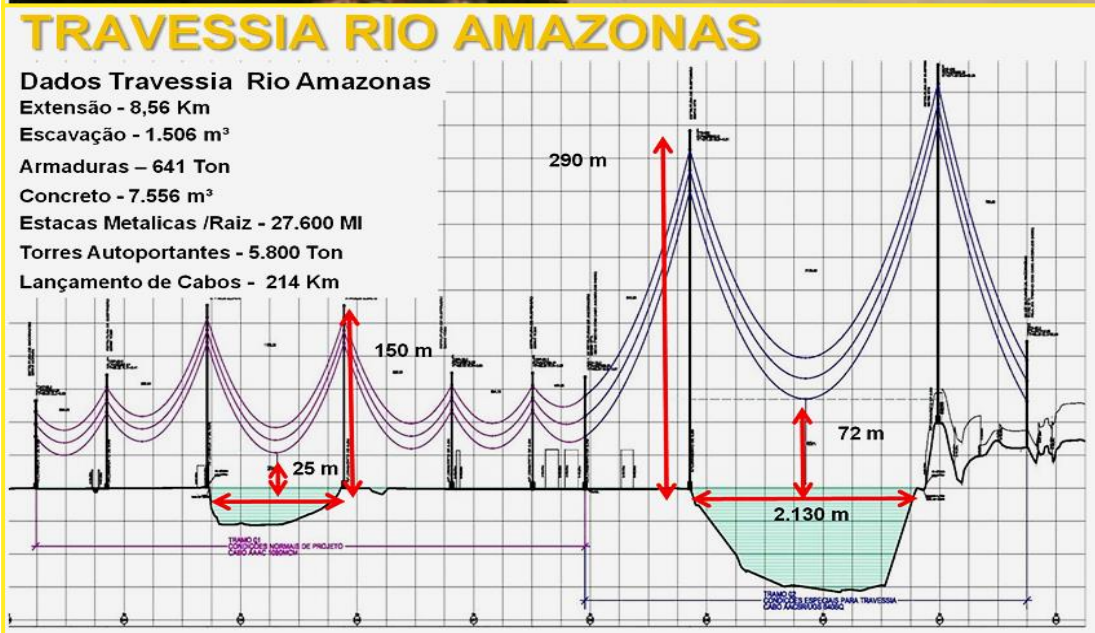
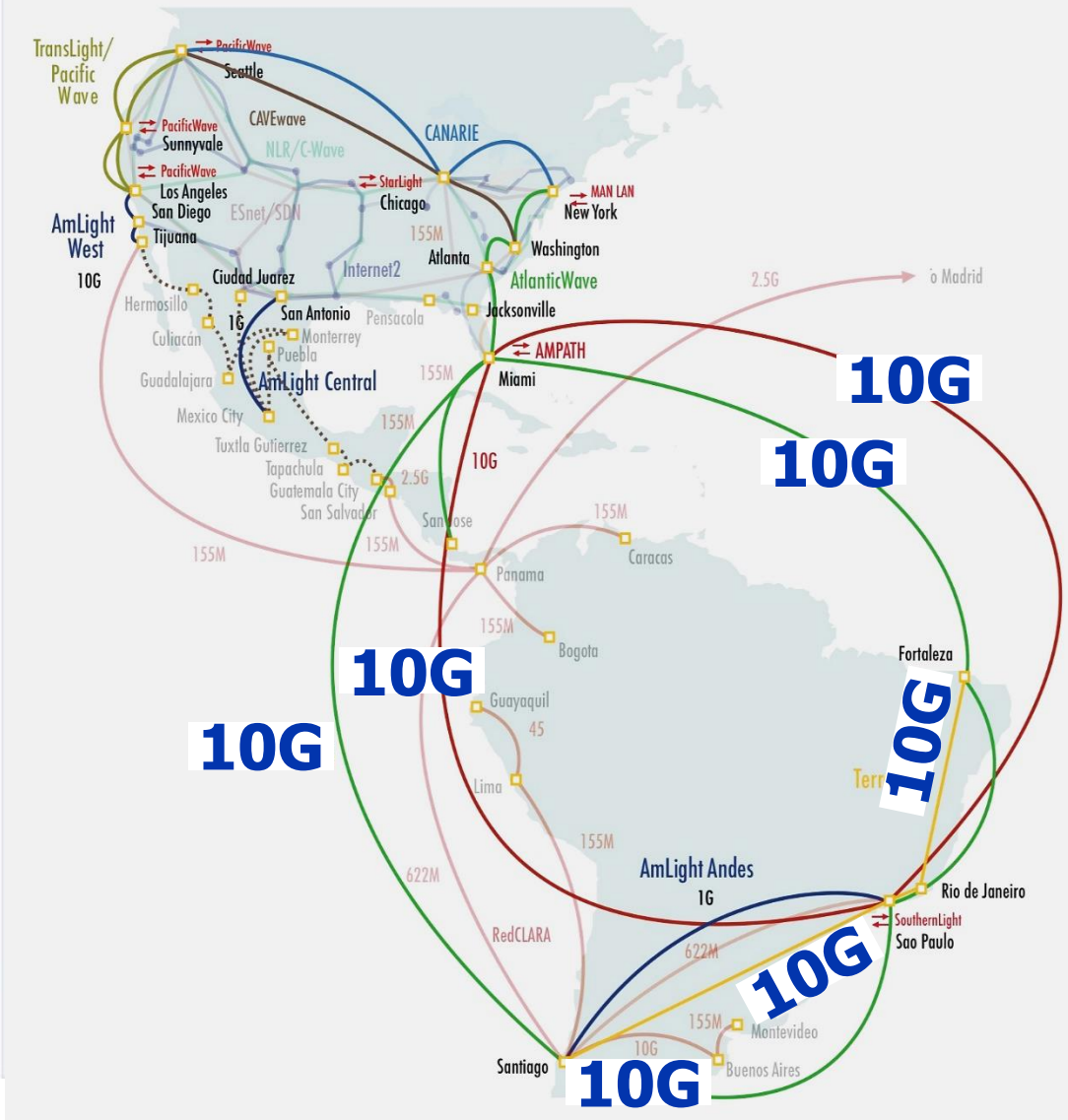


Figure N+3: Details of the Amazon crossing at Jurupari.

- New 2nd fiber across Amazon reaches the northern capital cities Macapa and Manuas
  - Brings competition to the 1st subfluvial link to Manaus
  - RNP expects to get multi-Gbps access to these cities soon

Closing the Digital Divide: 10G Links within and to Latin America in 2013-14

RNP, ANSP, AmLight (US NSF)



- **Subsea Links Upgraded to Four 10G links on two cables:** Sao Paulo, Rio, Santiago to Miami **(RNP + ANSP)**
- **Supports Rio and Sao Paulo Tier2s, and GridUNESP** Regional Tier1
- Carries **1G for RedCLARA** and ~10G general purpose Internet traffic
- **Terrestrial backbone:** Santiago – Sao Paulo – Rio – Fortaleza
- **AmLight Andes:** Link to Chile, shared between CLARA and the US Astronomy community
- **Amlight (US NSF):** Connects to Atlantic Wave at 10G in Miami

100G Experiment and New Cable Brazil - Europe

Feb. 2014

M. Stanton
RNP

- **100G Experiment:** Alien 100G wave on an existing cable Brazil – Miami
- Financed by NSF and FAPESP
- Using Padtec(br) 100G equipment. Demonstrated with the HEP team led by Caltech at Supercomputing (Denver) in November 2013

- **New Cable Brazil – Europe Planned by 2016** Using ~15 100G waves
- **10,500 km Linking Santos and Fortaleza (br) to Lisbon (pt);** spur to Tenerife
- **Opens new horizons** by providing new routes to Europe, Africa and Asia

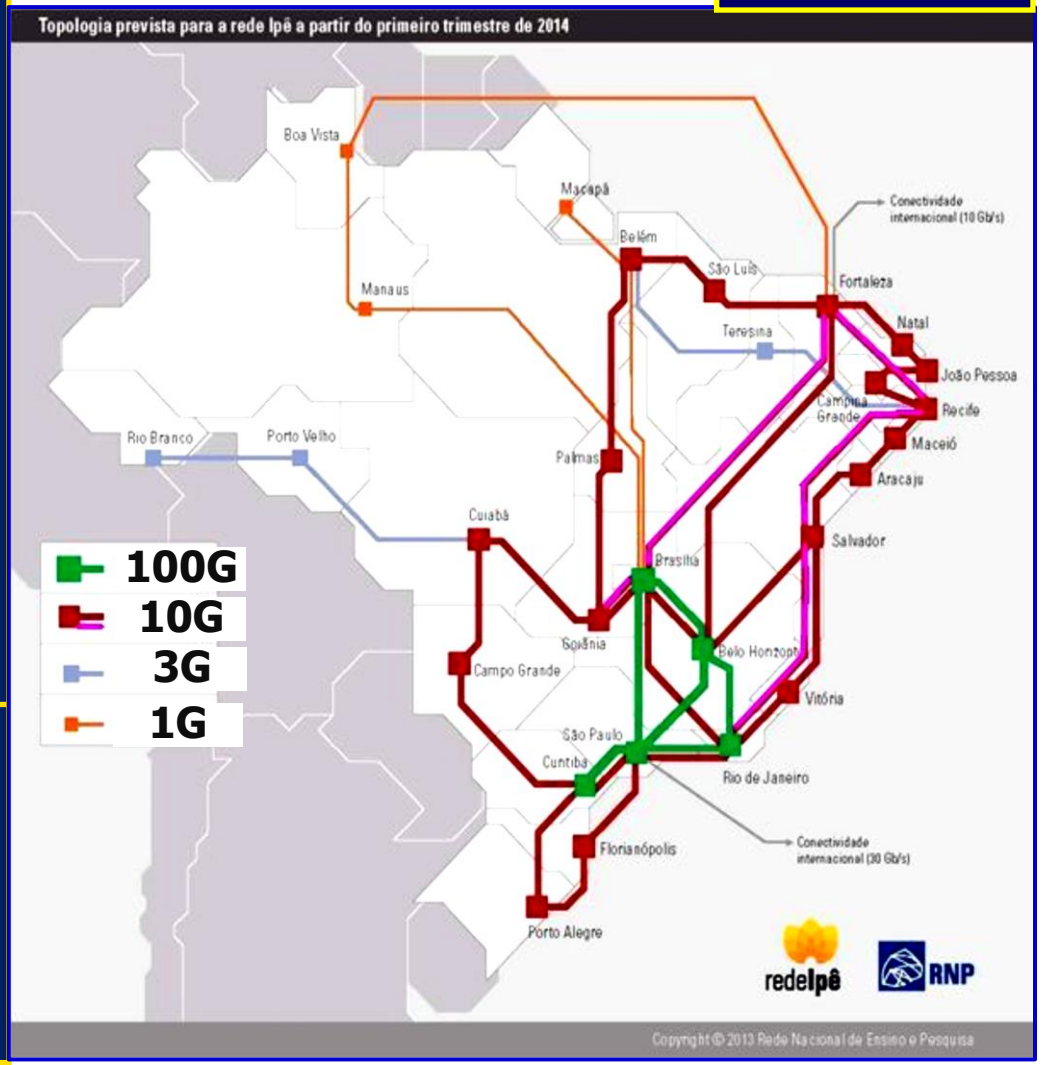
Brazil: Future Internet, SDN and 100G in the Backbone

Feb. 2014

M. Stanton
RNP

- Layer 2 Circuit technology is used to construct large scale testbeds for R&D in Future Internet architectures
- SDN (OpenFlow) can be used to determine the network architecture
- FIBRE2, a new fiber testbed project in Brazil, is federated with well-known US, EU, Jp projects in this area: GENI (US), FIRE (EU), AKARI (Japan)
- ANSP and RNP will deploy SDN on their networks; RNP has a longer range plan to migrate to an SDN-based production network nationwide

- RNP intends to deploy several 100G links at the core of its network already by 4Q 2014
- This will serve as a pilot for its SDN-based future network with appropriately abundant capacity



RedCLARA Extra-regional Connectivity to Participating Latin American Networks

Marco Teixeira (RNP)

Latin American Country	NREN Organization	RedCLARA Connectivity (Gbps)
Argentina	INOVARED www.innova-red.net	*0.500*
Bolivia	ADSIB www.adsib.gob.bo	*Off*
Brazil	RNP www.rnp.br	1.5
Chile	REUNA www.reuna.cl	1.0
Colombia	RENATA www.renata.edu.co	*0.500*
Costa Rica	CR2Net www.conare.ac.cr	*0.400*
Ecuador	CEDIA www.cedia.org.ec	*0.223*
El Salvador	RAICES www.raices.org.sv	*0.125*
Guatemala	RAGIE www.ragie.org.gt	*0.125*
México	CUDI www.cudi.edu.mx	*0.200*
Panama	PANNET/SENACYT www.redcyt.org.pa	*Off*
Paraguay	ARANDU - www.arandu.net.py	*Off*
Peru	CONCYTEC www.raap.org.pe	*Off*
Uruguay	RAU www.rau.edu.uy/redavanzada	*0.155*
Venezuela	REACCIUN www.cenit.gob.ve	*0.300*

Inter-regional Connectivity to Latin American NRENs via RedCLARA is hardly increasing or getting worse. *A pricing/policy issue*

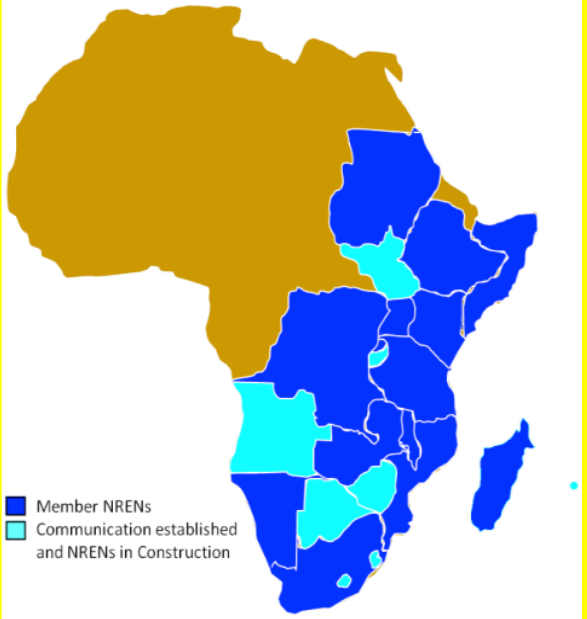
NREN Network Connectivity within APAN

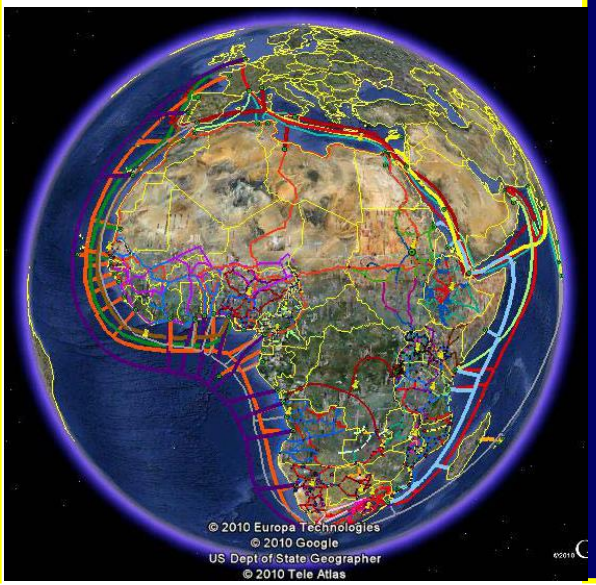
	Domestic	International
Australia	10G → 100G	Multiple 2.5G and 10G links into Asia and North America
Bangladesh	45M → 1 - 10G	45M
China	Multiple 10G	Multiple 1G and 10G links
Hong Kong	1 - 10G	1 - 10G
India	< 1G - 10G	2.5G
Japan	Multiple <1G - 10G	1.5M (satellite) to multiple 10G
Korea	Multiple 10G	Multiple 10G
Sri Lanka	1M - 500M	45M → 1G or more
Malaysia	1G	100M - 622M
Nepal		45M
Philippines	2M - 1G	100M - 622M
Pakistan		155M
Singapore	10G	10G
Thailand	1G	622M
Taiwan	10G and Above	Multiple 2.5 - 10G
Vietnam		622M

The UbuntuNet Alliance www.ubuntunet.net

UbuntuNet Alliance
14 Eastern and Southern Africa NRENs

Ebale (Rep. of Congo)
EthERNet (Ethiopia)
iRENALA (Madagascar)
KENET (Kenya)
MAREN (Malawi)
MoRENet (Mozambique)
RENU (Uganda)
RwEdNet (Rwanda)
SomaliREN (Somalia)
SUIN (Sudan)
TENET (South Africa)
TERNET (Tanzania)
Xnet (Namibia)
ZAMREN (Zambia)





UbuntuNet Alliance
10G Link South Africa to London

Phase 1 continental backbone done in Spring 2013: interconnecting Mtunzini, Maputo, Dar es Salaam, Nairobi, Kampala and Kigali, and a backup link between Nairobi and Mtunzini.

Additional Information on Ubuntunet: Jan. 2014 "Nuance" Newsletter available at:

http://www.ubuntunet.net

SCIC Main Conclusions for 2014

- We are continuing our work in many countries to Close the Digital Divide
  - Both in the physics community and in general
- To make physicists from all world regions full partners in the scientific discoveries
- We are learning to help do this effectively, in some cases in partnership with many agencies and HEP groups:
  - → Brazil (RNP), Mexico (CUDI), Asia Pacific (APAN)
  - → AmLight (FIU)
  - → "Taj" Extension of GLORIAD to Middle East and India
- But we are indeed leaving other countries and regions behind, for example: Africa, the Rest of Latin America, Most of the Middle East, South and SE Asia
- A great deal of work remains: The PingER Monitoring Effort at SLAC is a vital part of it

Networks for HEP
Journey to Discovery

- Run 1 brought us a centennial discovery: the Higgs Boson
- Run 2 will bring us (at least) greater knowledge, and perhaps greater discoveries: Physics beyond the Standard Model.
- *Advanced networks will continue to be a key* to the discoveries in HEP and other fields of data intensive science and engineering
- Technology evolution *might* fulfill the short term needs
- A new paradigm of global circuit based networks will need to emerge during LHC Run2 (in 2015-18)
- *New approaches + a new class of global networked systems to handle Exabyte-scale data are needed*
  [building on LHCONE, DYNES, ANSE, OliMPS]
- Worldwide deployment of such systems by 2023 will be:
  - Essential for the High Luminosity LHC HL-LHC
  - A game-changer that could shape both research and daily life

THANK YOU!

Harvey Newman
newman@hep.caltech.edu

The State of the Art in Optical Network Transmission

400G Production-Ready Waves Demonstrated
400GE Link in Production (RENATER)

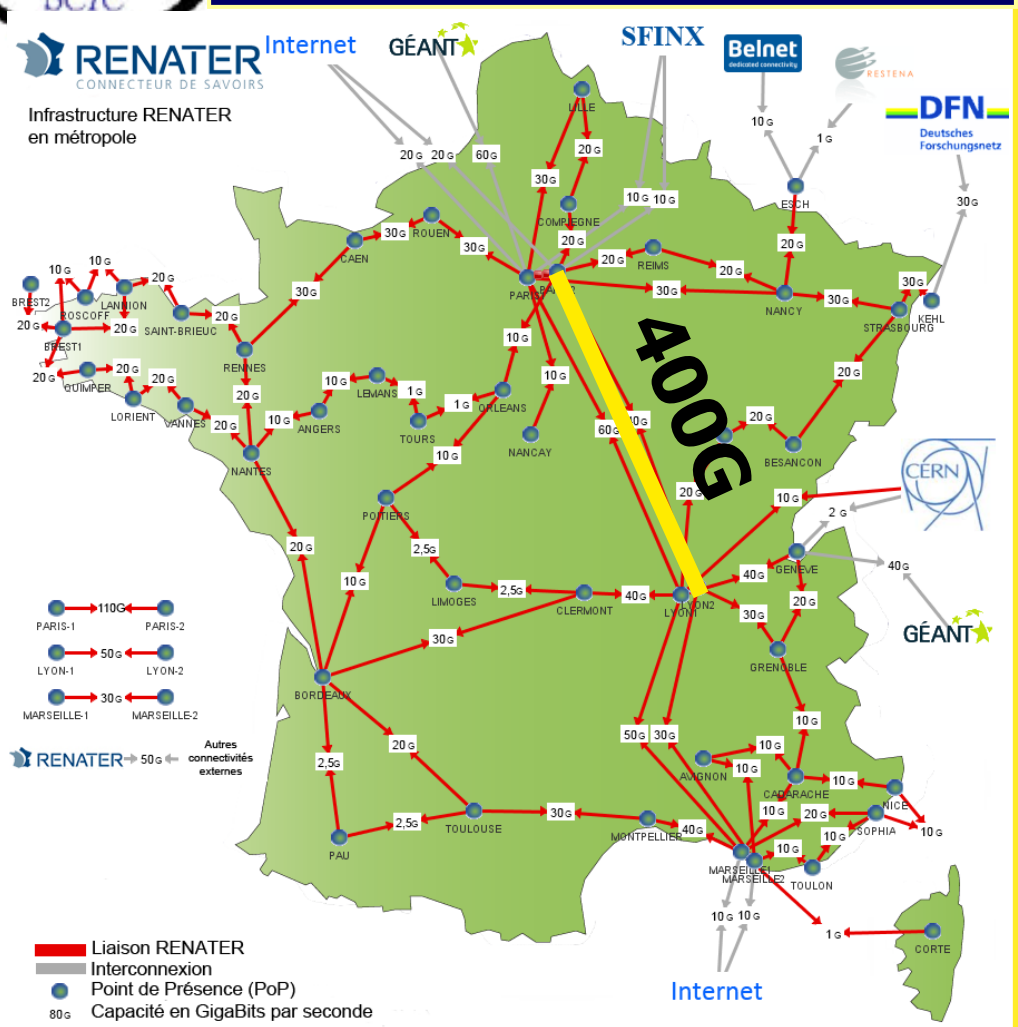
Chinese telecoms equipment vendor Huawei successfully completed a field trial using new optical fiber transmission technologies on Vodafone's live network, reaching 2 Terabit/s transmission over 3,325 km, or 2066 miles. This capacity is ~20 times higher than current commercially deployed 100G systems.
http://www.huawei.com/en/about-huawei/newsroom/press-release/hw-202114-vodafone.htm

February 6, 2012: Orange, Alcatel-Lucent provide a live 400G link to RENATER (Paris – Lyon)

France Telecom-Orange and Alcatel-Lucent have deployed the world's first optical link with a capacity of 400 Gbps per wavelength in a live network. Following a successful field trial, the 400-Gbps-per-wavelength fiber-optic link is now operational between Paris and Lyon (289 miles).
[System capacity: 17.6 Tbps on 44 400G waves.]

http://www.lightwaveonline.com/articles/2013/02/orange--alcatel-lucent-provide-live-400g-link-to-renater.html

France: RENATER5
Dark Fiber Infrastructure



- 11,900 km dark fiber
- 665 institutions connected at over 1346 sites, in French cities and overseas
- External connections: ~160 Gbps; Traffic: 343 Pbytes/Yr internationally
- 145 10G wavelengths on the backbone: 20 Added in 2013; several for HEP

➡ *Connected to LHCONE in 2013, at Paris and Geneva*

➡ *3 PoPs 100G ready;*
Optical infrastructure upgrades to 100G will begin in 2014

Laurent Gyde

100G Tests Since 2010, between CERN and CC-IN2P3
First 400G live link in the world (Paris-Lyon) in 2013

1.05 *Petabit/sec* Over a Multicore Fiber

Spatial Mode + Spectral + Polarization Multiplexing

January 22, 2012: [http://optics.org/news/4/1/29] Researchers from NEC Labs in Princeton and from Corning's Research Center successfully demonstrated ultra-high speed transmission with a capacity of 1.05 petabit/s (10^{15} bits per second) over a novel multi-core fiber that contains 12 single-mode and two few-mode cores by employing an advanced space division multiplexing scheme and optical multiple-input multiple-output signal processing technique.

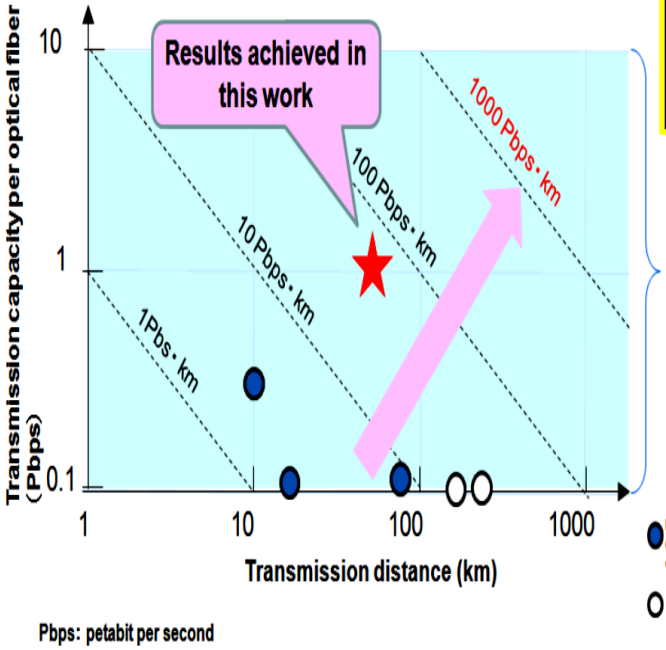
The fiber designed by Corning researchers has cores arranged in a triangular lattice, which enables transmission over a large number of spatial modes. By combining spectral multiplexing with polarization and spatial mode multiplexing and employing multilevel modulation formats, NEC researchers achieved an aggregate transmission of 1.050 Petabit/s, which is claimed to be the highest transmission capacity over a single optical fiber reported so far.

Optical Data Transmission: State of the Art

1 *Petabit/sec* On a 12-Core Fiber over 52 km

Spatial Mode + WDM + 32 QAM + Polarization Multiplexing

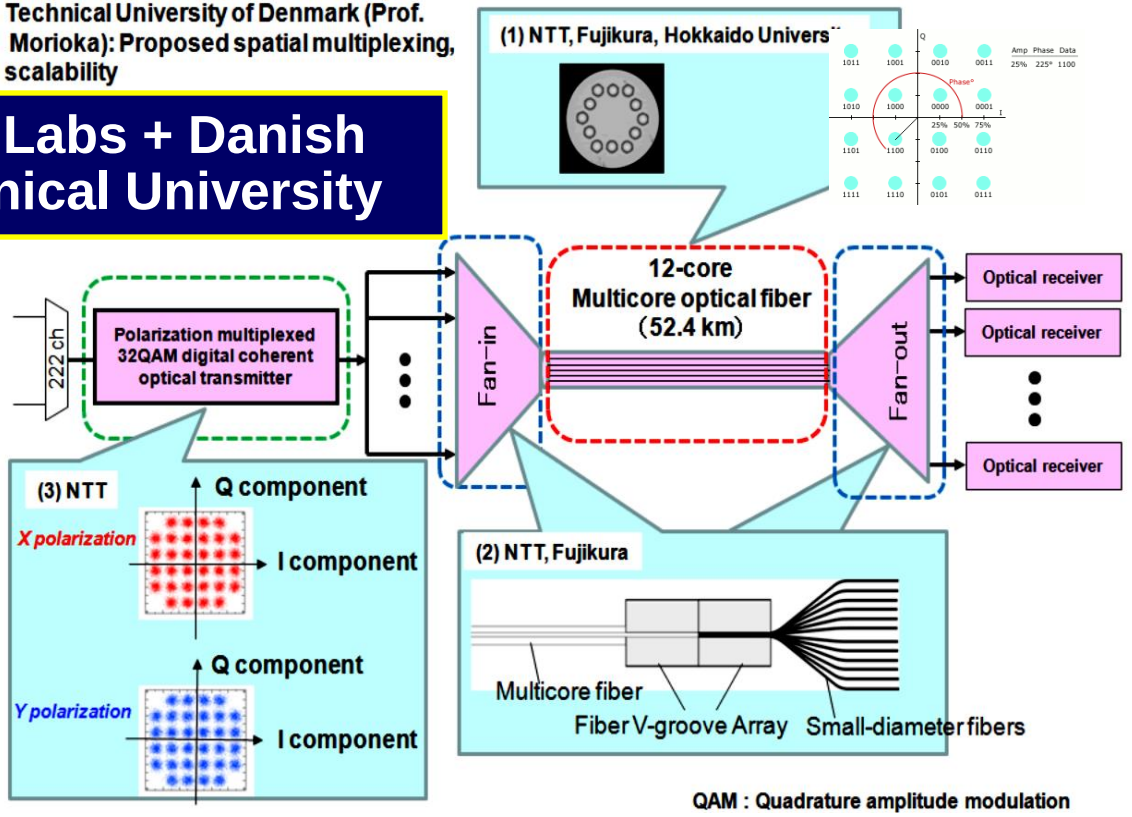
Proposed large-capacity transmission using spatial multiplexing optical communication technology and relative performance of this work



Pbps: petabit per second

Technical University of Denmark (Prof. Morioka): Proposed spatial multiplexing, scalability

NTT Labs + Danish Technical University

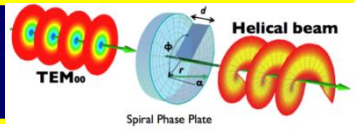


QAM : Quadrature amplitude modulation

1.01 Pbps Throughput: 12 Cores X 222 Channels/Core X 380Gbps/Channel

96 bps/Hz across 11 THz http://www.ntt.co.jp/news2012/1209e/120920a.html

Other developments: Using *Orbital ang. momentum;* Willner et al.



The End

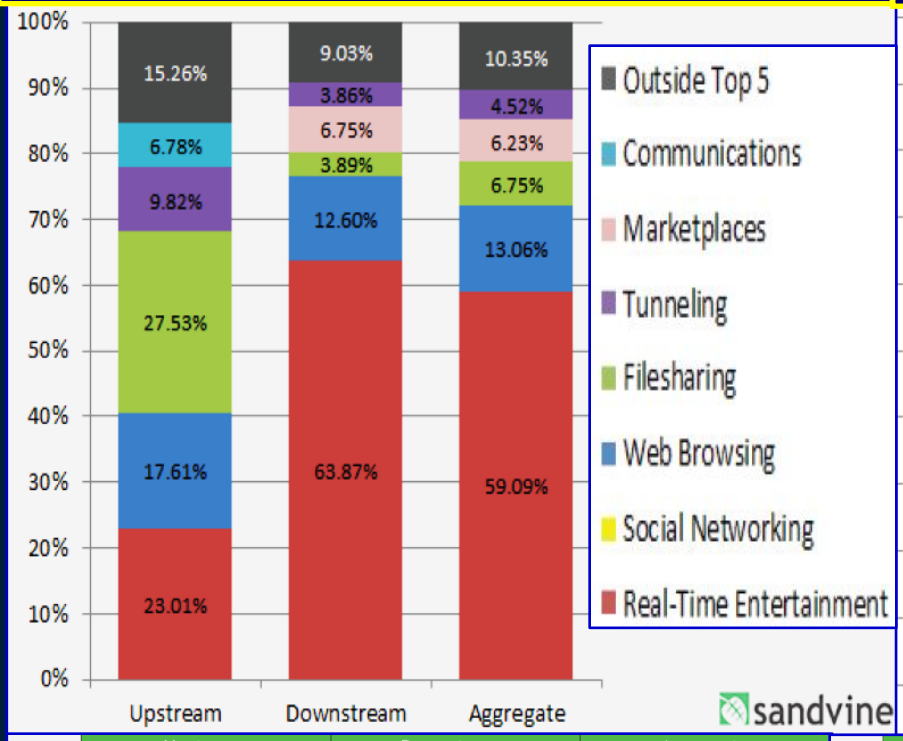
Internet World Trends in 2014 Part 2

Users, Penetration and Broadband Global Traffic Evolution

Global Internet Use: What Fills the Internet During Peak Periods ?

Sandvine.com

N. America Fixed Access



	Upstream		Downstream		Aggregate	
Rank	Application	Share	Application	Share	Application	Share
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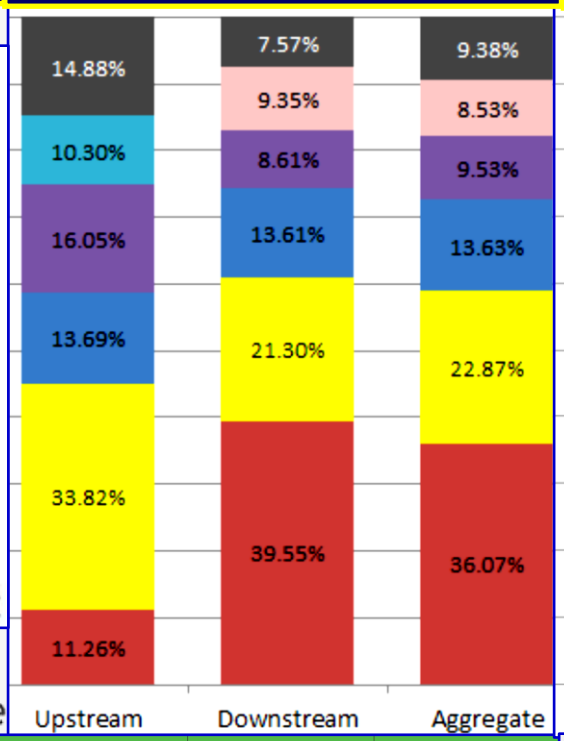
3	SSL	6.54%	HTTP	11.65%	HTTP	11.84%
4	Netflix	6.44%	iTunes	3.64%	BitTorrent	5.96%
5	YouTube	5.52%	SSL	3.42%	SSL	3.80%
6	Skype	2.23%	BitTorrent	3.40%	iTunes	3.33%
7	Facebook	2.17%	MPEG	2.85%	MPEG	2.62%
8	FaceTime	1.50%	Facebook	1.99%	Facebook	1.83%
9	Dropbox	1.20%	Amazon Video	1.90%	Amazon Video	1.82%
10	iTunes	1.15%	Hulu	1.74%	Hulu	1.58%
		64.40%		76.24%		74.58%

N. America Mobile



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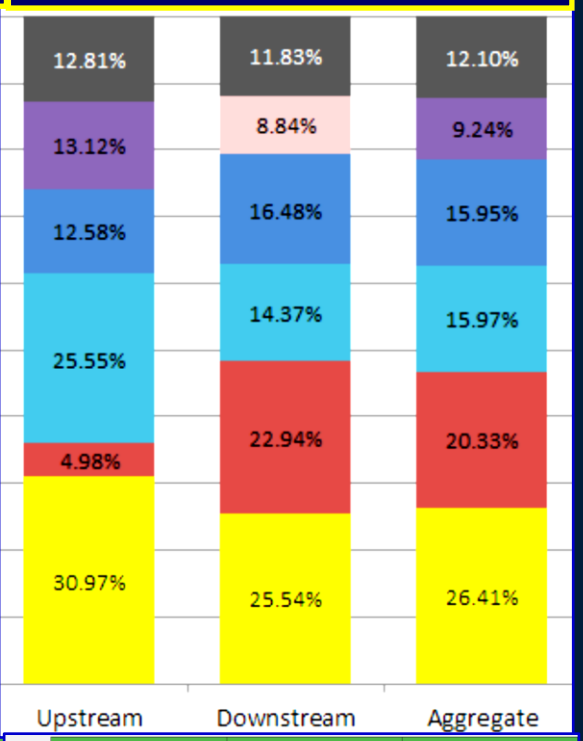
4	YouTube	3.77%	MPEG	8.64%	MPEG	7.77%
5	Instagram	3.47%	SSL	6.52%	SSL	7.25%
6	BitTorrent	2.09%	Google Market	5.27%	Google Market	4.78%
7	MPEG	1.70%	Pandora Radio	5.15%	Pandora Radio	4.72%
8	Pandora Radio	1.61%	Netflix	5.05%	Netflix	4.55%
9	Gmail	1.61%	Instagram	3.49%	Instagram	3.49%
10	iCloud	1.56%	iTunes	3.10%	iTunes	2.84%
		65.50%		78.46%		77.17%

Latin America Mobile



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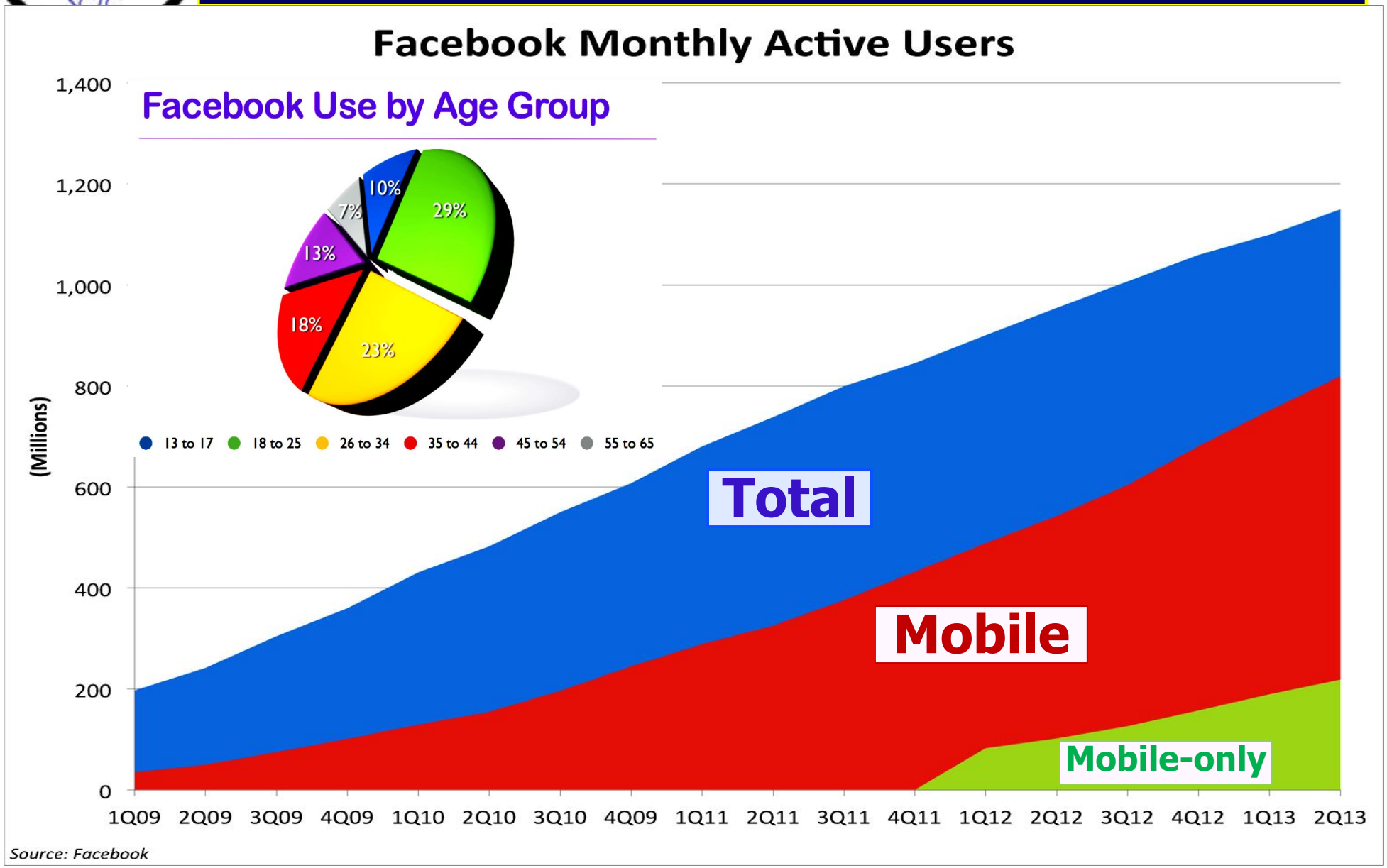
3	BlackBerry	10.80%	HTTP	13.73%	HTTP	13.04%
4	HTTP	8.75%	BlackBerry	9.12%	BlackBerry	9.37%
5	Whats App	5.71%	SSL	8.31%	SSL	8.83%
6	YouTube	3.05%	Google Market	5.25%	Google Market	4.66%
7	Gmail	2.29%	Instagram	3.57%	Instagram	3.27%
8	Twitter	2.12%	MPEG	3.26%	MPEG	2.85%
9	Ares	2.12%	Whats App	2.33%	Whats App	2.81%
10	Skype	2.04%	Twitter	2.02%	Twitter	2.12%
		71.54%		77.75%		76.43%

http://www.sandvine.com/news/global_broadband_trends.asp

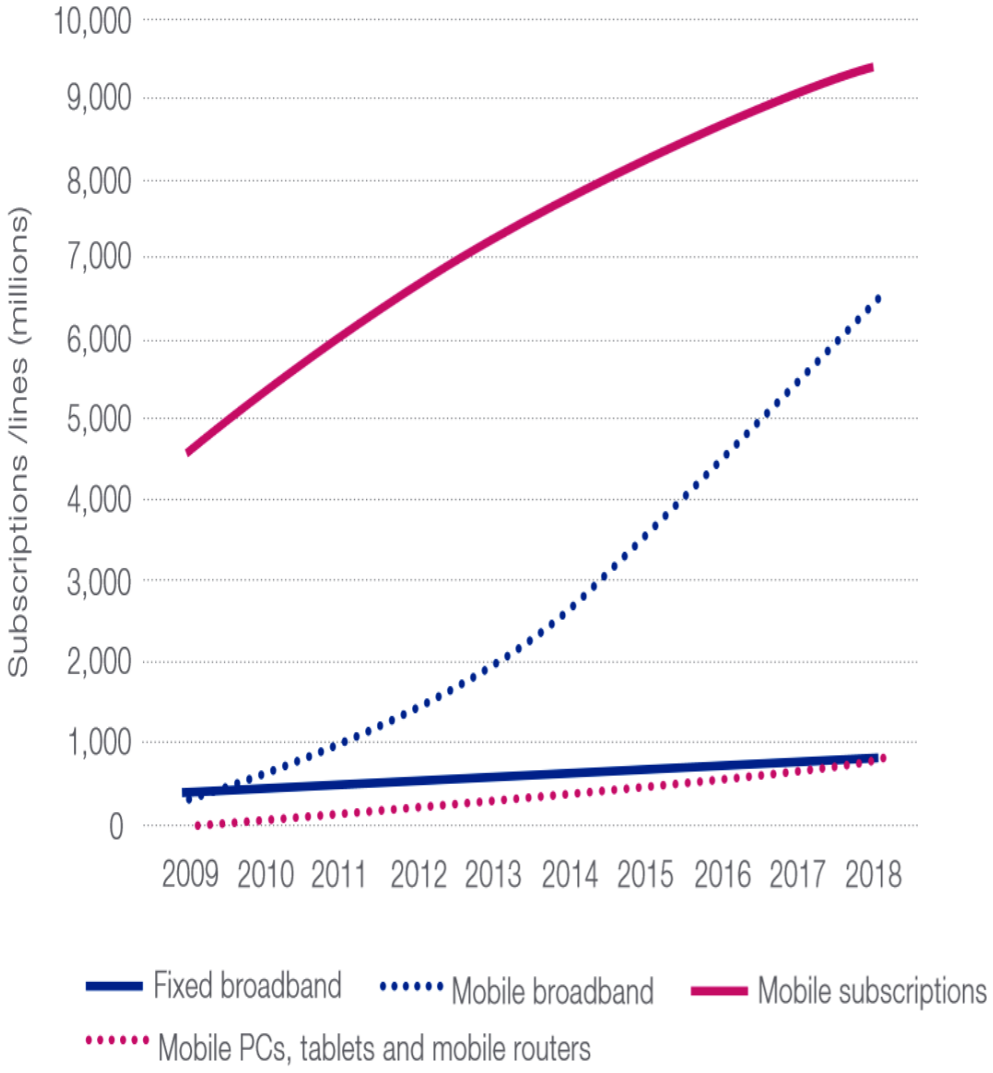
Facebook: 1.2B Monthly Active Users
and Use by Age Group



Source: Facebook

Fixed & Mobile Broadband Subscriptions 2009-18

1.5B Mobile Broadband Users in 2013; 3.3-5B by 2018



	Total end 2013	Broadband Total, end 2013	% Global Total high-speed, end 2013
Internet users	2.749 billion	-/-	-/-
Fixed Internet subscriptions	-/-	696 million (2013)	-/-
Mobile subscriptions	6.835 billion	2.096 billion	30.7%***
Unique mobile users *	3.3* - 5 billion**	1.5 billion**	30%
Handset shipments	1.736 billion (2012)****	712.6 million smartphones (2012)****	41.1%[18] (2012) 44.5%[19] (2012)

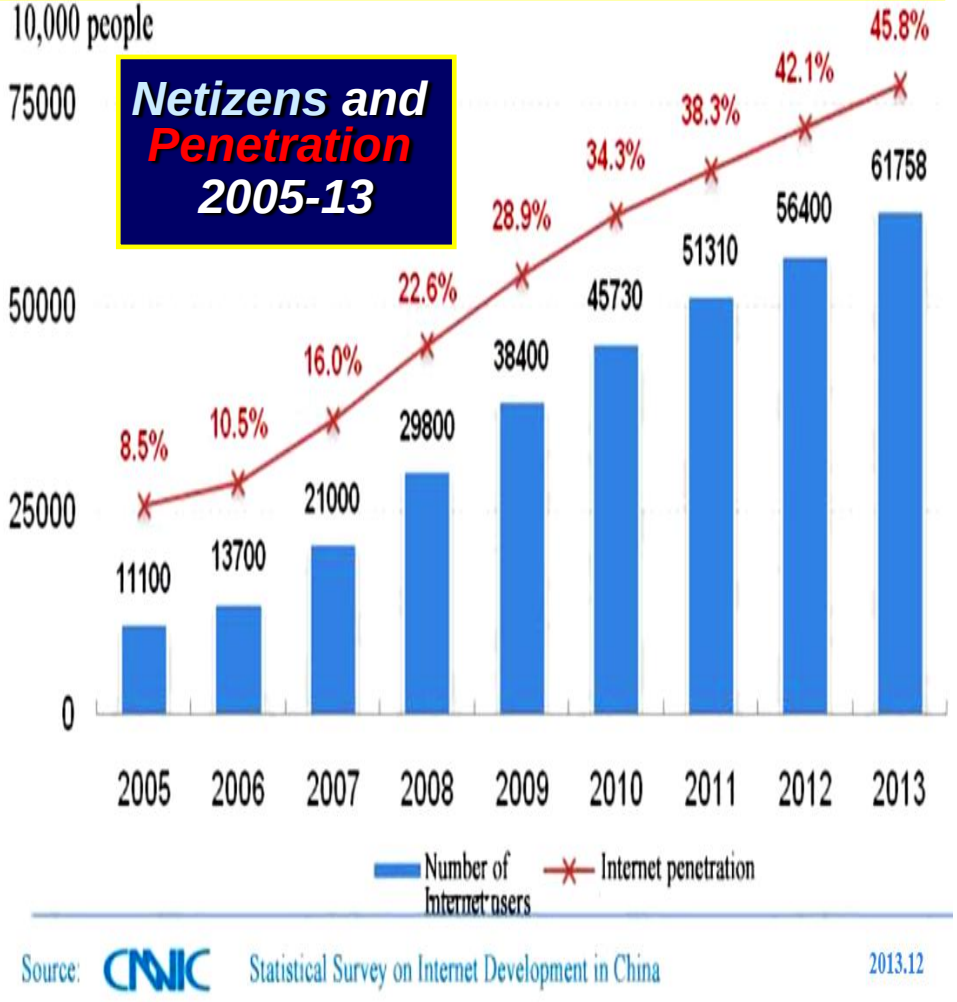
Broadband Commission Annual Report 2013
http://www.broadbandcommission.org/Documents/bb-annualreport2013.pdf

China's Netizens: Reached 642M by 2014

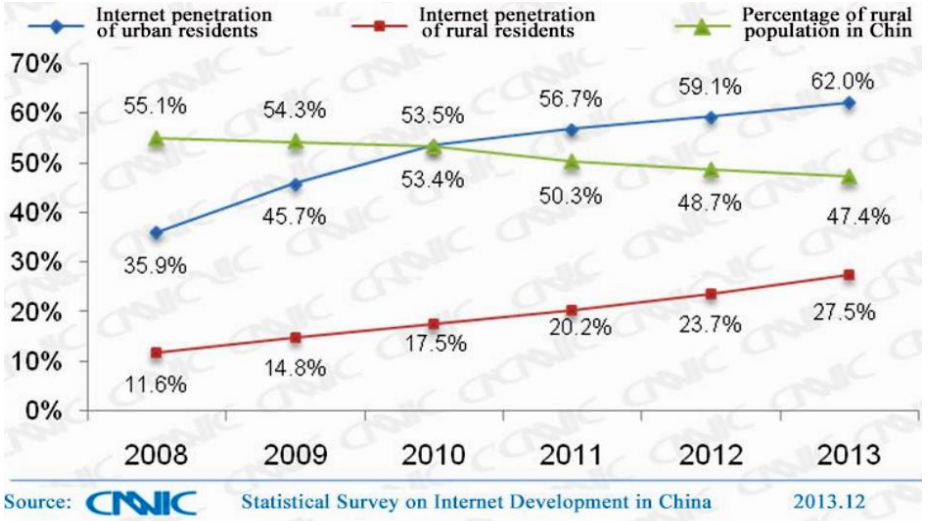
~500M (81%) with Broadband; 46% Penetration

CNNIC 33rd Annual Survey Report:
http://www1.cnnic.cn/IDR/ReportDownloads/201404/U020140417607531610855.pdf

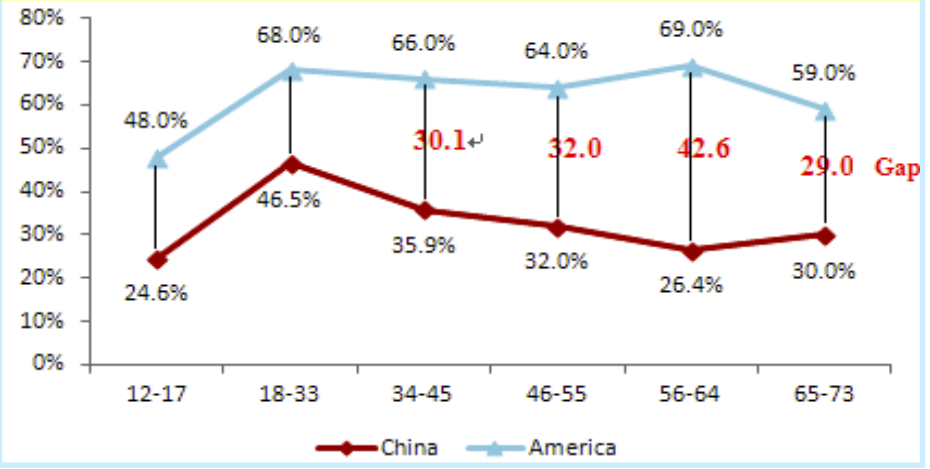
Netizens and Penetration 2005-13



Penetration in Urban and Rural Areas 2008-13



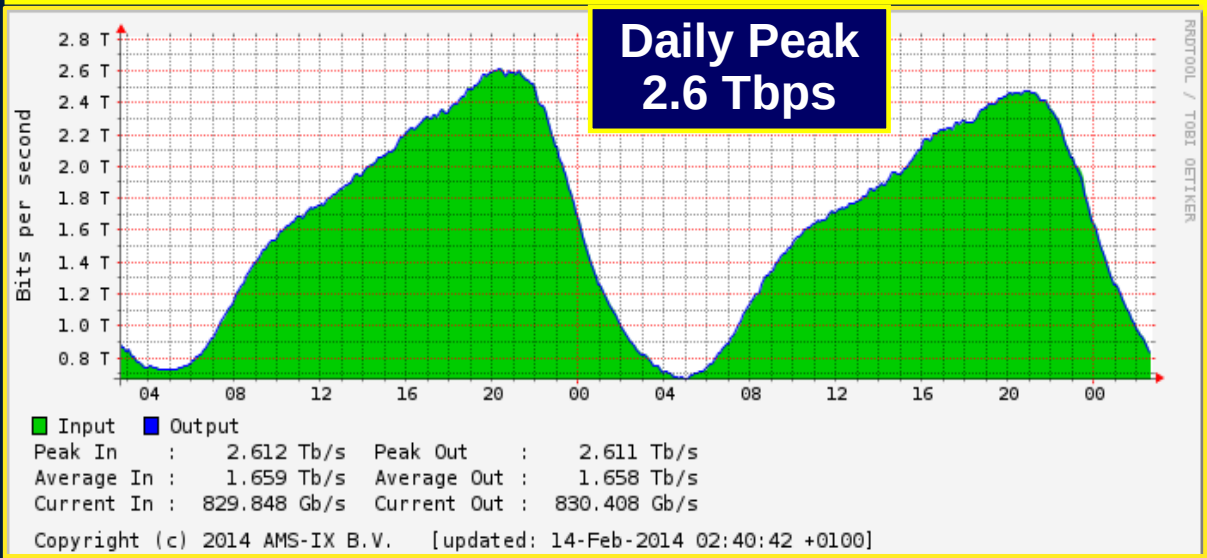
Online Shopping Rate vs. Age "Gap" China Vs. America (2011)

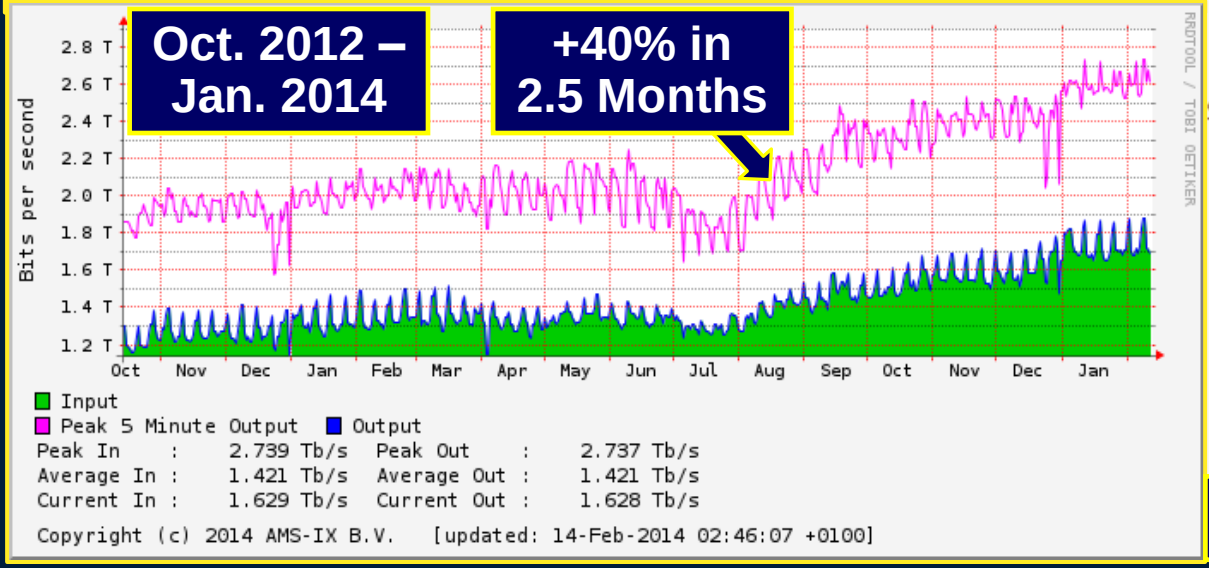


AMS-IX Traffic 2/13/14: 2.6 Tbps Peak

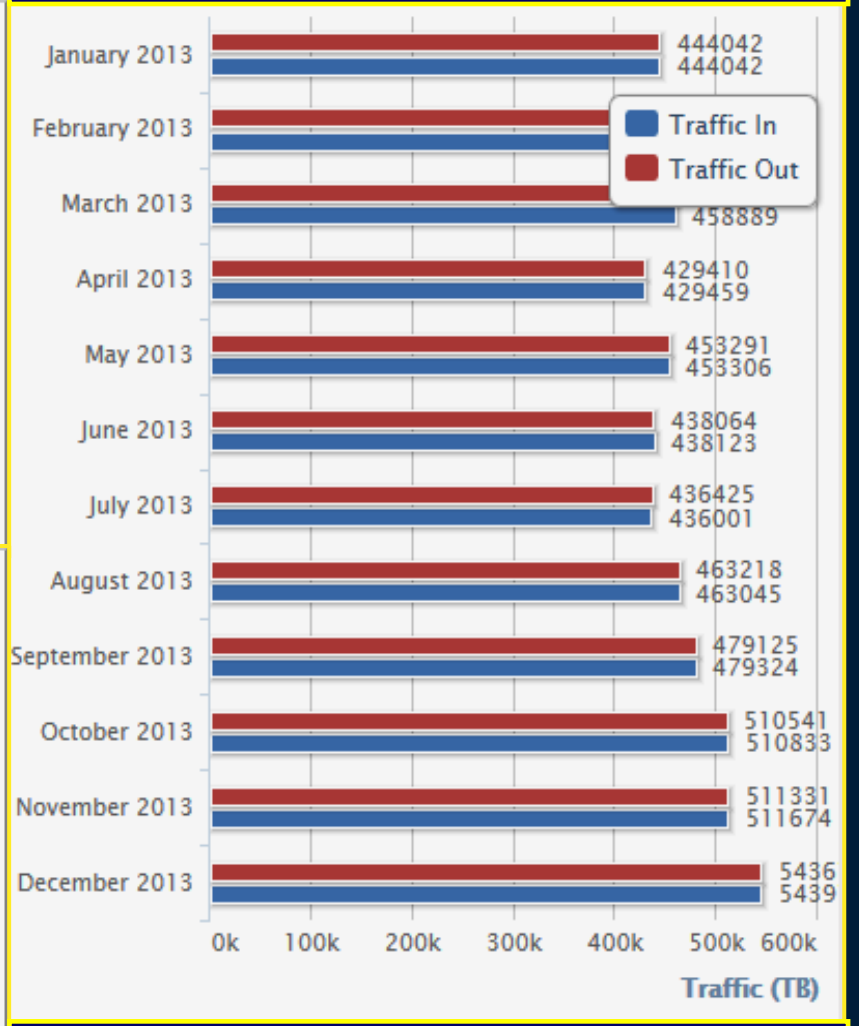
5X Growth in 2008-13. To 543 Pbytes/Month

Amsterdam Internet Exchange Point Daily Traffic





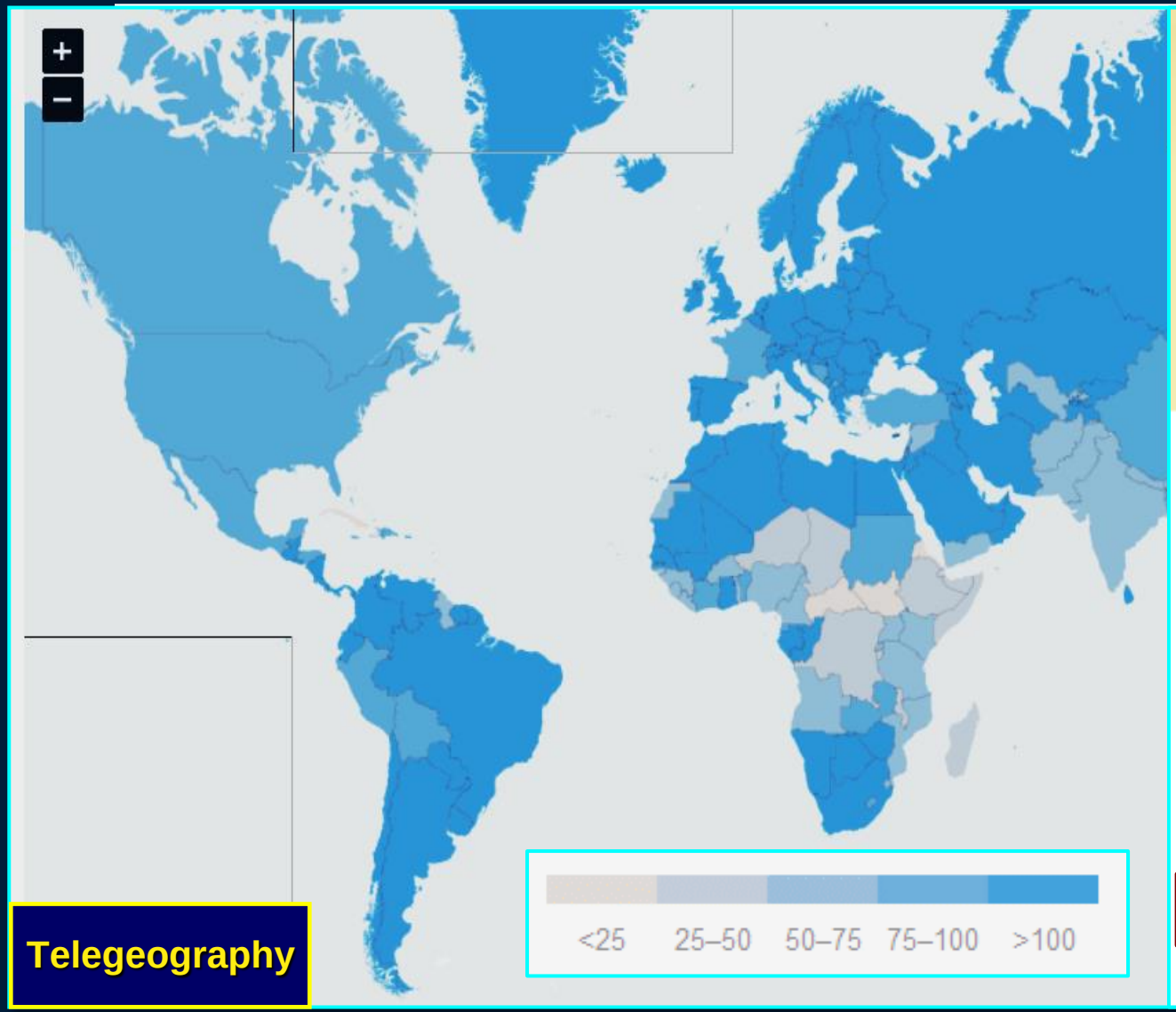
Monthly Traffic: 2013



543 Petabytes in Dec. 2013

World Wireless Penetration

http://www.telegeography.com/products/telegeography-insider/maps/country/insider.html [register for free]



World

Wireless population penetration:	96.7%
Broadband household penetration:	37.3%
Wireline household penetration:	50.2%

Wireless

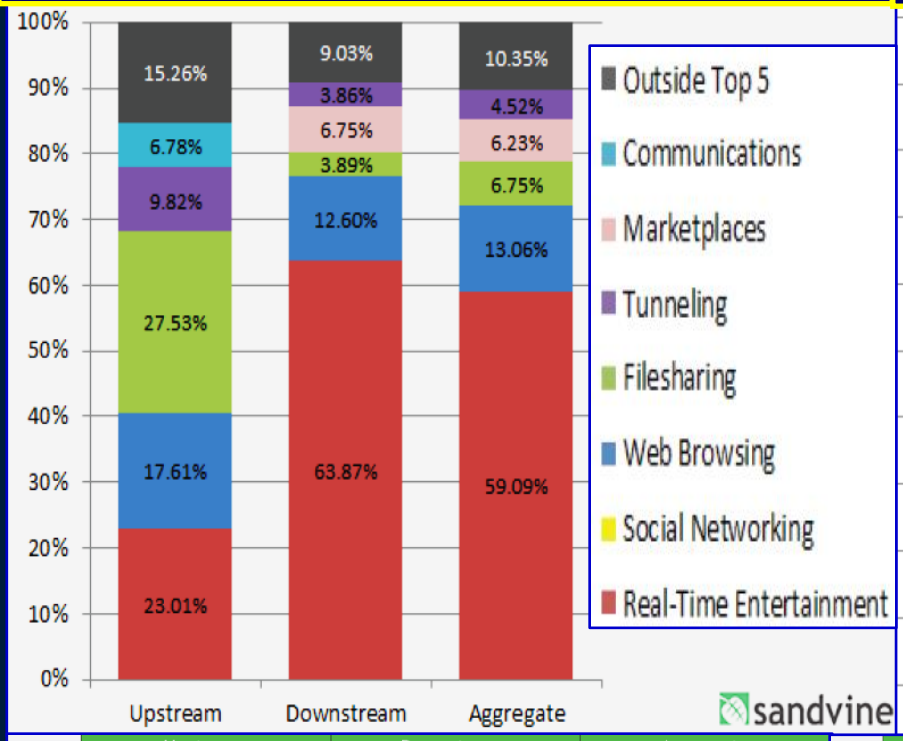
Total subscribers (Mar 2014): 6,875,904,278

Population penetration:	
116.8%	Latin America
75.8%	Africa
110.0%	Middle East
89.2%	Asia & Pacific
97.2%	U.S. & Canada
156.4%	Eastern Europe
129.6%	Western Europe

Global Internet Use: What Fills the Internet During Peak Periods ?

Sandvine.com

N. America Fixed Access



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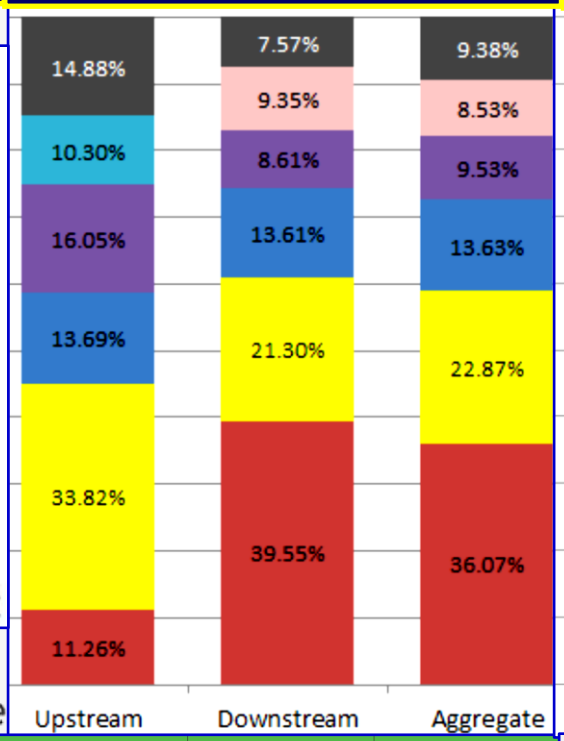

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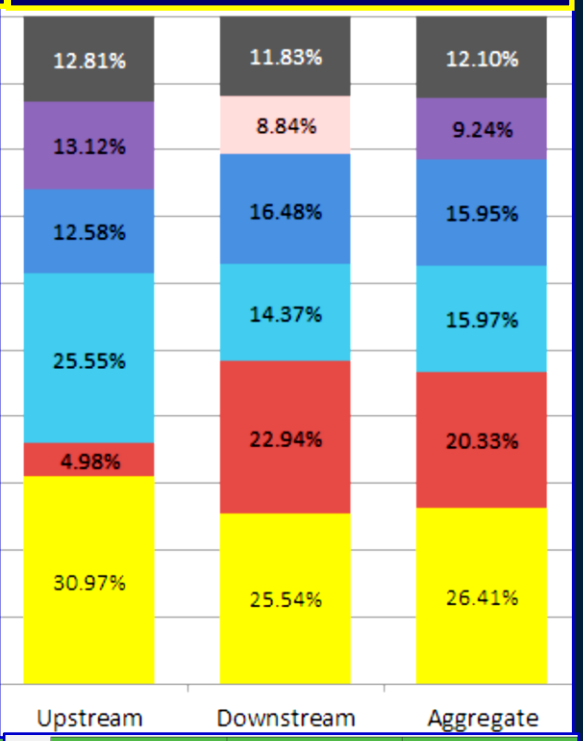
Latin America Mobile



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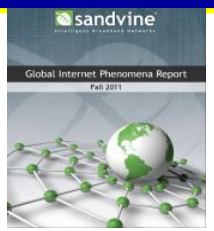
http://www.sandvine.com/news/global_broadband_trends.asp

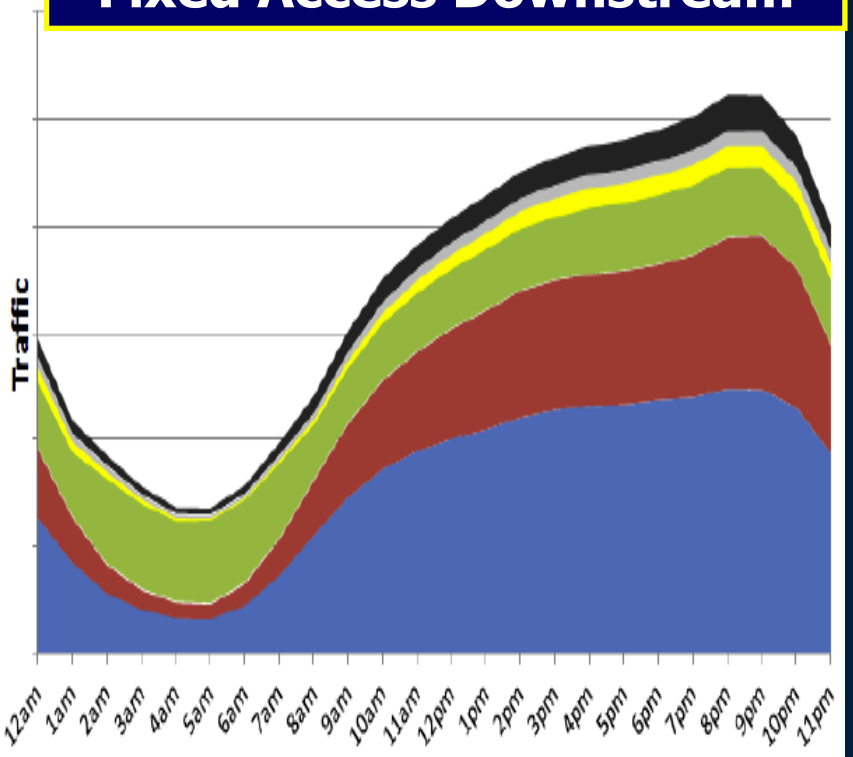
Global Internet Use: Asia Pacific and Eastern Europe Downstream Fixed Access

Average Day:Asia Pacific Fixed Access Downstream

Sandvine.com 2013



Average Day: East. Europe Fixed Access Downstream



	Region		
Category	Eastern Europe	Brazil	Africa
Real-Time Entertainment	26.9%	41.3%	23.2%
Web Browsing	47.4%	24.2%	32.3%
P2P Filesharing	12.8%	12.0%	19.3%

	Monthly Aggregate Data Consumption	
Region	Median	Mean
Eastern Europe	227.3 MB	1.0 GB
Brazil	6.3 GB	14.8 GB
Africa	2.4 GB	6.8 GB

China's Netizens: Reached 642M by 2014

~500M (81%) with Broadband; 46% Penetration

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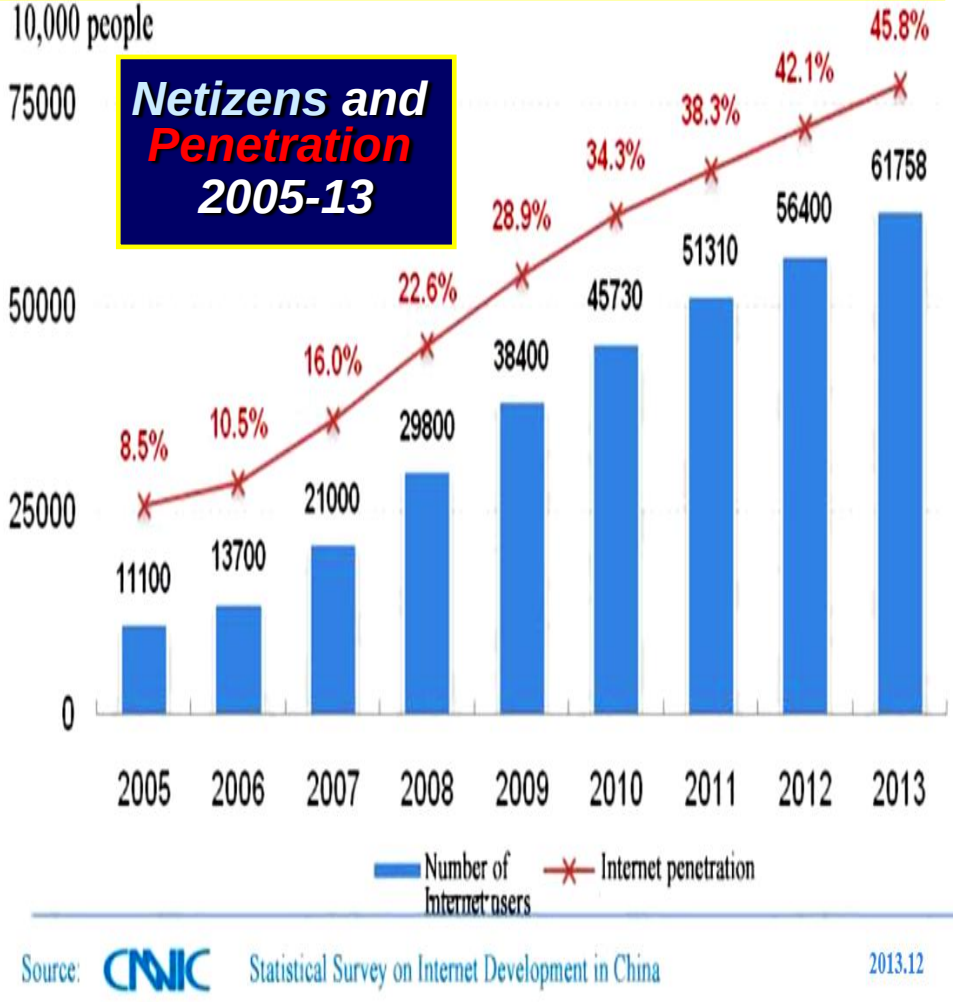

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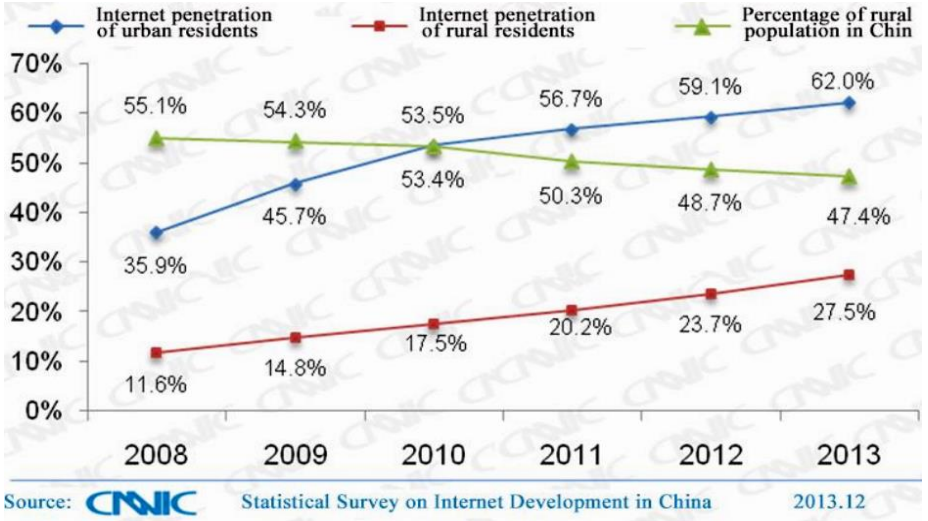

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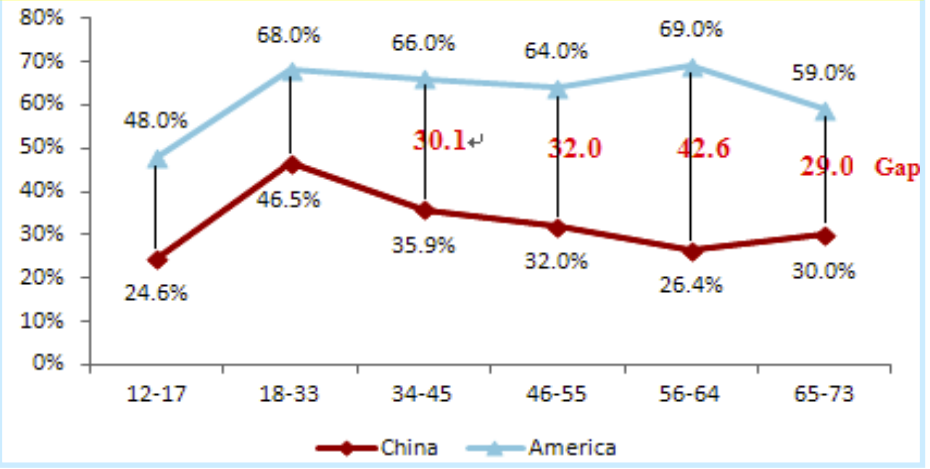
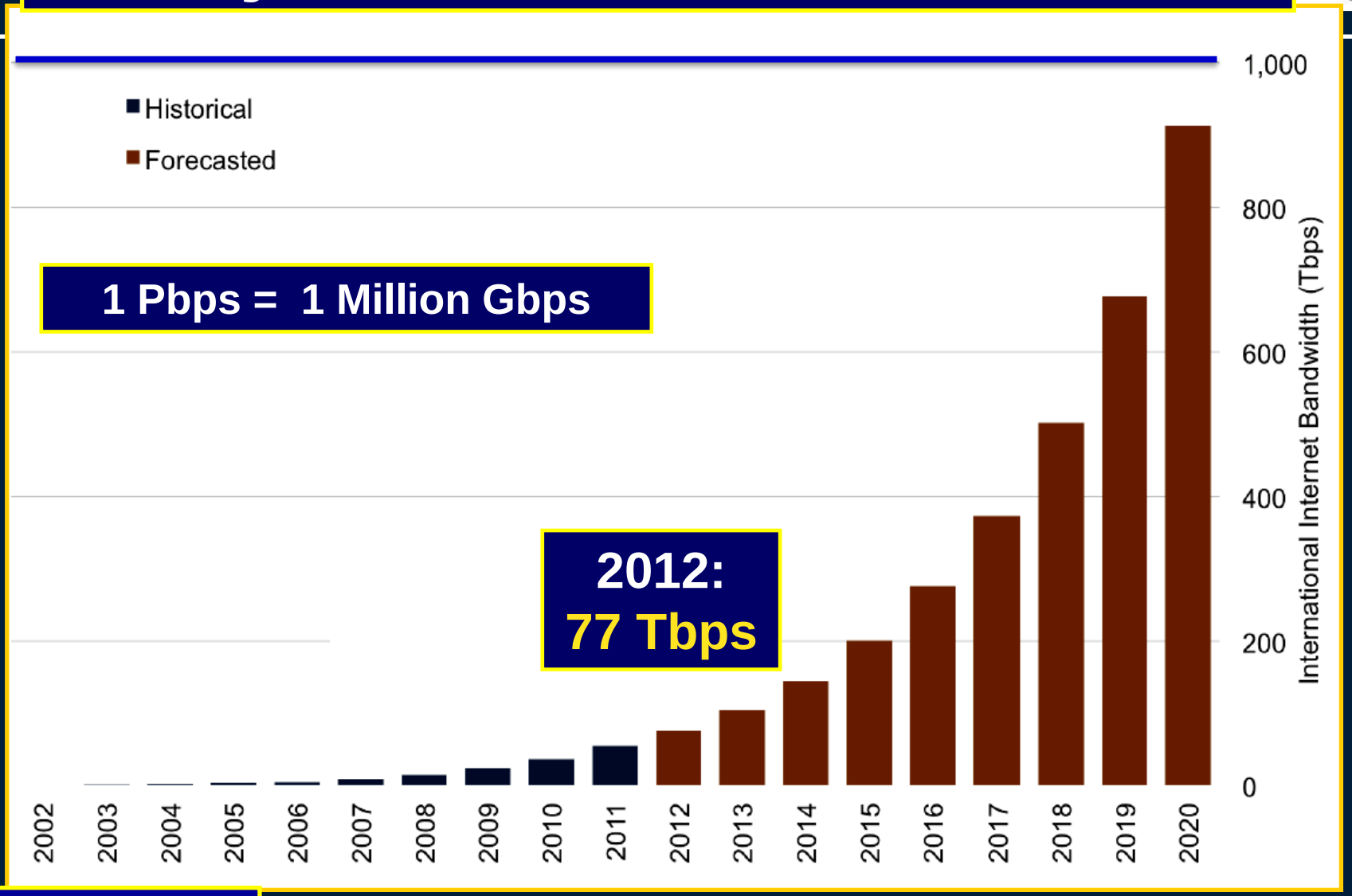


International Internet Traffic, Capacity Growth and Pricing Trends

Telegeography

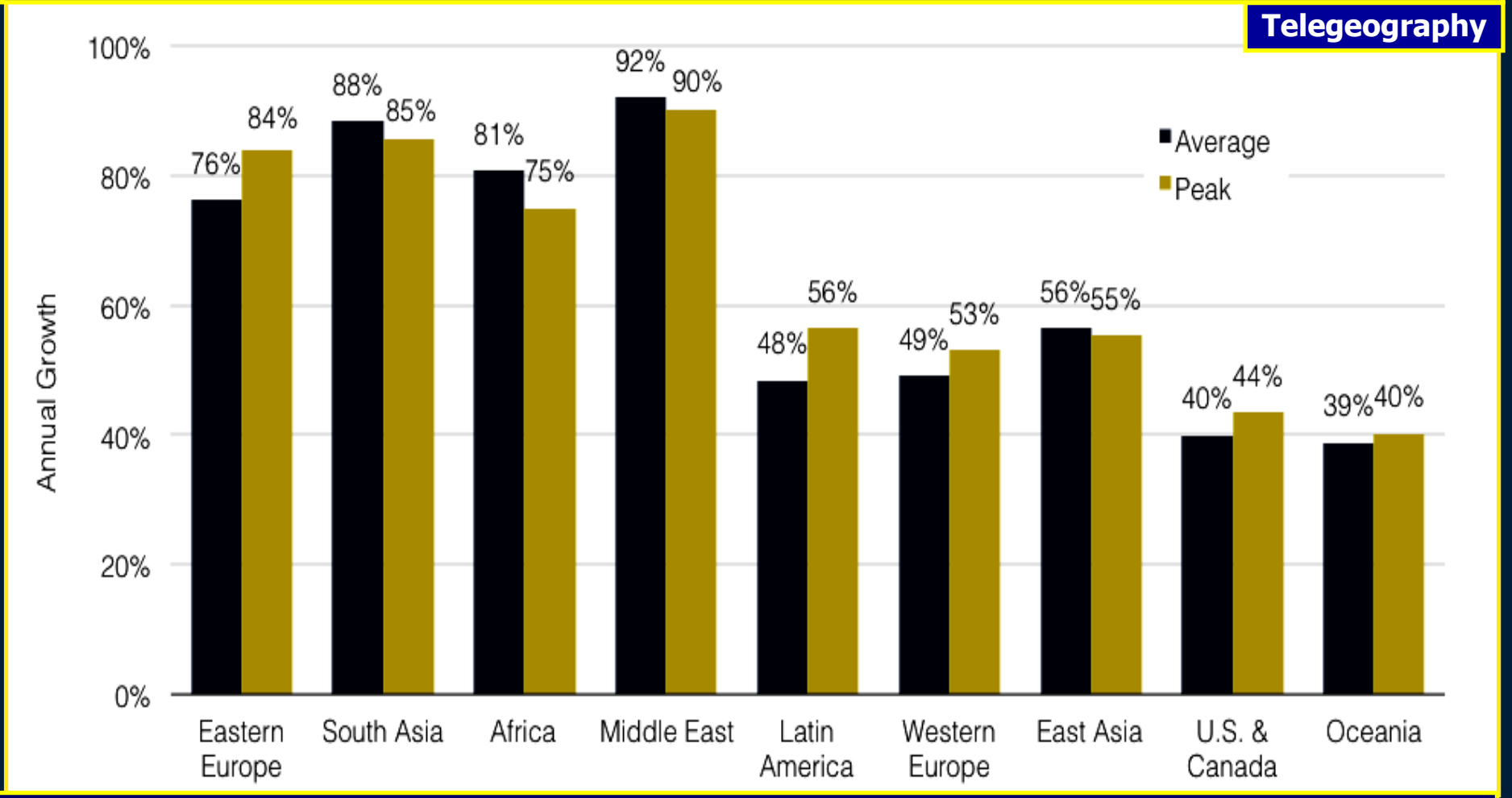
Demand for Int'l Bandwidth Only Goes Up
Project 1 Petabit/sec Before HL-LHC



Telegeography

2008-12 Intl Pace of Growth Varies by Region: 75 – 92% CAGR in Developing Regions

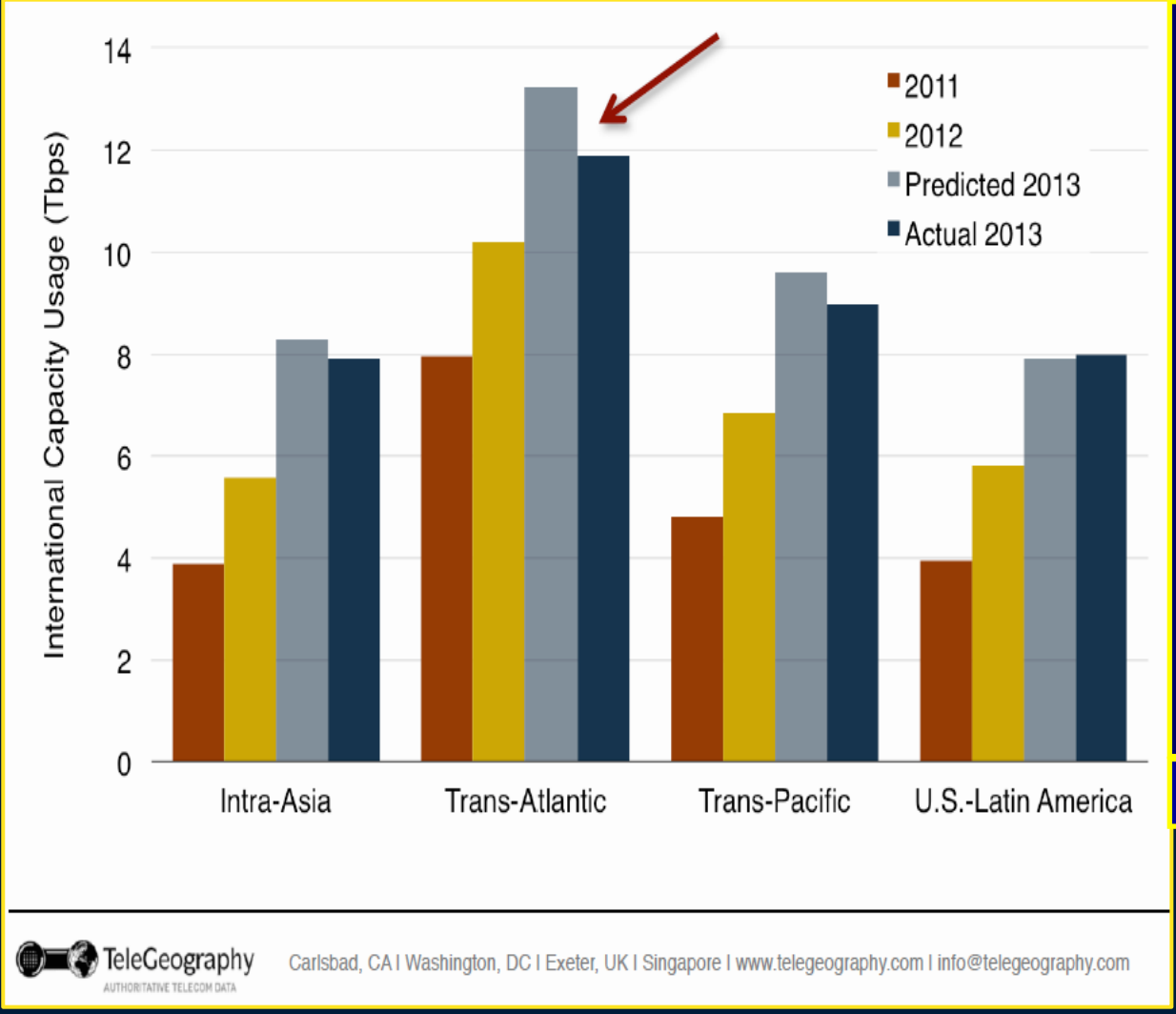
Average and Peak CAGR 2008-12 by Region; Overall Growth Rate Declined by 2012 from 65-70% to 40%



Slowdown of Global Growth: Effect of Caching and CDNs ?

International Capacity Growth by Region

Recent Slowdown in Growth: 2011-13 Predicted vs Actual



Why the shortfall transatlantic:

Caching

Serving content from Europe

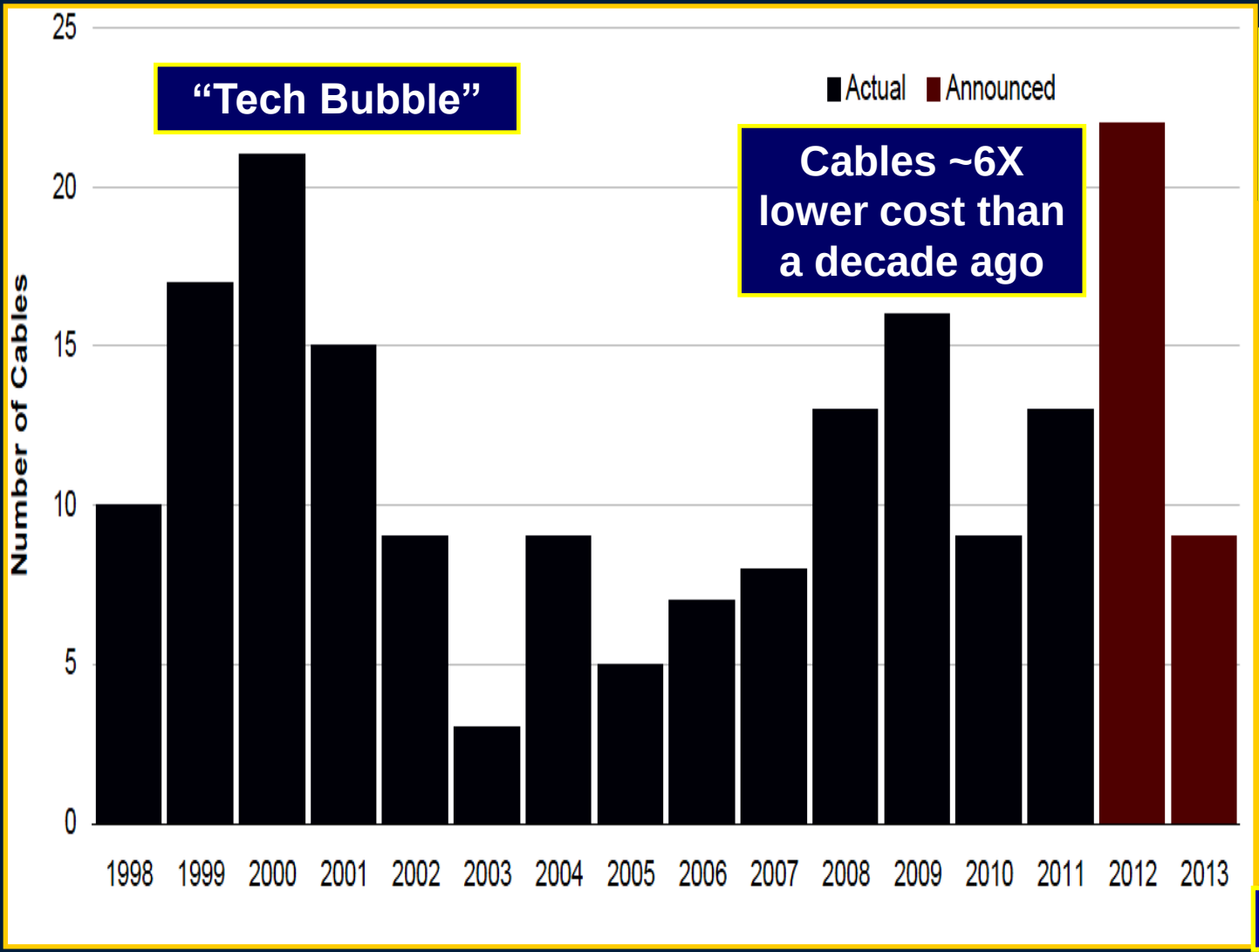
More peerings in Europe

"The pace will likely stabilize"

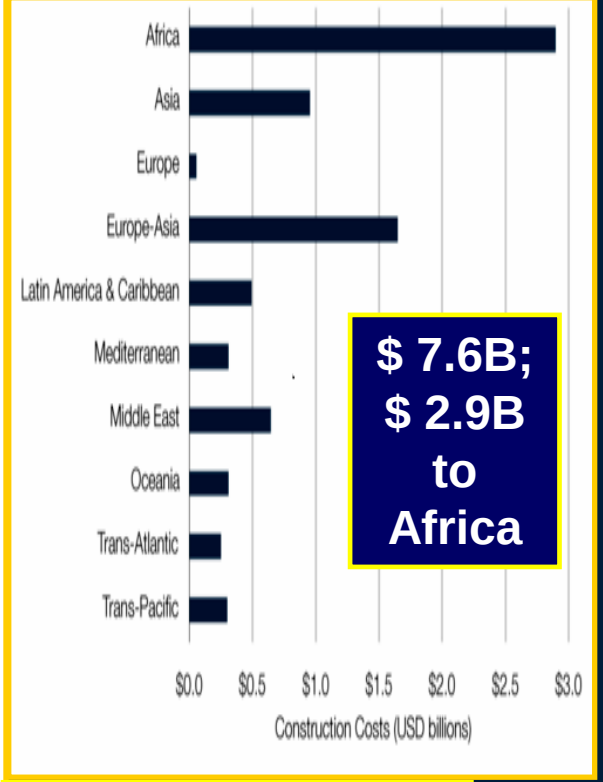
Telegeography

13 New Submarine Cables in 2011

30 Cables Planned in 2012-13



Construction Costs of New Cables Entering Service in 2012



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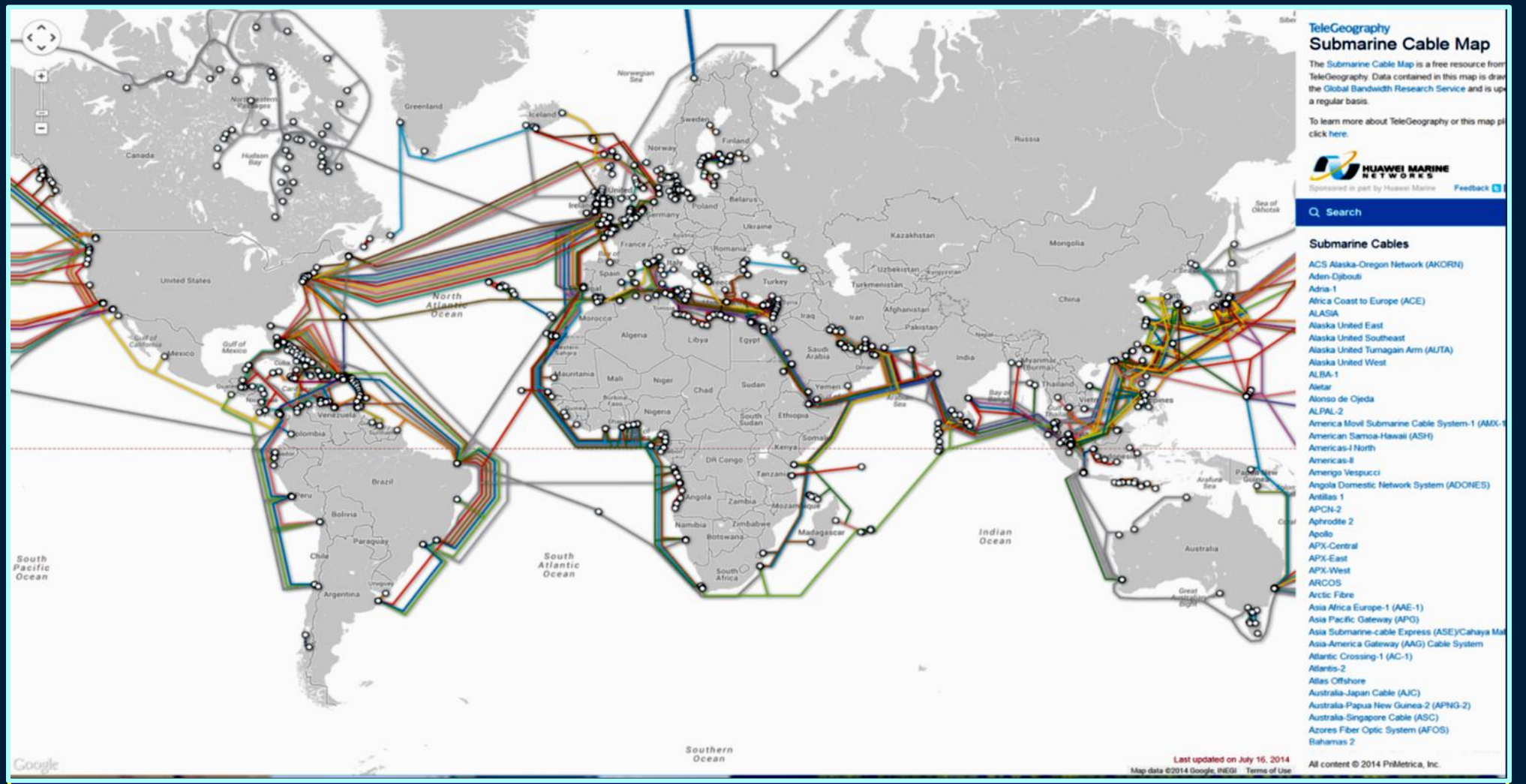
Undersea Cables 2014

264 In Service + 22 Planned



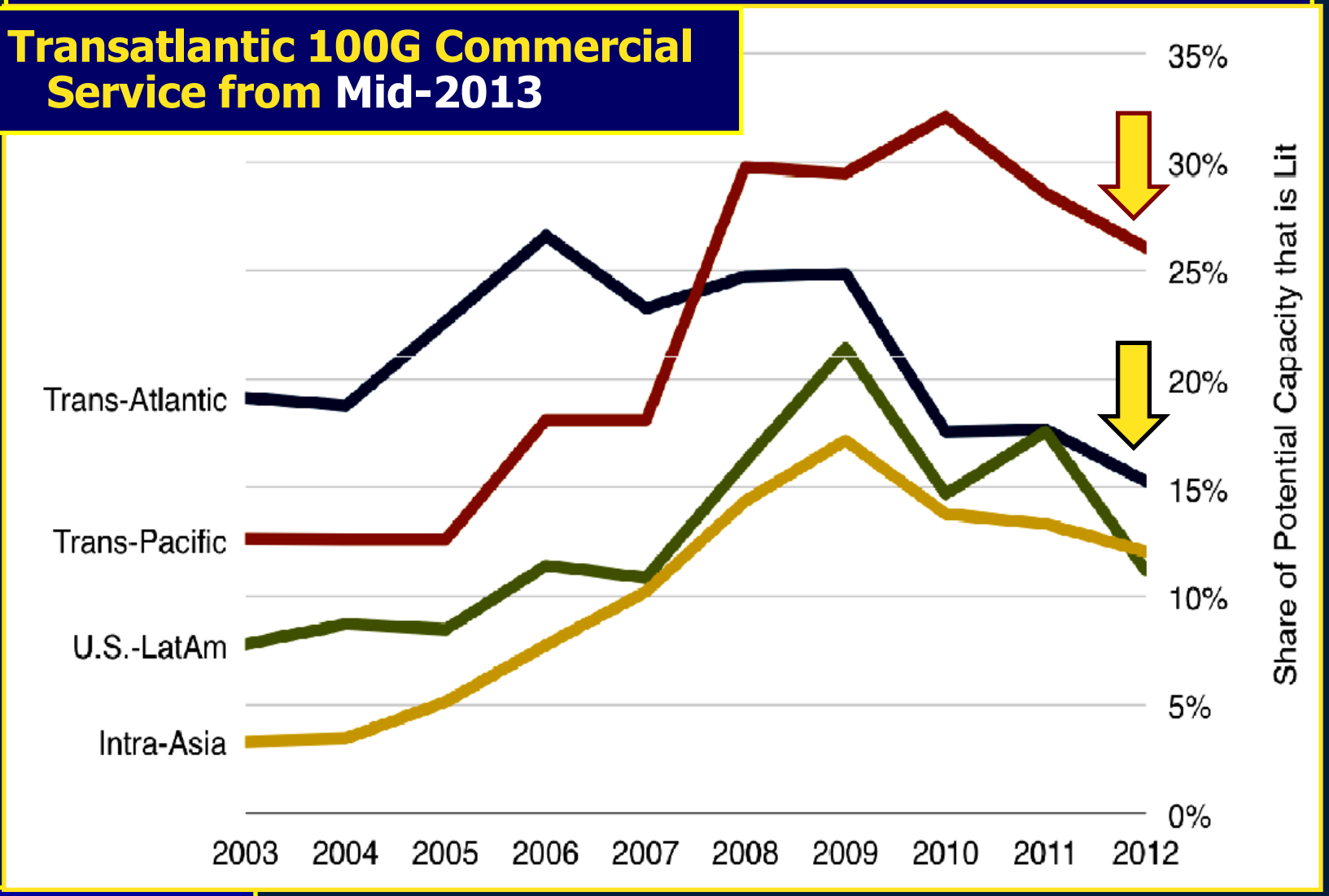
Telegeography 2014 Submarine Cable Map

Interactive Version: http://www.submarinecablemap.com/

Cable Capacity Exhaustion ?

Avoided by Start of 40G and 100G Link Services

First Transatlantic 100G Commercial Service from Mid-2013

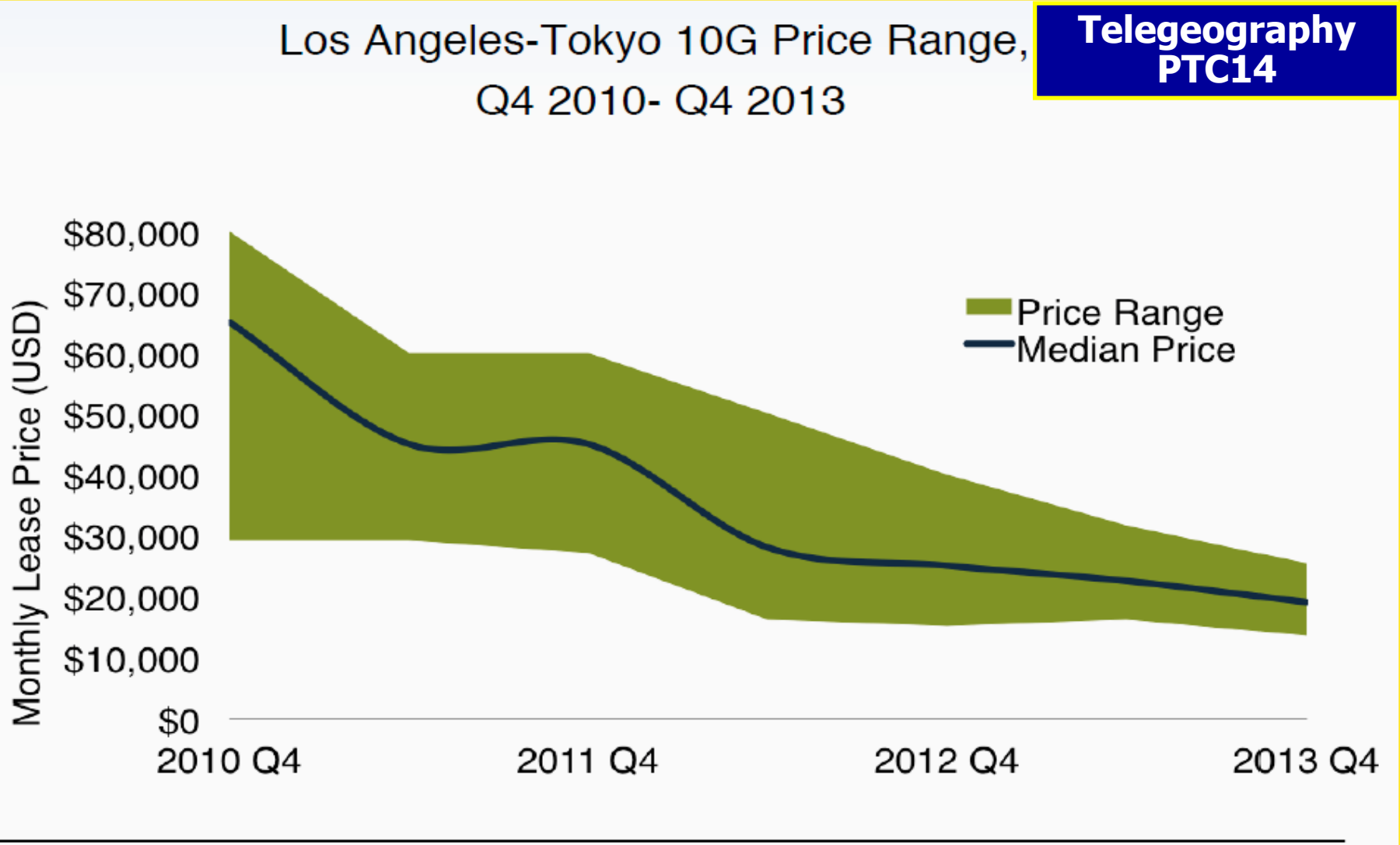


Telegeography

Bandwidth Pricing Trends

Unit Prices Continue to Fall

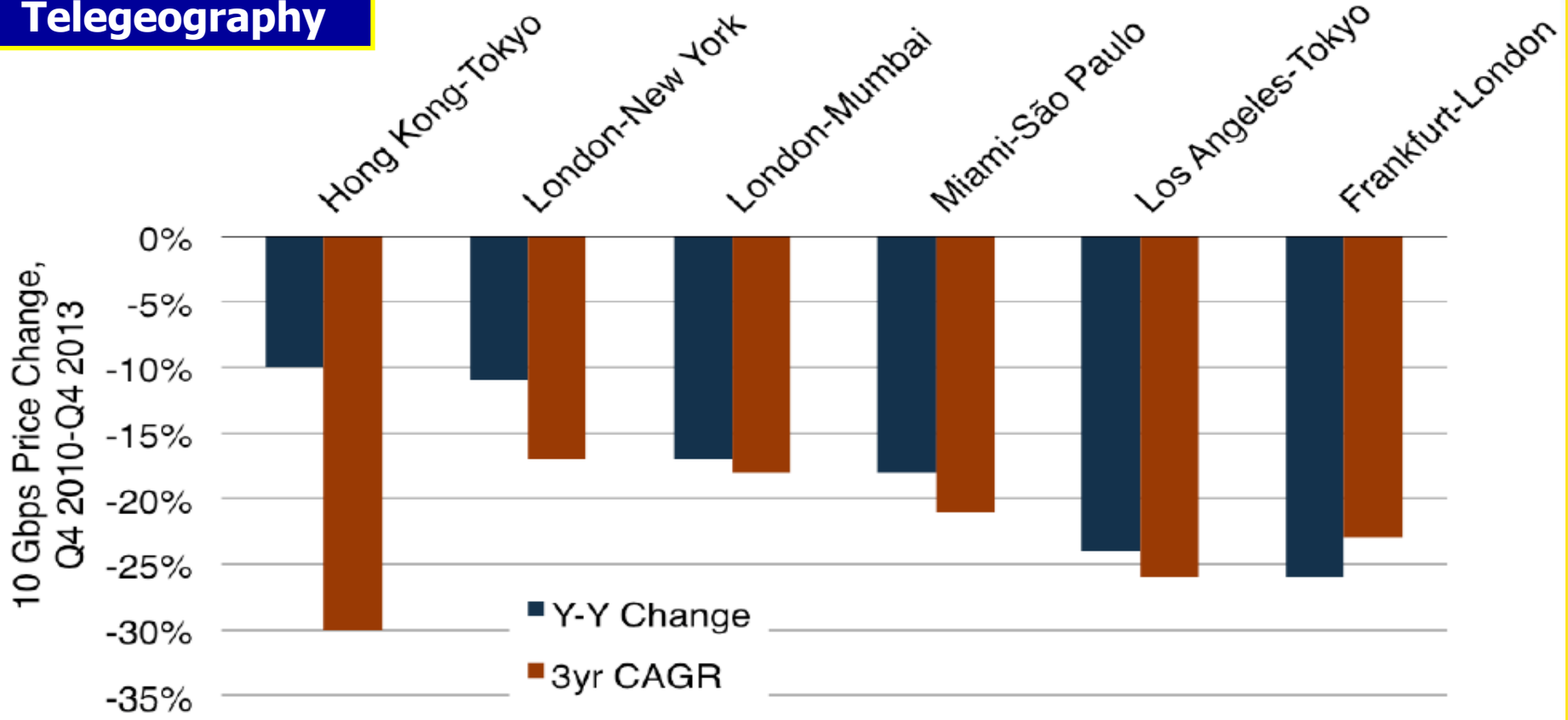
Telegeography PTC14



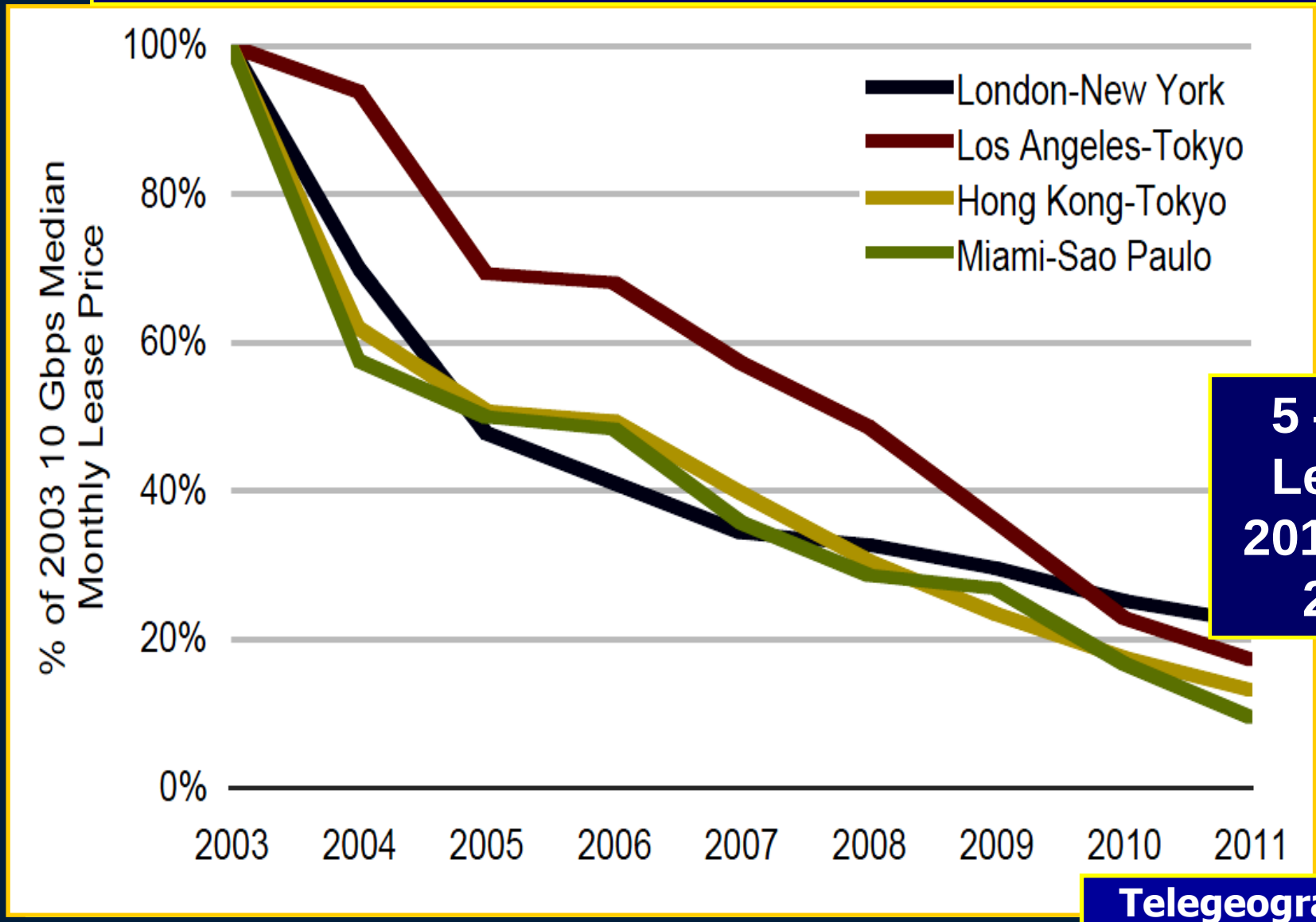
Rate of Price Decrease Varies by Region

-10-26% in 2013; -17-30% CAGR Since Q4 2010

Telegeography



Longer Term 10G Link Prices Decline 2003-11: Rate Varied by Region

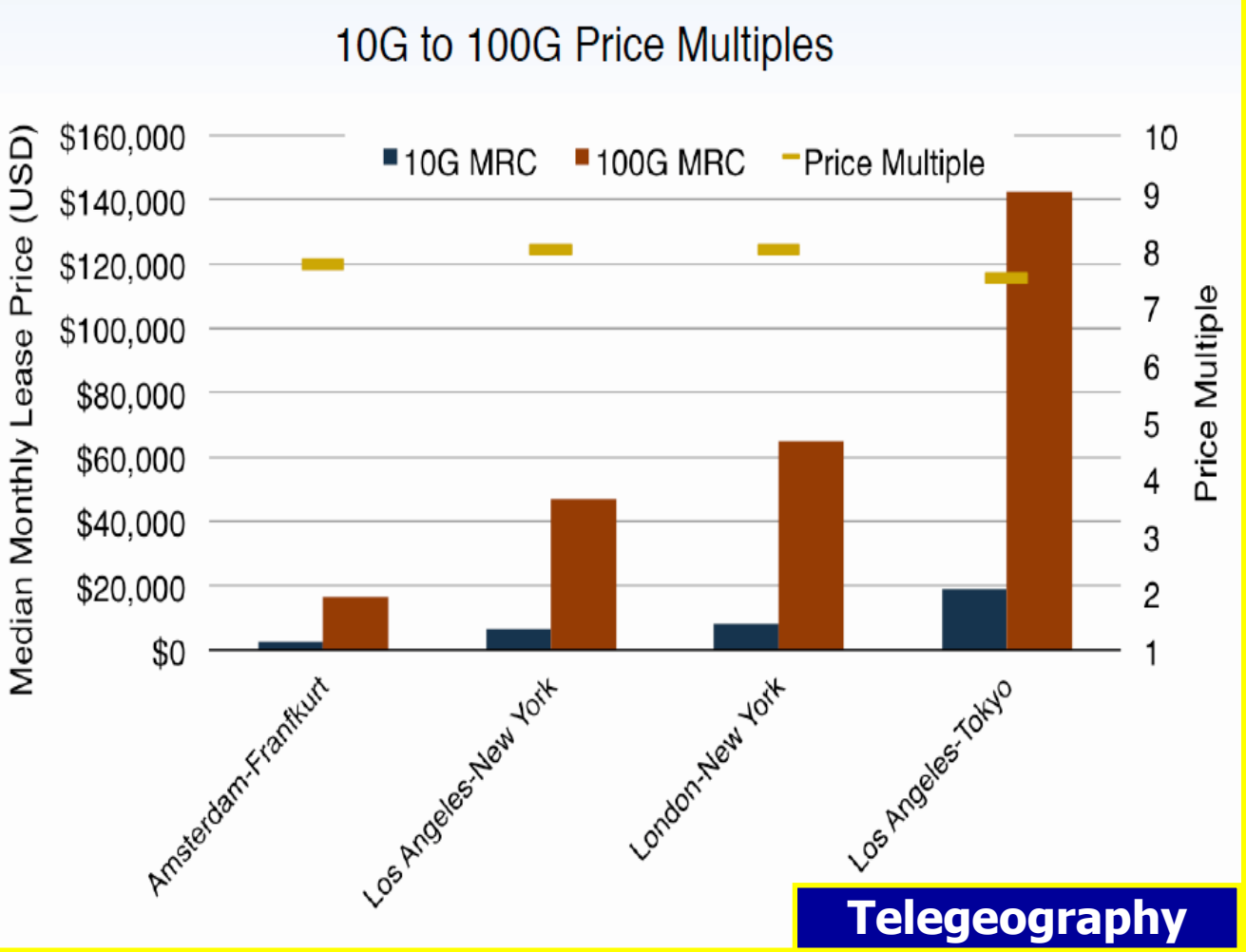


5 – 10X Less in 2011 than 2003

Telegeography

Emergence of 100G

10G to 100G Price Multiples on Major Routes



Telegeography

Typical Cost Multiple is Now 8.
Transition is Cost Effective at ~4

Major Backbones in US (Internet2, Esnet) and Europe (GEANT) Transitioned to 100G in 2012-13.

ANA-100 TA research link installed in 2013

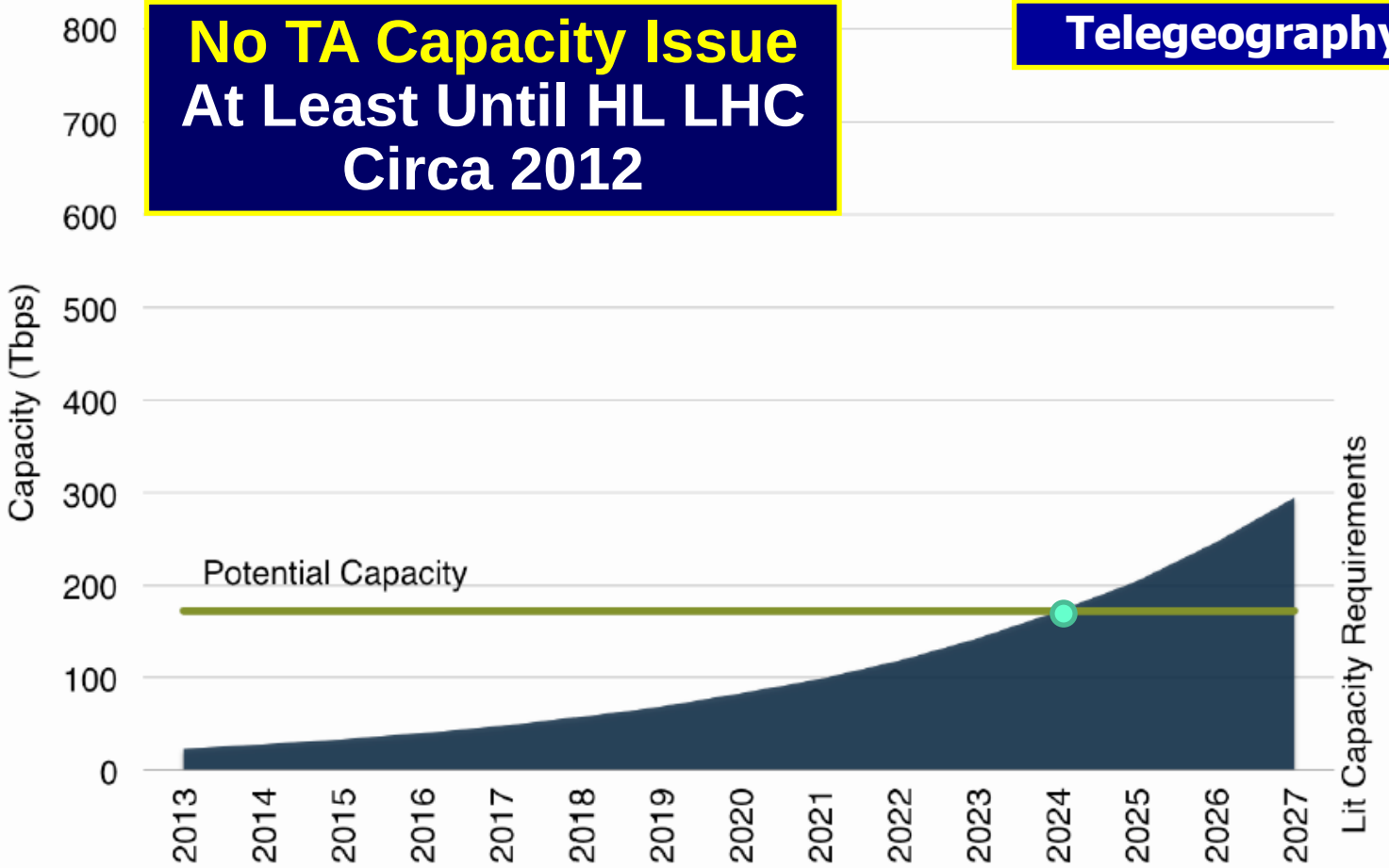
Expect TA Transition to 100G within the next 2-4 years

Transatlantic Capacity vs Requirements

As Currently Announced by Operators (January 2014)

No TA Capacity Issue
At Least Until HL LHC
Circa 2012

Telegeography



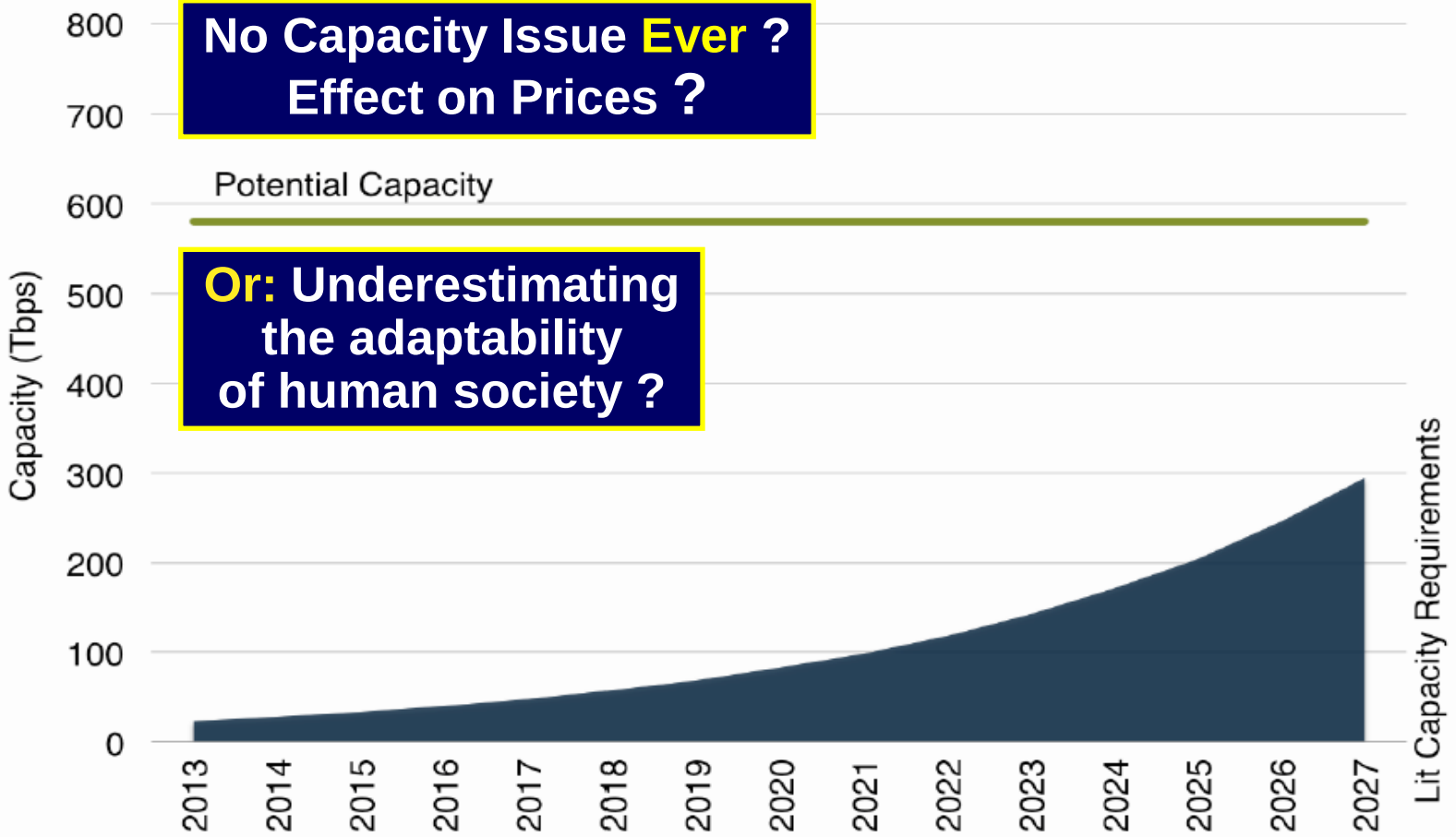
Notes: Estimates found in TeleGeography *Global Bandwidth Forecast Service*. Figures show demand vs. supply with no new cable construction.

TransAtlantic Capacity vs Requirements

If 100 X 100G Wavelengths Per Fiber Pair

No Capacity Issue Ever ?
Effect on Prices ?

Or: Underestimating the adaptability of human society ?



Notes: Estimates found in TeleGeography *Global Bandwidth Forecast Service*. Figures show demand vs. supply with no new cable construction.

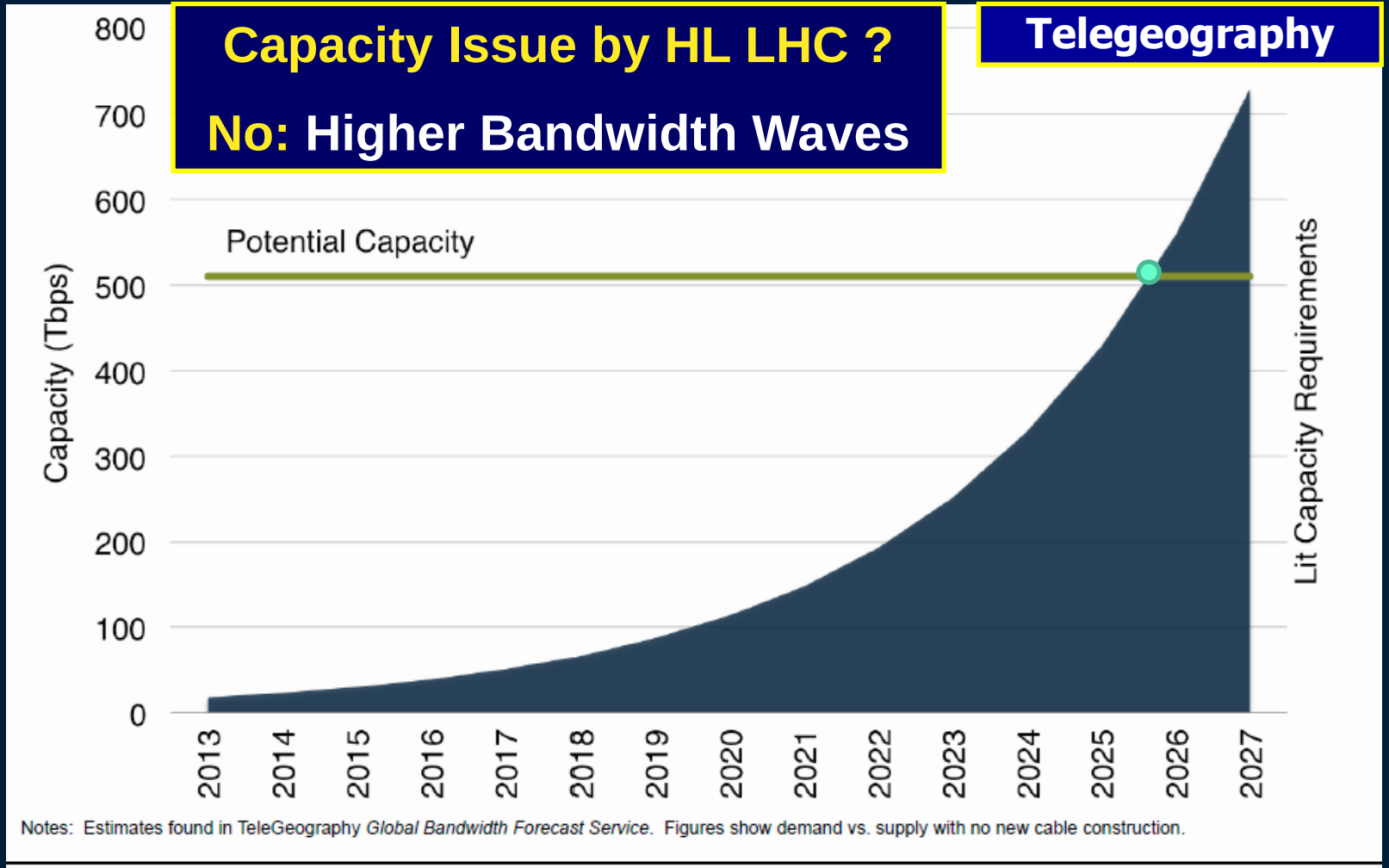
TransPacific Capacity vs Requirements

If 100 X 100G Wavelengths Per Fiber Pair

Capacity Issue by HL LHC ?

No: Higher Bandwidth Waves

Telegeography



Notes: Estimates found in TeleGeography *Global Bandwidth Forecast Service*. Figures show demand vs. supply with no new cable construction.