IEEE 802.3 Ethernet Working Group Communication

From: IEEE 802.3 Ethernet Working Group[1]

Subject: IEEE Industry Connections Ethernet Bandwidth Assessment

Date: 19th July 2012

Approval: Agreed to at IEEE 802.3 Plenary meeting, San Diego, 19th July 2012

During the IEEE P802.3ba 40Gb/s and 100Gb/s Ethernet project, it was observed that the bandwidth requirements for core networking and computing applications were growing at different rates, driving the need to develop the two new wireline Ethernet speeds. In order to maintain an ongoing understanding of the industry bandwidth trends, the IEEE 802.3 Ethernet Bandwidth Assessment Ad Hoc was created. The scope of this ad hoc was to focus on gathering information that would enable an assessment of the bandwidth needs for Ethernet wireline applications, including, but not limited to, core networking and computing.

The attached assessment is the culmination of the open 2011 industry assessment performed by the ad hoc. It includes a summary of the data brought forward by individuals throughout the Ethernet ecosystem. All contributed information is solely the perspective of the respective contributors. It should be noted that all submitted data should be considered a snapshot of the perceived bandwidth requirements at the time of submission.

Sincerely,

David Law

Chair, IEEE 802.3 Ethernet Working Group

<dlaw@hp.com>

[1]The views expressed in this document solely represent the views of the IEEE 802.3 Working Group, and do not necessarily represent a position of the IEEE, the IEEE Standards Association, or IEEE 802.

IEEE 802.3 BWA Ad Hoc Report, 19th July 2012

IEEE 802.3™ Industry Connections Ethernet Bandwidth Assessment

Prepared by the

IEEE 802.3 Ethernet Working Group

This is a report on the future bandwidth needs of Ethernet wireline applications.

This report can be found at the following URL:-

http://www.ieee802.org/3/ad_hoc/bwa/BWA_Report.pdf

Participants

The following individuals were officers and members of the IEEE 802.3 working group when this report was approved.

David J. Law, *IEEE 802.3 Working Group Chair*
Wael William Diab, *IEEE 802.3 Working Group Vice-Chair*
Adam Healey, *IEEE 802.3 Working Group Secretary*
Steven B. Carlson, *IEEE 802.3 Working Group Executive Secretary*
Valerie Maguire, *IEEE 802.3 Working Group Treasurer*

John D'Ambrosia, *IEEE 802.3 Industry Connections Bandwidth Assessment Ad Hoc Chair*
Pete Anslow, *IEEE 802.3 Industry Connections Bandwidth Assessment Ad Hoc Editor*

Abaye, Ali
Abbas, Ghani
Abbott, John
Allard, Michel
Amleshi, Peerouz
Anderson, Jon
Balasubramanian, Koussalya
Balasubramanian, Vittal
Baldwin, Thananya
Barnett, Barry
Barr, David
Barrass, Hugh
Beaudoin, Denis
Belopolsky, Yakov
Bennett, Michael
Bhatt, Vipul
Bhoja, Sudeep
Bliss, William
Booth, Brad
Boyd, Edward
Braun, Ralf-Peter
Breuer, Dirk
Brophy, Timothy
Brown, Alan
Brown, Kevin
Brown, Matthew
Bugg, Mark
Busse, Robert
Carroll, J. Martin
Chadha, Mandeep
Chalupsky, David
Chang, Frank
Chang, Fuhlim

Chen, Chung-Jue
Cheng, Wheling
Chou, Joseph
Choudhury, Golam
Cideciyan, Roy
Cole, Christopher R.
Cui, Kai
Dai, Eugene
Dawe, Piers
Diamond, Patrick
Diminico, Chris
Donahue, Curtis
Donnay, Beth
Dove, Dan
Dudek, Mike
Dwelley, David
Elbakoury, Hesham
Estes, David
Ewen, John
Farhoodfar, Arash
Flatman, Alan
Forbes, Harry
Frazier, Howard
Fu, Hongyan
Ganga, Ilango S.
Ghiasi, Ali
Giannakopoulos, Dimitrios
Goergen, Joel
Grimwood, Michael
Grow, Robert
Gundubogula, Sudhakar
Gustlin, Mark
Hajduczenia, Marek
Hamano, Hiroshi
Hammond, Bernie
Heath, Jeffrey
Hidaka, Yasuo
Hou, Victor
Huang, Xi
Irwin, Scott
Ishida, Osamu
Isono, Hideki
Iwadate, Hirotake
Jain, Rajeev
Jewell, Jack
Jiang, Hongtao
Jiang, Wenbin
Jimenez, Andrew
Kasturia, Sanjay
Kawatsu, Yasuaki
Kim, Yong
Kimmitt, Myles
King, Jonathan
Kipp, Scott
Kodama, Satoshi
Kolesar, Paul
Kolze, Tom
Kono, Masashi
Kosanovich, Keith
Kramer, Glen
Kvist, Bengt
Lackner, Hans
Lamb, Lowell
Larsen, Wayne
Latchman, Ryan
Laubach, Mark
Le Cheminant, Greg
Lewis, David
Li, Mike Peng
Lingle, Robert
Liu, Alexander
Lusted, Kent
Lutz, Sharon
Maki, Jeffery J.
Mallette, Edwin
Marris, Arthur
Matsuda, Shougo
Mcclay, Phil
McCormack, Michael S.
Mcdermott, Thomas
McDonough, John
McNarney, Martin
Meghelli, Mounir
Mei, Richard
Meier, Wolfgang
Mellitz, Richard
Misek, Brian
Moeller, Merrick
Montreuil, Leo
Moore, Charles
Muller, Shimon
Nikolich, Paul
Nishihara, Susumu
Noll, Kevin
Nordin, Ronald
Northcott, Philip
Nowell, Mark
Ofelt, David
Ossman, Valy
Palkert, Tom
Panguluri, Sesha
Park, Jisang
Parthasarathy, Vasu
Patel, Pravin
Pepeljugoski, Petar
Pepper, Gerald
Perrie, Randy
Petrilla, John
Pimpinella, Rick
Powell, William
Prodan, Richard
Rabinovich, Rick
Rahman, Saifur
Ran, Adee
Remein, Duane
Ressl, Michael
Riani, Jamal
Salinger, Jorge
Salunke, Vineet
Sambasivan, Sam
Schmitt, Matthew
Searles, Shawn
Sela, Oren
Shanbhag, Megha
Shang, Song Quan
Shariff, Masood
Shellhammer, Stephen
Sheth, Siddharth
Shrikhande, Kapil
Slavick, Jeff
Solomon, Joe
Sommers, Scott
Sparrowhawk, Bryan
Sprague, Edward
St Peter, Matthew
Stassar, Peter
Sugawa, Jun
Suzuki, Ken-Ichi
Swanson, Steve
Szczepanek, Andre
Tawa, Katsuhisa
Tazebay, Mehmet
Teixeira, Antonio
Thompson, Geoffrey
Tracy, Nathan
Tremblay, Francois
Trowbridge, Stephen
Ulm, John
Umnov, Alexander
Vaden, Sterling A.
Valle, Stefano
Vanderlaan, Paul
Wagner, Robert
Wang, Zhong Feng
Warland, Tim
Warren, David
Winkel, Ludwig
Wong, Ching
Woodruff, Bill
Wu, Wendy
Zambell, Andrew
Zang, meiyan
Zeng, Li
Zhang, James
Zhao, Wenyu
Zimmerman, George
Zivny, Pavel

Contents

Executive summary

The release of this assessment completes a year-long effort by the IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc to provide an updated view of industry bandwidth trends impacting Ethernet wireline applications. Maintaining an ongoing understanding of bandwidth trends should be beneficial to a future higher speed study group, as the time necessary to develop this knowledge is significant, as evident by the effort exerted by this ad hoc.

This assessment builds upon the work of the 2007 IEEE 802.3 Higher Speed Study Group (HSSG), which observed that core networking and computing applications were growing at different rates. The bandwidth associated with core networking was observed, on average, to be doubling every eighteen months. On the other hand, the bandwidth capability associated with high volume x86 servers and computing applications, fueled by Moore's Law, was doubling every twenty-four months [1].

Input was submitted from eleven source presentations, which looked at a variety of application spaces including servers, data center networks, high performance computing, financial markets, carrier and cable operators, Internet exchanges, and the scientific community. In addition to the different application spaces, data on different geographical regions was also explored. This data can be thought of in two different manners: end-station applications, which initiated the transmission and receipt of the data, and network aggregation nodes.

The 2007 HSSG observed that the computing end-station application was growing at a slower pace than the aggregation networks. This ad hoc obtained data from multiple sources that indicated the continuation of the trend that the bandwidth requirements of aggregation nodes were growing at a faster rate than end-station applications. Furthermore, while there was a wide variation in aggregated bandwidth needs, the observed trend that the doubling every eighteen months on average of bandwidth requirements associated with core networking is still a reasonable approximation.

If the current trend continues, then this translates to an increase in traffic of a factor of 10 by 2015 compared to 2010 and by a factor of 100 by 2020. While this is the forecasted bandwidth capacity requirement, no assumptions regarding a given interface speed have been made by the ad hoc. Such bandwidth requirements might be serviced by a given higher interface speed or some parallel configuration of lower speeds. It is left to future standards activities to determine the best way to service these application spaces.

1. Abbreviations

This document contains the following abbreviations:

1GbE	1 Gb/s Ethernet
10GbE	10 Gb/s Ethernet
40GbE	40 Gb/s Ethernet
100GbE	100 Gb/s Ethernet
3D TV	three-dimensional television
BW	bandwidth
CAGR	compound annual growth rate
CMTS	cable modem termination system
DAC	digital-to-analog converter
DAS	direct attached storage
DOCSIS™	Data Over Cable Service Interface Specification
DS	downstream
EPON	Ethernet passive optical network
FCoE	Fibre Channel over Ethernet

HDTV	high-definition television
HHP	house-holds passed
HPC	high performance computing
HSSG	Higher Speed Study Group
I/O	input/output
IP	Internet Protocol
iSCSI	Internet small computer system interface
ISP	Internet service provider
IXP	Internet exchange point
LAN	local area network
LAG	link aggregation
LHC	Large Hadron Collider
LOM	LAN on motherboard
MAN	metropolitan area network
MSO	multi-system operator
NAS	network attached storage
NIC	network interface card
OEM	original equipment manufacturer
OTN	Optical Transport Network
P2P	peer-to-peer
PC	personal computer
PCIe	Peripheral Component Interconnect Express
QAM	quadrature amplitude modulation
RFOG	radio frequency over glass
SAN	storage area network
SMB	small and medium business
US	upstream
VOD	video on demand
WAN	wide area network
x86	a family of architectures based on the Intel® 8086 CPU

2. Introduction

During the 2007 incarnation of the IEEE 802.3 Higher Speed Study Group (HSSG), there was a significant amount of debate regarding whether two rates of Ethernet were needed. Multiple meetings and presentations were necessary to resolve this debate, and ultimately, it was agreed that core networking and computing applications were growing at different rates. The bandwidth associated with core networking was observed, on average, to be doubling every eighteen months, while the bandwidth capability associated with high volume x86 servers and computing applications, fueled by Moore's Law, was doubling every twenty-four months [1]. These observations, illustrated in Figure 1, drove the rate objectives for the two new wireline Ethernet speeds that were developed by the IEEE P802.3ba Task Force - 40 Gigabit Ethernet and 100 Gigabit Ethernet.

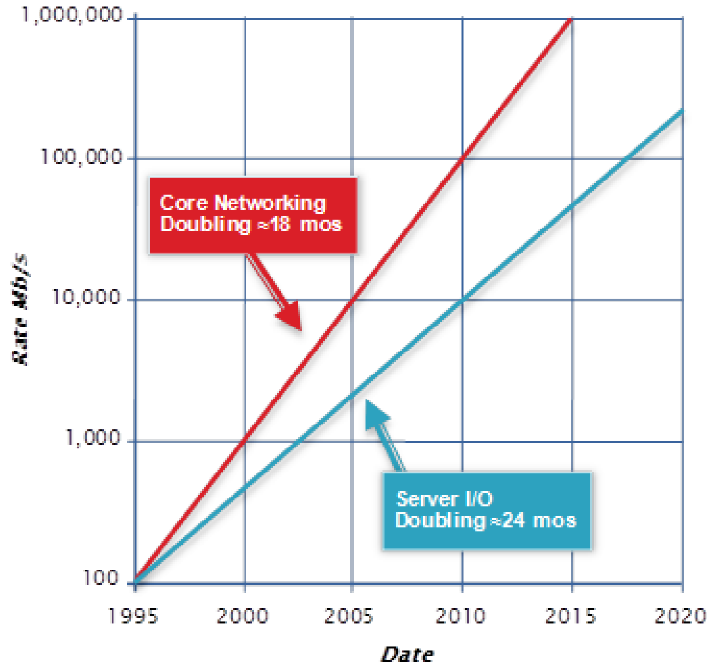

Figure 1—2007 IEEE 802.3 HSSG bandwidth demand projections

Looking ahead, the exponential growth cited by multiple end-users was such that they told the HSSG that work on the next speed of Ethernet needed to begin once 100 Gigabit Ethernet was completed [2], [3], [4]. This need is corroborated by the bandwidth growth rate for core networking illustrated in Figure 1, where 400 Gb/s is shown as needed by 2013 and 1 Tb/s is shown as needed by 2015. As “The Great Rate Debate” was a source of delay during the effort to develop the next rate of Ethernet beyond 10 Gb/s, it was realized that a pro-active effort to provide an updated view of industry bandwidth trends impacting Ethernet wireline applications would be beneficial to the Ethernet industry and future standards efforts targeting an Ethernet rate beyond 100 Gb/s. Thus, the IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc was created.

2.1 Overview

The IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc was formed in early 2011. Its scope was to focus on gathering information that would enable an assessment of the bandwidth needs for Ethernet wireline applications including, but not limited to, core networking and computing. The gathered information forms the basis for an assessment that can be used for future reference by an appropriate related standards activity. It should be noted that the role of this ad hoc was solely to gather information, and not make recommendations or create a call-for-interest for the next speed of Ethernet.

To gather this information, the ad hoc sought out contributions from individuals from various application areas and made a public request for information [5]. The following individuals presented their information to the ad hoc at various meetings and teleconferences throughout 2011:

- Scott Kipp, Brocade, “Data Center Bandwidth Scenarios” [6];
- Andy Bach, NYSE Euronext, “Bandwidth Demand in the Financial Industry - The Growth Continues”[7];

- Kimball Brown, LightCounting, “Server Bandwidth Scenarios - Signposts for 40G/100G Server Connections” [8];
- Tom Cloonan, Arris, “Bandwidth Trends on the Internet... A Cable Data Vendor's Perspective” [9];
- Scott Kipp, Brocade, “Storage Growth and Ethernet” [10];
- Mark Nowell, Cisco, “Cisco Visual Networking Index (VNI) Global IP Traffic Forecast Update; 2010 - 2015” [11];
- Petar Pepeljugoski and Paul Coteus, IBM, “Bandwidth needs in HPC taking into account link redundancy” [12];
- Xi Huang, Huawei, “Bandwidth Needs in Core and Aggregation nodes in the Optical Transport Network” [13];
- Henk Steenman, AMS-IX / Euro-IX, “The European Peering Scene” [14];
- Lone Hansen, BSRIA, “Global Data Centres Presentation IEEE” [15];
- Eli Dart, ESnet, “Data Intensive Science Impact on Networks” [16].

All contributed information is solely the perspective of the respective contributors.

2.2 Assessment limitations

Given the magnitude of the task, it is understandable that there were a number of limitations faced by the ad hoc during the course of this assessment:

- As approved, the duration of the Ad Hoc was for a maximum duration of 18 months [17]. This time duration placed a limit on the amount of data that could be gathered. This is countered, however, by the fact that the longer the duration of the information gathering, the more the data becomes dated and potentially inaccurate. It should be noted that all submitted information should be considered a snapshot of the perceived bandwidth requirements at the time of submission.
- Bandwidth forecasts based on past trends may not be an accurate predictor of future bandwidth requirements. Other influences such as, but not limited to, emerging bandwidth intensive applications, availability of technologies to support higher bandwidth needs, costs, and standardization efforts may have an impact on bandwidth requirements. Also, the potential inaccuracy in any forecasted data will grow the further out in time one looks.
- There are underlying assumptions regarding market adoption of technologies and the continuation of businesses and consumers utilizing applications (present, emerging, and yet to be developed) that require increasing bandwidth capabilities.

3. Key findings

3.1 Introduction

The following is a summary of the key findings from all contributed information. All contributed information is the sole perspective of the respective contributors. It should be noted that all submitted data should be considered a snapshot of the perceived bandwidth requirements at the time of submission.

3.2 Visual Networking Index

This section discusses the overall global IP network and the various trends within the network that are behind the on-going bandwidth explosion being seen throughout the network [11].

As noted in the 2007 IEEE 802.3 Higher Speed Study Group (HSSG) Tutorial [18], the bandwidth explosion everywhere was being driven by the increase in the number of users, increased access methodologies and rates, and increased services (such as, but not limited to, video on demand, social media, etc.). It was simplistically captured by Equation (1). While simplistic, this equation provides a meaningful way to understand the underlying forces driving the never-ending bandwidth explosion networking has been experiencing.

$$\text{Increased no of users} \times \text{Increased access rates and methods} \times \text{Increased services} = \text{Bandwidth explosion} \qquad (1)$$

Globally, the number of Internet users is forecast to increase from 1.9 billion users in 2010 to 3 billion Internet users in 2015. Table 1 breaks down these numbers by region.

Table 1—2015 Regional forecast of users and connections

Region	Internet users (million)	Network connections (billion)
North America	288	2.2
Latin America	260	1.3
Western Europe	314	2.3
Central/Eastern Europe	201	0.902
Asia Pacific	1330	5.8
Japan	116	0.727
Middle East & Africa	495	1.3

The number of Internet users alone is insufficient information, as a single end-user may have multiple types of devices. It is forecast that in 2015 there will be nearly 15 billion fixed and mobile networked devices and machine-to-machine connections. The increase in the number of consumer broadband devices affects bandwidth in a number of ways. It enables a consumer to be continuously consuming bandwidth, as well as to be consuming bandwidth on multiple devices simultaneously. Also, different consumer broadband devices enable different applications, which may have greater traffic generation capability. For example, Table 2 compares the amount of traffic on a fixed network that newer, next-generation devices will create, using the traffic created by a 32-bit laptop as a baseline [11].

In addition to these increases, a 4 times increase in fixed broadband speeds is forecast for 2015, as the average fixed broadband speed of 7 Mb/s in 2010 is expected to rise to 28 Mb/s in 2015 [19]. Table 3 tabulates the growth of average broadband speeds for the 2010 to 2015 time period [11].

These forecasts are all for average fixed broadband speeds. However, in 2015 68 % of all broadband connections are forecast to be at least 5 Mb/s, 40 % will be at least 10 Mb/s, and 3 % will be at least 100 Mb/s [11].

Table 2—Fixed network traffic generation comparison

Device	Traffic multiplier
Tablet	1.1
64-bit Laptop/PC	1.9
Internet enabled HDTV	2.9
Gaming console	3.0
Internet enabled 3D TV	3.2

Table 3—Growth of broadband speeds by region

Region	2010 (Mb/s)	2015 (Mb/s)	Growth factor
North America	7.5	27	3.7
Latin America	2.8	8	2.9
Western Europe	9.2	36	3.9
Central/Eastern Europe	6.1	20	3.3
Asia Pacific	5.5	25	4.6
Japan	15.5	64	4.1
Middle East & Africa	2.8	7	2.5

As described in Equation (1) with the increase in access capabilities and applications, one would expect increased bandwidth usage. This expectation is observed by various forecasts [11]:

- Traffic per average Internet user will grow from 7.3 gigabyte per month to 24.8 gigabyte per month
- Traffic per average Internet household will grow from 17.1 gigabyte per month to 61.8 gigabyte per month
- Global consumer Internet traffic / applications will have a 34 % compound annual growth rate (CAGR) from 2010 to 2015 and reach nearly 60 exabytes per month. (1 exabyte is 10^{18} bytes.)
- Consumer Internet video will experience a 48 % CAGR from 2010 to 2015 and reach approximately 35 exabytes per month.
- Internet video (including video calling) will increase from 40 % to approximately 61 % of all consumer Internet traffic [19].

Taking all of these trends into consideration, it is forecast that from 2010 to 2015 global IP traffic will experience a 4-fold increase from 20 exabyte per month in 2010 to 81 exabyte per month in 2015, a 32 % CAGR. Table 4 provides a breakdown of predicted IP traffic for 2015 by region [11].

Mobile data will experience a 92 % CAGR between 2010 and 2015, but still only account for 7.77 % of the overall traffic in 2015. Fixed/Wired will experience a 24 % CAGR during the same period, and account for 46.1 % of the overall traffic in 2015. Finally, Fixed/Wi-Fi® will experience a 39 % CAGR over this period, and account for 46.2 % of all traffic. Figure 2 summarizes the global IP traffic by local access technology [11].

Table 4—2015 Regional IP traffic forecast

Region	IP Traffic (exabyte/month)	Growth factor since 2010 (CAGR)
North America	22.3	3 x (26 %)
Latin America	4.7	7 x (48 %)
Western Europe	18.9	4 x (32 %)
Central/Eastern Europe	3.7	5 x (39 %)
Asia Pacific	24.1	4 x (35 %)
Japan	4.8	3 x (27 %)
Middle East & Africa	2.0	8 x (52 %)

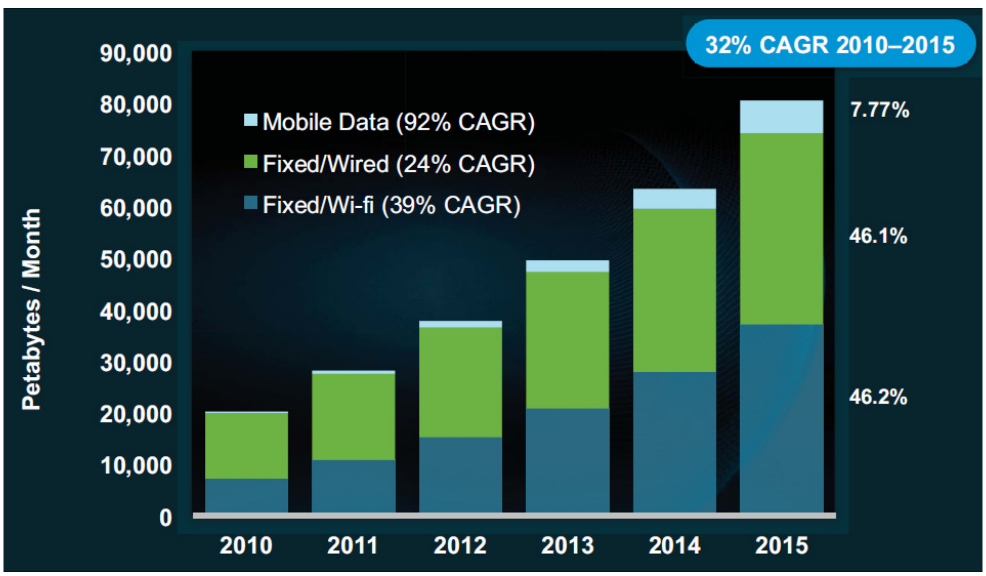

Figure 2—Global IP traffic by local access technology

3.3 Storage growth

The total amount of data created or replicated on the planet in 2010 was over 1 zettabyte (1 zettabyte is 10^{21} bytes) - that's 143 GB for each of the 7 billion people on the planet [10].

According to the "Digital Universe" study [10], stored data is growing at 40 % to 50 % per year (i.e., doubling every two years) compared to IP traffic growth of 30 % to 40 % per year. While 75 % of this data is created by individuals, enterprises have some responsibility for 80% of it at some point in its life. 25 % of data is generated by machines and that is growing fast with sensors and remote monitoring on the increase.

Over the next decade, the number of servers (physical and virtual) is expected to grow by a factor of 10, storage is expected to grow by a factor of 50 (see Figure 3) and the number of files is expected to grow by a factor of 75 [10].

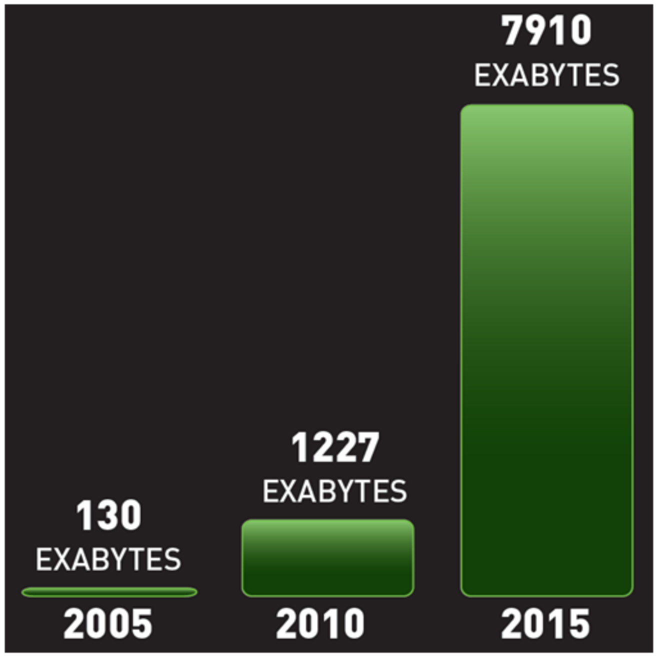

Figure 3—Storage growth

One example of a large data source is the Large Hadron Collider [10] which generates 15 petabyte of data per year (1 petabyte is 10^{15} bytes) which is then replicated at 11 Tier 1 storage sites around the world (150+ petabyte of storage) and partially replicated at a further 160 Tier 2 sites requiring an additional 150+ petabyte of storage per year.

There are a number of ways to access storage from the network [10] as shown in Figure 4.

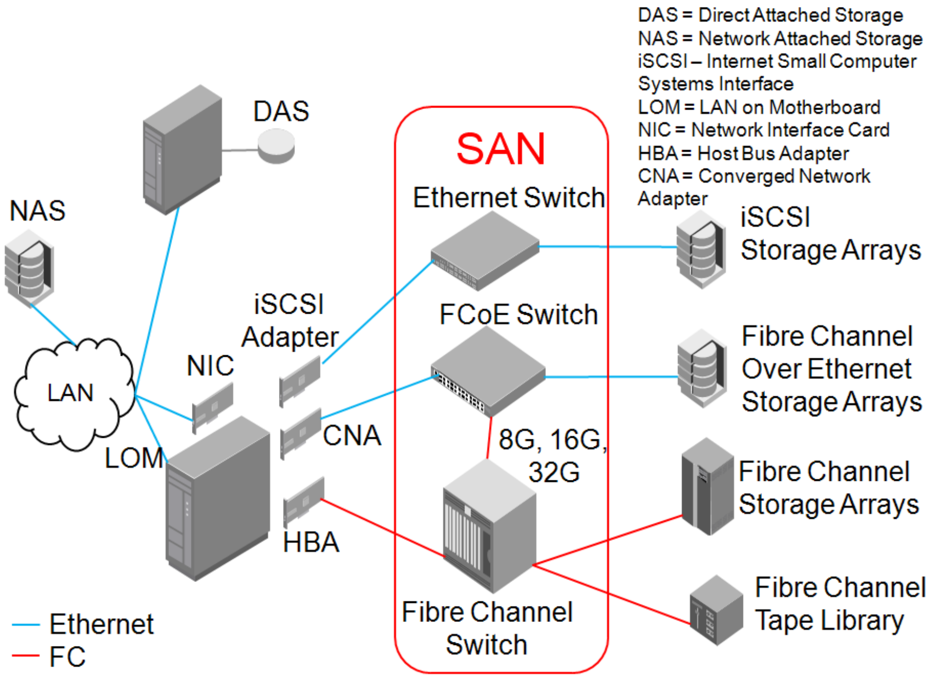

Figure 4—Storage access arrangements

External storage sales was about 17 exabyte in 2011 and is projected to grow to about 90 exabyte in 2015 (About 1 % of the digital universe as shown in Figure 3). Ethernet-based storage is expected to grow to over 50 % of storage capacity in 2015 [10]. See Figure 5.

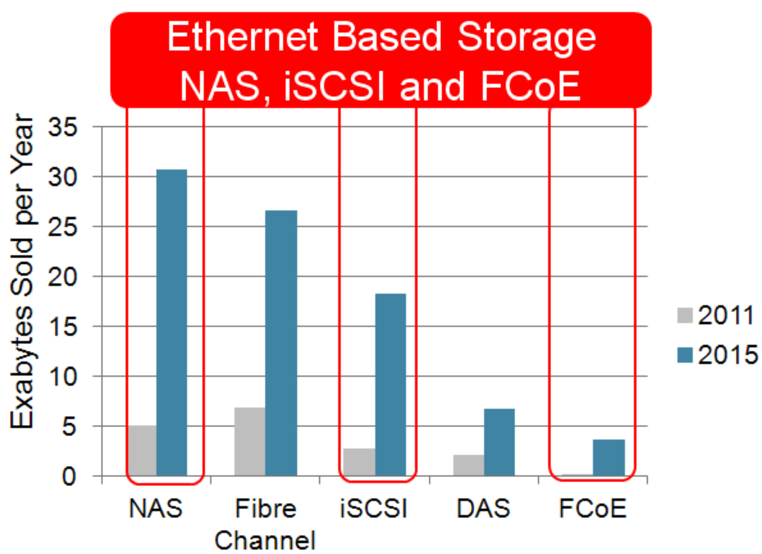

Figure 5—Ethernet based storage growth

Some discernible trends in storage are [10]:

- Application migration benefits from networked storage compared to direct attached storage;
- Cloud computing requires major data moves;
- Virtual Desktop Infrastructure (VDI) leads to centralized storage and increased network traffic;
- Solid State Drives (SSDs) or flash storage leads to higher bandwidth demands on the network.

Cloud computing offers the vision of hosting and scaling applications from the data center to the cloud provider or another data center on demand [10]. To enable this transition, the data needs to be exchanged or mirrored from the primary data center to the cloud provider or secondary data center first. See Figure 6.

From the total storage of 7.9 zettabyte projected to be needed in 2015, 0.8 zettabyte (10 %) is expected to be in maintained in a cloud and 1.4 zettabyte (20 %) is expected to be "touched" by cloud computing service providers [10].

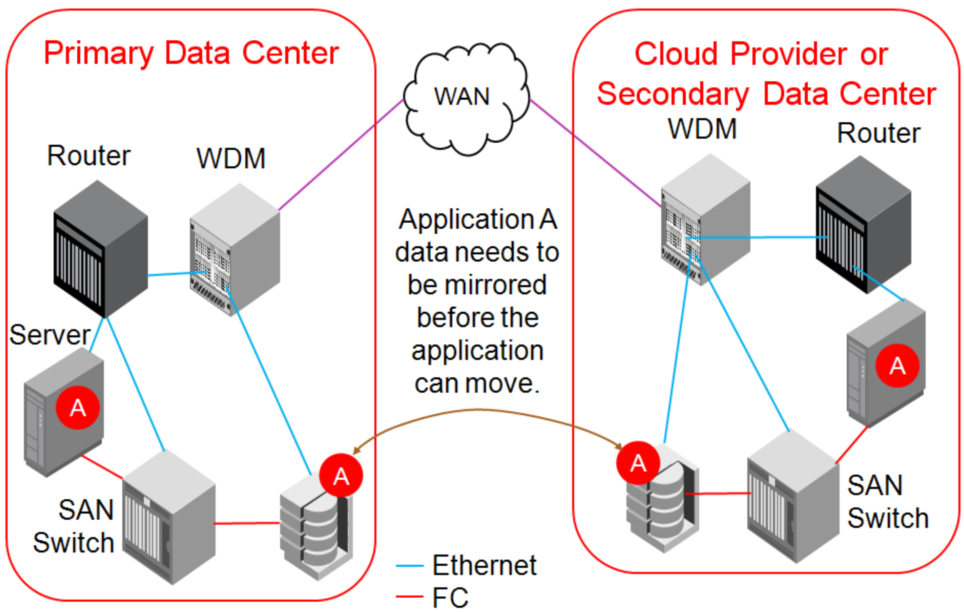

Figure 6—Data mirroring between storage arrays

Virtual Desktop Infrastructure (VDI) as depicted in Figure 7 enables centralized management and simple upgrades to software and applications at the expense of an increase in LAN traffic [10].

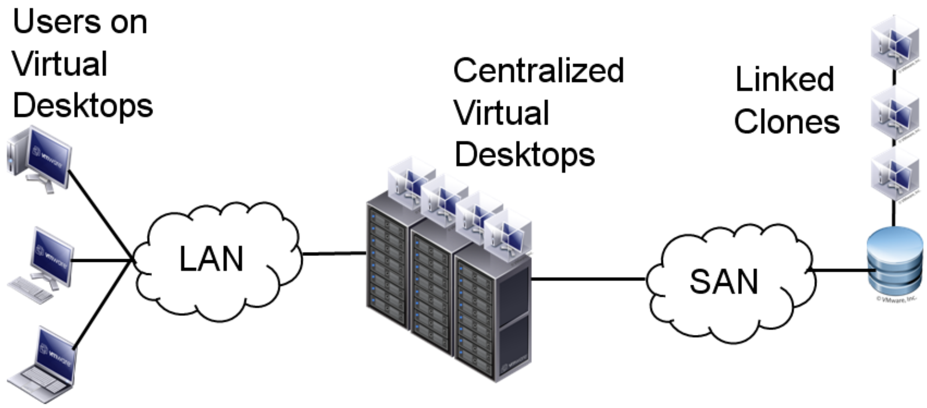

Figure 7—Virtual desktop infrastructure architecture

3.4 Data center

3.4.1 Server bandwidth scenarios

This section will cover information related to server bandwidth scenarios [8].

Today, 90 % of server units in the market are based on the x86 architecture. Figure 8 shows LightCounting's forecast of the transition of 1GbE server ports to 10GbE server ports. In 2011 10GbE server ports account for about 17 % of the total, but this is forecast to grow to 59 % in 2014.

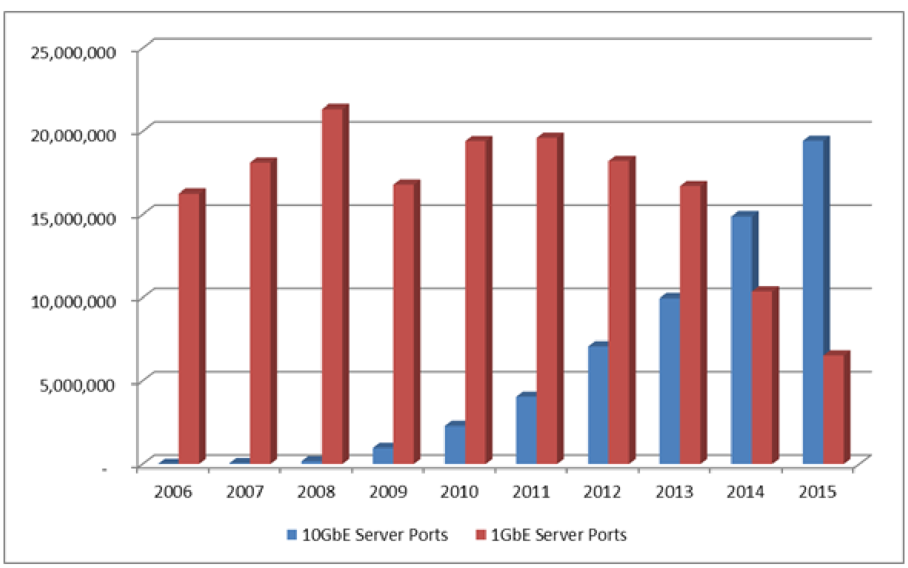

Figure 8—LightCounting forecast: server transition, 1GbE to 10GbE

This growth is fueled by the capabilities of PCIe (Peripheral Component Interconnect Express). Table 5 tabulates the total bandwidths (both directions) for the different generations of PCIe and Figure 9 plots the PCIe bandwidth (both directions) for x8 links by generation.

Table 5—PCIe bandwidth (both directions)

	Link width				
	x1	**x2**	**x4**	**x8**	**x16**
PCIe 1.x (gigabyte/s)	0.5	1	2	4	8
PCIe 2.x (gigabyte/s)	1	2	4	8	16
PCIe 3.0 (gigabyte/s)	2	4	8	16	32

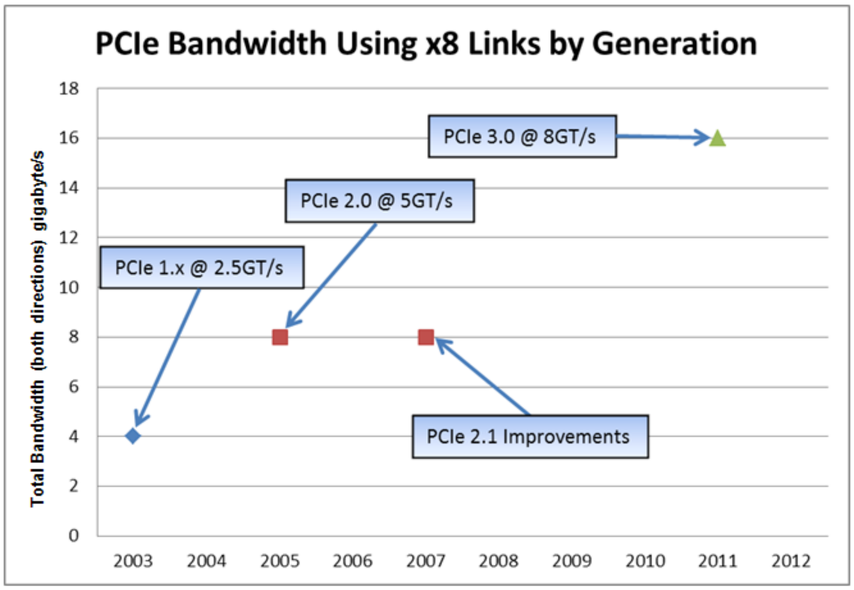

Figure 9—PCI Bandwidth by generation

From an Ethernet perspective, PCIe 3.0 can support 40 Gb/s in a x8 configuration. It is anticipated that the next generation of PCIe will support 100 Gb/s in a x8 configuration, but the future of PCIe was unknown at the time of writing this assessment. It was suggested that PCIe 4.0 would enable dual 100GbE server ports starting in 2015 [8].

A view of how the I/O bandwidth for servers is expected to grow over the next few years is shown in Table 6. This perspective is based on three definitions of classes for servers:

- Free: A large portion of server buyers will only implement what is offered as the base configuration. These buyers would choose the "Free" option.
- Performance: Users who demand more I/O performance due to virtualization or, in some cases, the desire to converge the SAN and LAN networks within the rack.
- Fringe: Users who demand the most possible bandwidth. The servers that would need this bandwidth would typically be the high end 4 or 8 socket versions (translating into 40 or 80 cores in Intel's Romley cycle, and huge amounts of memory).

Table 6—Server interconnect scenarios

Year	Free	Performance	Fringe
2011	2 x 1GbE LOM	2 x 1GbE LOM n x 1GbE NIC	2 x 1GbE LOM n x 10GbE NIC
2012	2 x 1GbE LOM Option	2 x 10GbE LOM Option	2 x 10GbE LOM Option n x 40GbE NIC
2014	2 x 10GbE LOM Option	2 x 10GbE LOM Option n x 10GbE NIC	2 x 40GbE LOM Option n x 40GbE NIC
2016	2 x 10GbE LOM Option	2 x 10GbE LOM Option n x 40GbE NIC	2 x 40GbE LOM Option n x 100GbE NIC

3.4.2 High performance computing

This section describes observations of bandwidth needs in high performance computing (HPC) [12].

During the 2006 IEEE 802.3 Call-For-Interest for a Higher Speed Ethernet Study Group, it was observed that during the period of 1993 to 2005 performance, as measured by average gigaflops per second, had proceeded in a very predictable linear manner for High Performance Computing: every four years corresponded to a 10x leap in processing power [20]. See Figure 10.

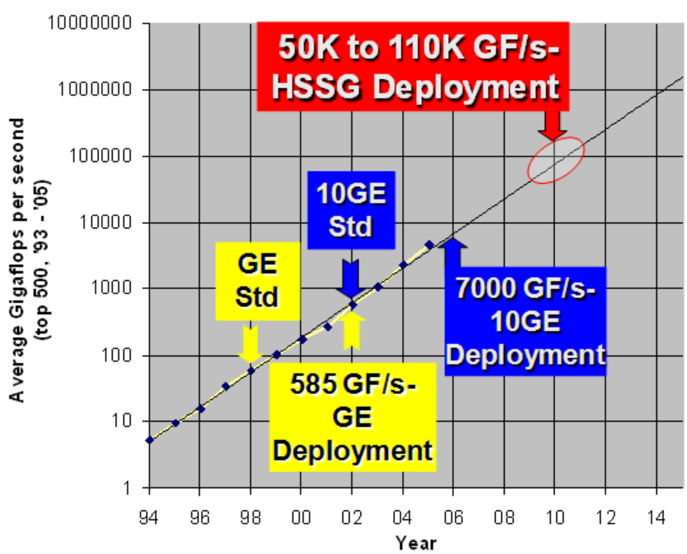

Figure 10—Observed HPC performance trend from 2006 HSSG CFI

At this point in time, the US government is targeting an exascale machine by 2019, which is more than two orders of magnitude in performance improvement over today's fastest machines [12].

While single line data rates are anticipated to increase, it is not anticipated that they will grow by a corresponding two orders of magnitude in performance, hence it is anticipated that increased parallelism will be necessary to meet the performance requirements for system interconnects in order to meet the necessary performance targets.

Current Ethernet link technologies do not employ lane redundancy. There is a concern that the use of increased parallelism will make these links more vulnerable to failure. Failure analysis indicates an unacceptable number of single fiber fails for a typical HPC/server environment.

It has been suggested by the authors that at least 400 Gb/s will be needed for future HPC/server environments. It has also been suggested that investment in extra bandwidth for lane redundancy is also necessary.

3.4.3 Data center bandwidth scenarios

This section discusses potential bandwidth scenarios by looking at different server configurations and then looking at the bandwidth throughout the data center network [6].

Four types of intra / inter cluster traffic were identified: 1) Within a rack; 2) Between racks; 3) Cluster-to-cluster; and 4) Server-to-link. Their characteristics are defined in Table 7.

Table 7—Types of communication

	No of switches	Latency (No of switches)	No of links	Reach
Within a rack	1	1	2	Few meters
Between racks within a cluster	3	3	4	< 100 m
Cluster to cluster	5+	5+	6	100’s of m
Server to Internet	3+	3+ plus router	4+	100’s of m

The bandwidth to and from rack switches, based on various I/O capabilities per server, number of uplinks, and different subscription rates is tabulated in Table 8.

The bandwidth of a cluster will then depend on the number of racks within a given cluster. For example, a 40 server rack might produce anywhere from 0.4 to 3.2 terabit per second (Tb/s). A cluster, consisting of twenty-five of these racks, would produce 10 to 80 Tb/s. Typically, there is a high oversubscription rate to the wide area network (WAN), as illustrated in Table 9. High oversubscription rates occur because users don't perceive a need for 1:1 subscription and won't pay for it.

3.4.4 Global data centers

This section covers the findings of an international survey conducted by BSRIA [15]. The scope of the online survey included individuals from the United States, United Kingdom, Germany, France, India, and China in the following sectors:

- Government (federal, military, state, and local)
- Finance and insurance
- Healthcare (and pharmaceutical)
- Education (primary, secondary, and universities)
- Professional and information services
- Co-location, co-hosting, and carrier hotels.

Table 8—Bandwidth to / from rack switches

	I/O per server (Gb/s)				
	5	10	20	40	80
Servers / rack	40	40	40	40	40
Bandwidth / rack (Gb/s)	200	400	800	1600	3200
10GbE uplinks with 1:1 subscription	20	40	80	160	320
40GbE uplinks with 1:1 subscription	5	10	20	40	80
100GbE uplinks with 1:1 Subscription	2	4	8	16	32
10GbE uplinks with 4:1 subscription	5	10	20	40	80
40GbE uplinks with 4:1 subscription	1.25	2.5	5	10	20
100GbE uplinks with 4:1 subscription	0.5	1	2	4	8

Table 9—Oversubscription to WAN

	Bandwidth cluster to core (Tb/s)			
	0.4	1	2	4
Clusters	10	10	10	10
Bandwidth to core (Tb/s)	4	10	20	40
Bandwidth to WAN (Gb/s)	20	40	200	400
Oversubscription to WAN	200	250	100	100

Figure 11 illustrates the speeds deployed within the surveyed data centers in 2011 and what is expected in 2013. The trend towards higher speed links and away from the lower speeds is noticeable. This is also noticeable in Figure 12, which is broken out to the Finance, Government, and Health sectors.

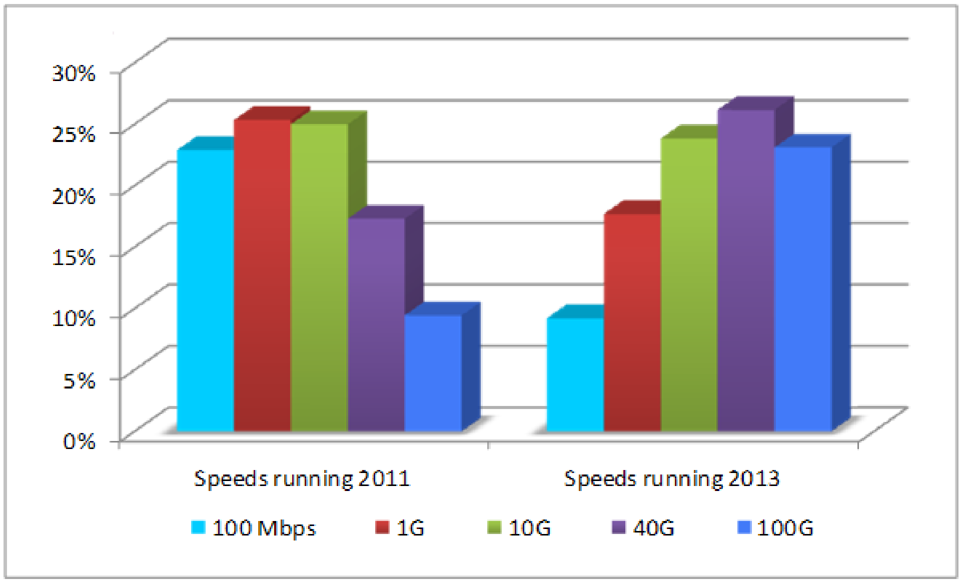

Figure 11—Data center study - percentage of links by speed

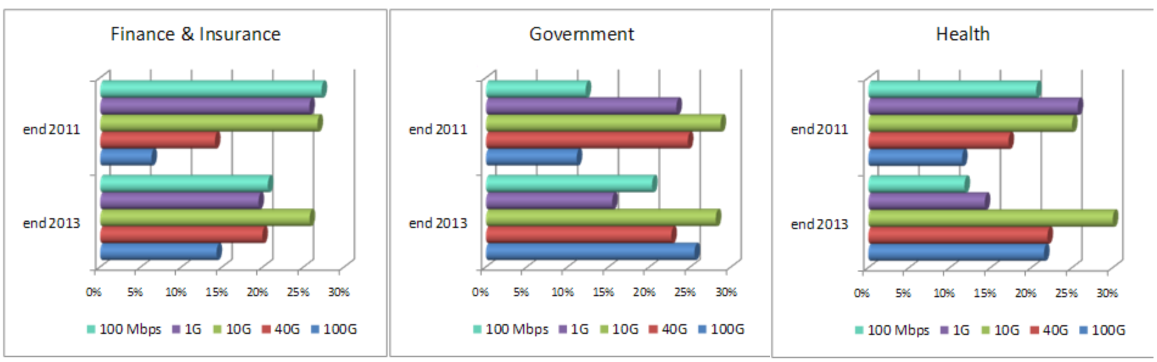

Figure 12—Speeds in finance, government, and health

Table 10 provides insight into deployed media on a per speed basis. Details regarding the information in Table 10 are not available for further exploration.

Table 10—Media deployment

Media	10 G	40 G	100 G
Over copper point-to-point links	33 %	11 %	11 %
Over copper structured cable	26 %	38 %	23 %
Over OM3 / OM4 multimode fiber cable	25 %	29 %	41 %
Over single-mode fiber cable	13 %	21 %	20 %

3.5 Data intensive science

Modern science is becoming increasingly dependent on high speed data networks and is generating ever increasing amounts of traffic [16].

Perhaps the best known example of this is the Large Hadron Collider (LHC) at CERN. The ATLAS detector alone generates very large data sets (transfers of tens of terabytes are routine) with automated data distribution to two tiers of storage sites [10] over multiple continents.

The ATLAS detector generates ~1 petabyte per second from the instrument (1 petabyte is 10^{15} bytes) and a multi-stage trigger farm reduces this to ~200 to 400 megabyte/s with additional data from event reconstruction. This data is then distributed to multiple international collaborating organizations via 10 to 40 Gb/s links out to large repositories in Europe, North America, and Asia as well as 5 to 10 Gb/s links to analysis centers worldwide [16]. This will increase over time as the LHC is upgraded.

A second example data source is genome sequencing [16]. While this field is clearly in its infancy, a significant increase in the data it is generating can already be seen. This increase is coming from two directions:

- Per-instrument data rate is increasing significantly (~10x over 5 years)
- Cost of sequencers is plummeting (10x over 5 years) – Human genome sequencing cost $10,500 in July 2011 from $8.9 million in July 2007 – NYTimes

The use of genomics (and hence the need to transfer genomics data) is expanding very rapidly as the science improves and new applications are discovered.

Many of the instruments used in basic science research are essentially high-resolution digital cameras and the data rates from these instruments are increasing with the capabilities of the instruments [16]. Some instruments in development will be able to collect terabits per second of data internally but there is not enough I/O capability on the chip to get all the data out so some level of on-chip data reduction will be required. Transfer or streaming of the resulting data to computing resources will then be necessary. This is typically at about 2.5 Gb/s today, but with a significant growth curve going forward.

An example of a new experiment that is currently under development is the Square Kilometer Array (SKA) [16]. This is a very large radio telescope in the southern hemisphere with approximately one square kilometer of combined signal collection area. This will have ~2800 receivers in the telescope array with most receivers within a 180 km diameter area. There is an average run of about 100 km to the central correlator which receives about 2 petabytes of data per second. Data will then be distributed to international collaborators with an expected rate of about100 Gb/s from the correlator to other analysis centers worldwide. Other experiments that are likely to generate large amounts of data include sensor networks, ITER, etc.

The very structure of modern science assumes there is a network interconnecting all parts of the collaboration [16]. Large, unique facilities (e.g. LHC, SKA, ITER) provide a focus for all members of a field with data distributed to scientists and analysis results distributed among collaborators. Data analysis using local resources also drives data movement. For example, a large simulation run at a supercomputer center followed by secondary analysis at home institution. The modern trend is towards large data sets with increasing scope for collaboration over analysis where scientific productivity is gated on data analysis. In the general case both data moved to analysis and analysis moved to data must be supported.

The Energy Sciences network (ESnet) provides a data network that links scientists at national laboratories, universities and other research institutions. Figure 13 shows how the traffic on this network has evolved from January 1990 to August 2011. This network is expecting 100 petabytes per month of data in 2015 [16].

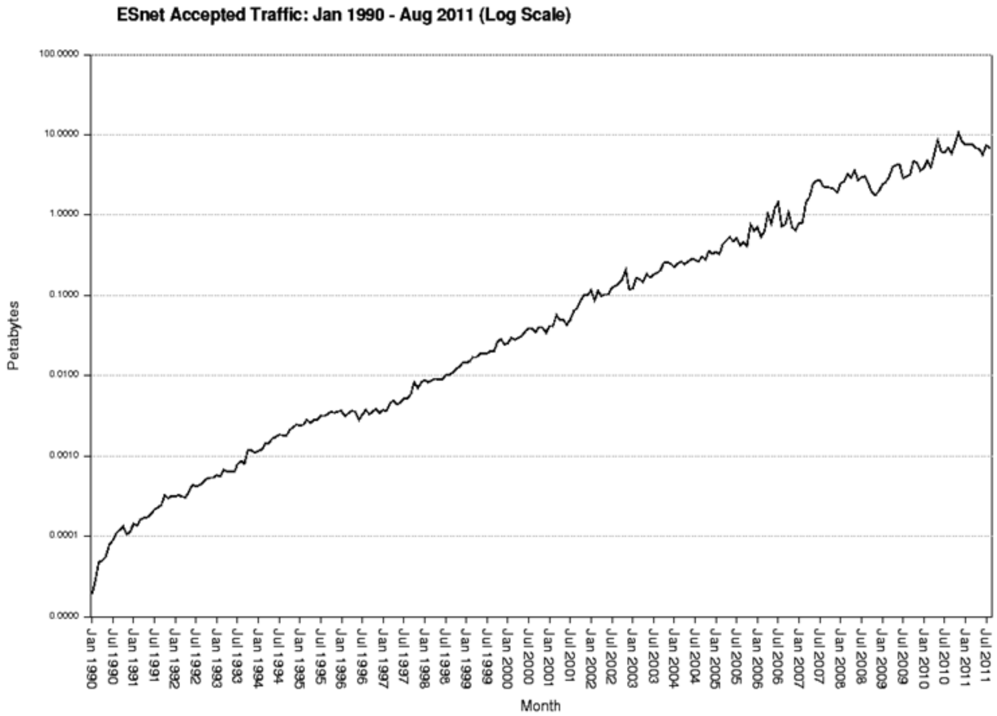

Figure 13—ESnet accepted traffic (petabytes per month)

Networks for data intensive science have somewhat different characteristics from other networks. For a given bandwidth, they have much larger per-flow rates and a much smaller flow count. There is often a significant fraction (10 to 50 %) of link bandwidth in a single flow (often over intercontinental distances). In future, data rates are expected to continue to increase due to sensor data rate scaling with semiconductor capabilities and large facilities replicating data multiple times within large collaborations [16]. Science networks are expected to continue to see a different traffic profile with relatively small flow count and relatively large flow rates (which does not favor LAG-like implementations).

3.6 Financial sector

This section examines the bandwidth demand in the financial industry [7].

The financial industry's use of networking technology has grown significantly. For example, Figure 14 demonstrates how the total number of messages per second for options data, equities trades, equities quotes, and order traffic has grown exponentially over the past few years.

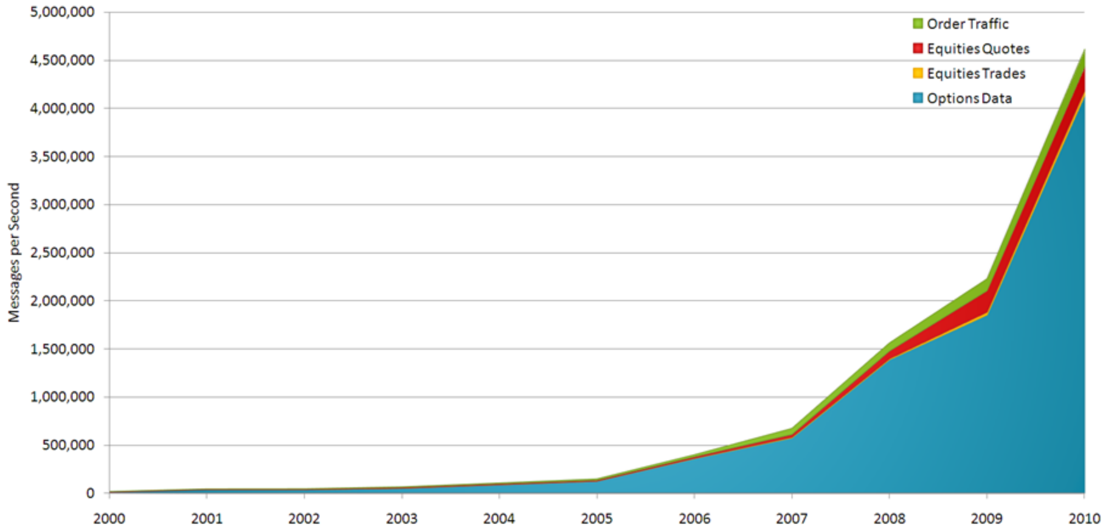

Figure 14—Financial industry and messaging

Another example is shown in Figure 15, which illustrates how source data from one data center was then distributed via multicast into the public network and the resulting bandwidth impact.

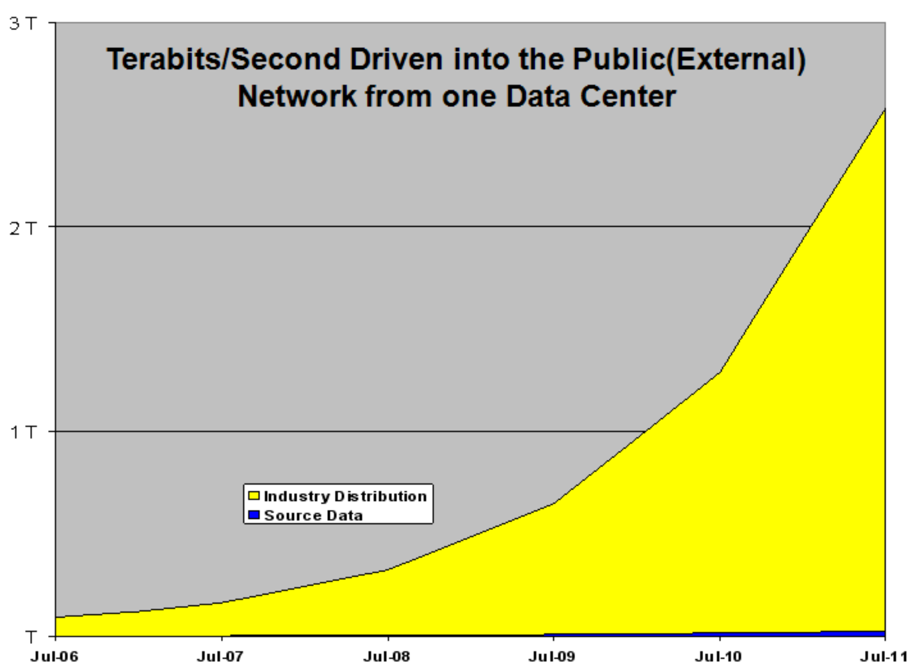

Figure 15—Bandwidth distributed to the financial community

Figure 16 illustrates an exemplar external network.

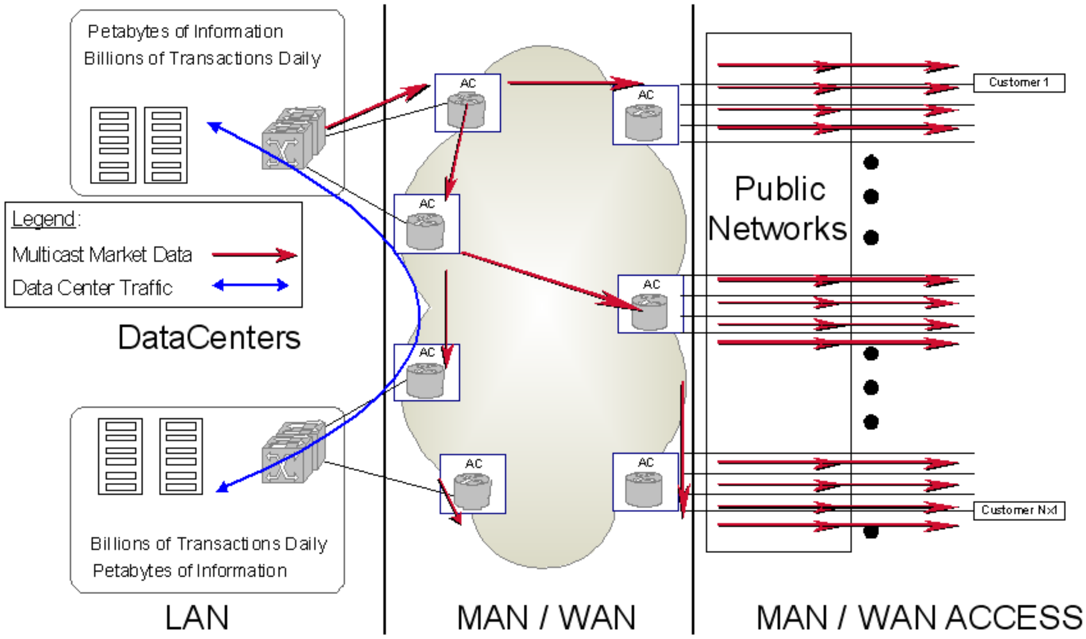

Figure 16—Exemplar external network

The next generation network will employ a flat layer 2 approach with reaches of approximately 1000 feet needed. Within an example data center environment, a number of interesting relevant data points were provided. There are approximately 10,000 servers that are mostly 2U and 4U rack servers with some blade servers. At the time of the presentation in mid 2011, there were more 1GbE servers than 10GbE servers, but 10GbE servers were being deployed that year, and it was indicated that 40GbE servers would be deployed in 2012. The servers were described as "off-the-shelf x86 servers from major OEM", which deploy x8 PCIe slots. The typical servers being deployed have six 10GbE ports and / or eight 1GbE ports. A top-of-rack (ToR) configuration is used, with two switches provided for every three racks. Multimode fiber links are being used for short reach connections to the top-of-rack switches. Furthermore, the data center core bandwidth was described as 18.35 Tb/s [21].

The optical footprint of a single center includes support for 170 lambdas, based on 10G and 100G wavelengths that support 1GbE and 10GbE circuits for a total delivery of 2.87 Tb/s. The 100G wavelengths bear further consideration - initially the plan for the specific data center specified four 100G wavelengths, but ultimately thirteen 100G wavelengths were deployed. At the time of the presentation the thirteen 100G wavelengths were being used to support delivery of one hundred and thirty 10GbE circuits. There was a stated immediate need for terabit links for the core network and external links [21].

Additionally, the financial industry is known to be sensitive to latency. Low latency data is uncompressed, and requires more bandwidth. The financial industry is looking for latency numbers to be reduced from milliseconds to microseconds.

3.7 Cable data

This section discusses the bandwidth trends for the cable industry and also aims to predict that trend in the future. The various devices involved in the cable infrastructure [9] are shown in Figure 17.

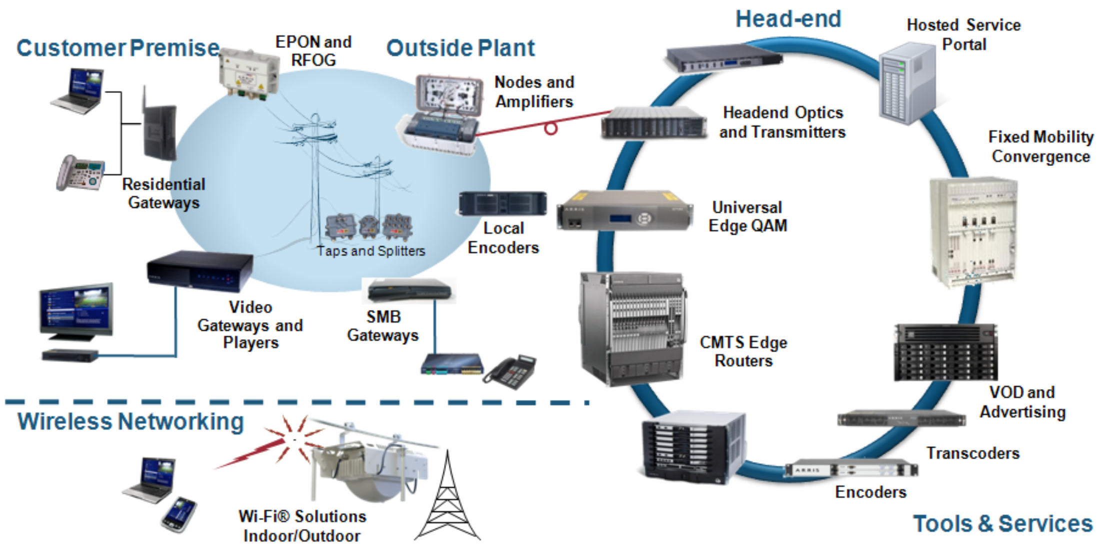

Figure 17—The cable infrastructure

The bandwidth related terms that are used in this section are defined according to Figure 18.

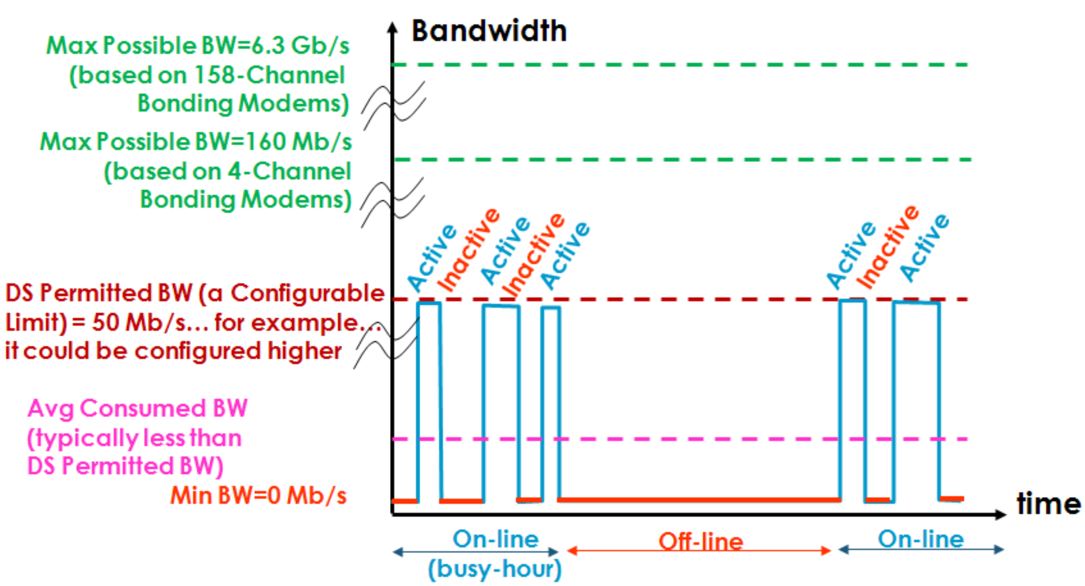

Figure 18—Bandwidth related terms

The average consumed bandwidth is used quite extensively for traffic engineering calculations (determining how much capacity is required to satisfy a given Service Group (pool) of subscribers).

Data for the maximum permitted downstream bandwidth over time is plotted in Figure 19 [9]. This plot (which is on a logarithmic vertical scale) shows a roughly constant rate of increase in maximum permitted downstream bandwidth of about 1.5 times per year over the 29 years from 1982 to 2011.

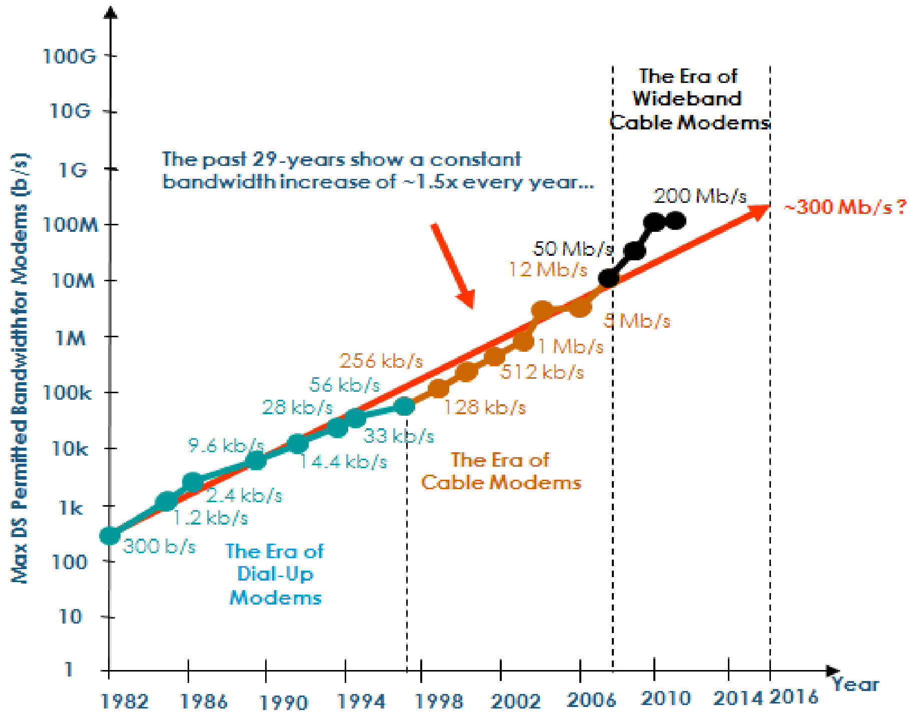

Figure 19—Maximum permitted downstream bandwidth trend

This trend (a 50% Compound Annual Growth Rate (CAGR) for a high end user's Internet connection speed) is called "Nielsen's Law of Internet bandwidth". If this trend were to be continued, it would predict a maximum permitted downstream bandwidth of about 300 Mb/s by 2016.

Data for the average downstream byte consumption for a typical 40k HHP (House-Holds Passed) head-end over time is plotted in Figure 20 [22]. This plot (which is also on a logarithmic vertical scale) predicts an average downstream byte consumption in a 40k HHP head-end of about 8.5×10^{15} bytes by 2016 which is an increase of roughly 10 times over the average downstream byte consumption seen in 2011.

Data for the average downstream bandwidth over time is plotted in Figure 20 [9]. This plot (which is also on a logarithmic vertical scale) predicts an average downstream bandwidth of about 3.5 Mb/s by 2016 which is an increase of roughly 10 times over the average downstream bandwidth seen in 2011.

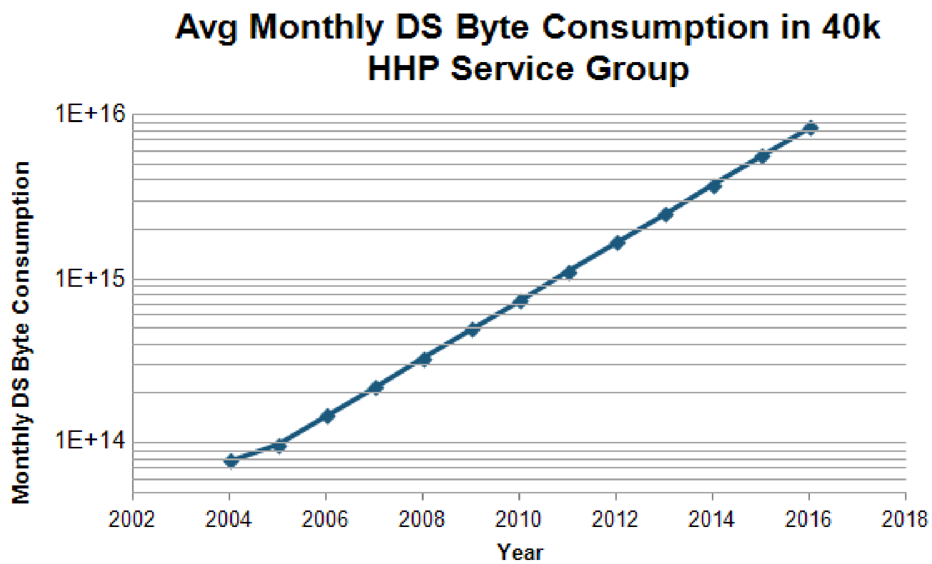

Figure 20—Average downstream byte consumption trend

Data for the maximum permitted upstream bandwidth over time is plotted in Figure 21 [9]. This plot (which is on a logarithmic vertical scale) shows a roughly constant rate of increase in maximum permitted upstream bandwidth of about 1.1 times per year. Upstream bandwidth is comprised of two types of traffic: protocol messages (e.g., HTTP GETs, TCP ACKs, etc.) and uploads (e.g., P2P torrents, web page inputs, FTP transfers). The protocol message bandwidth is predictable [9] and so it should increase in line with the rate of downstream bandwidth increase. The upload bandwidth is harder to predict [9] as it is highly dependent on the popularity of apps at any given time. For example when P2P represented a large percentage of the traffic in 2008, upstream bandwidth was ~41 % of downstream bandwidth. However, when over-the-top IP video (delivery of video content from sources other than the ISP) became popular in 2010, upstream bandwidth dropped to be only ~28 % of downstream bandwidth.

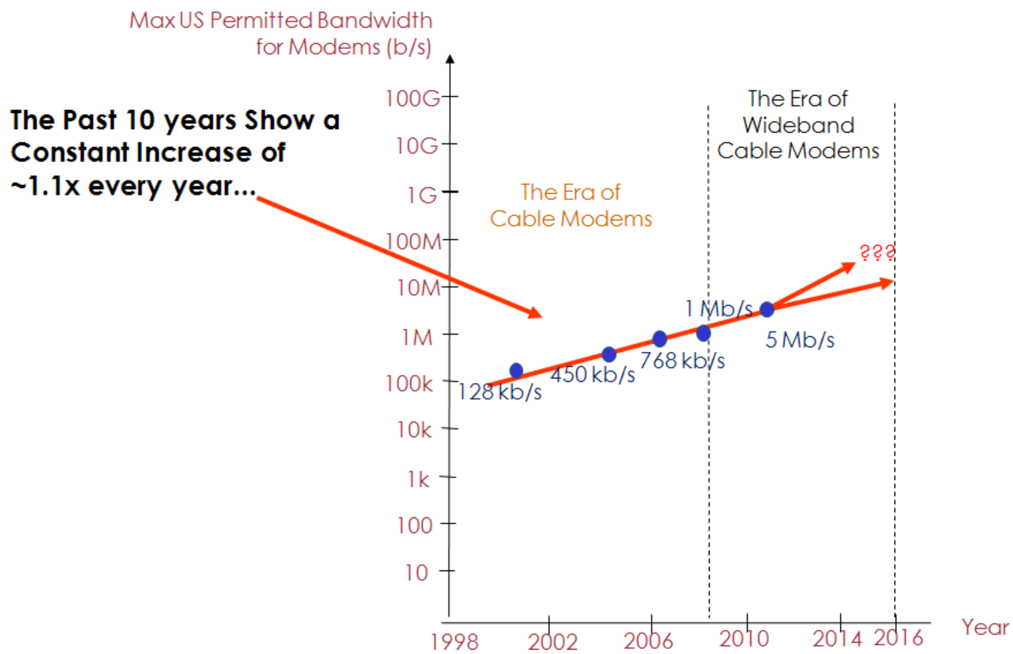

Figure 21—Maximum permitted upstream bandwidth trend

If the maximum permitted upstream bandwidth trend continues to grow at a 10 % CAGR, then it would be expected rise to ~8 Mb/s by 2016. However, indicators are that this upstream trend could grow at a much faster rate in the next four years.

Data for the average upstream byte consumption for a typical 40k HHP (House-Holds Passed) head-end over time is plotted in Figure 22 [22]. This plot (which is also on a logarithmic vertical scale) predicts an average downstream byte consumption in a 40k HHP head-end of about 4.2×10^{14} bytes by 2016 which is an increase of roughly 2.7 times over the average downstream byte consumption seen in 2011.

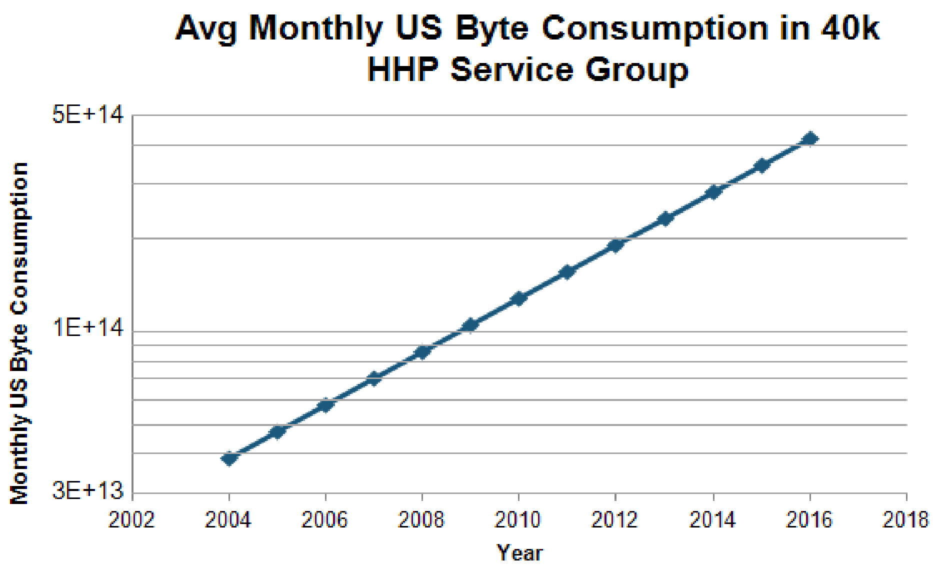

Figure 22—Average upstream byte consumption trend

In the period since 2009, there has been a rapid uptake of over-the-top IP video which has helped drive the continual increase in downstream consumption that is shown in Figure 20. This transition has also changed the mix of traffic types carried over the cable networks. These changes can be clearly viewed within Figure 23.

The increase in average downstream bandwidth per subscriber during the period 1Q 2010 to 1Q 2011 [9] is shown in Figure 23.

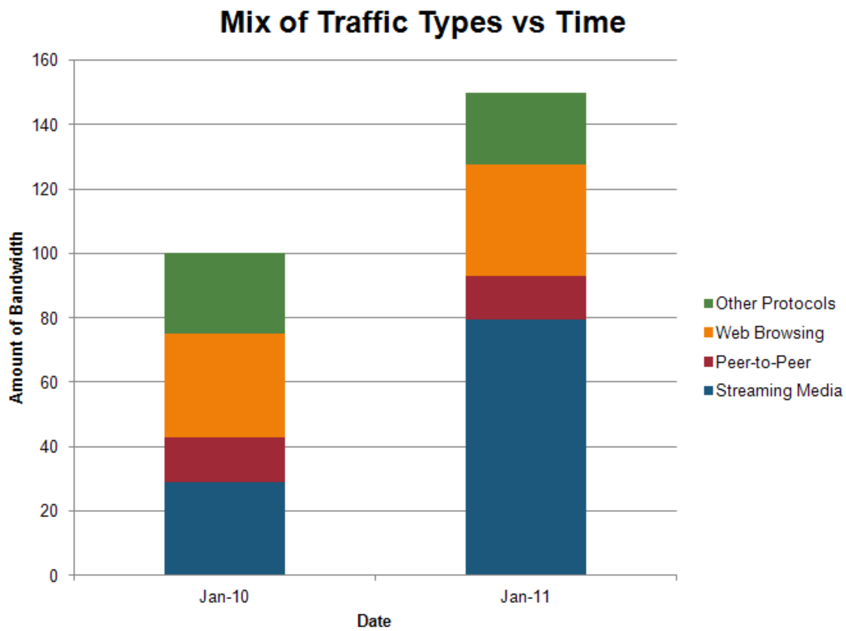

Figure 23—Mix of traffic type vs. time

In order for the bandwidth trends predicted above to materialize, the available equipment must be able to support the predicted bandwidths at acceptable cost levels. The following explores this topic from the point of view of DOCSIS Cable Modem Termination System (CMTS) equipment, which serve 20 to 50 "Service Groups". For a typical single high speed data "Service Group" with ~1000 homes passed, MSOs [9] predict:

- 2008: 1 DOCSIS Downstream (~40 Mb/s)
- 2011: 4 DOCSIS Downstreams (~160 Mb/s)
- 2015: ~20 DOCSIS Downstreams (~800 Mb/s)

To support this need the Converged Cable Access Platform (CCAP) has been designed with a 20 to 80 times increase in capacity, a 14 to 60 times power per bit reduction and a 20 to 80 times space per bit reduction [9]. The new technologies becoming available to support this are described in Table 11.

Table 11—Enabling technologies for CCAP

Building blocks	2007 capabilities	2011 capabilities	Increase factor
L2/L3 switch chips	60 Gb/s	640 Gb/s	10
Digital-to-analog converters	1 channel / chip	100+ channels / chip	100
Burst receivers	2 channels / chip	12 channels / chip	6
Processor chips	2 cores / chip	32 cores / chip	16

3.8 Optical Transport Network

For the purpose of this section the network is divided into the following categories [13] (See Figure 24):

- Access Node: xDSL, FTTx, 3G, Wi-Fi …
- Aggregation Node: Aggregate the data from access node to the edge of metro networks
- Core Node: Transport data in backbone networks

Where the "Optical Transport Network (OTN) consists of the Aggregation Nodes and the Core Nodes.

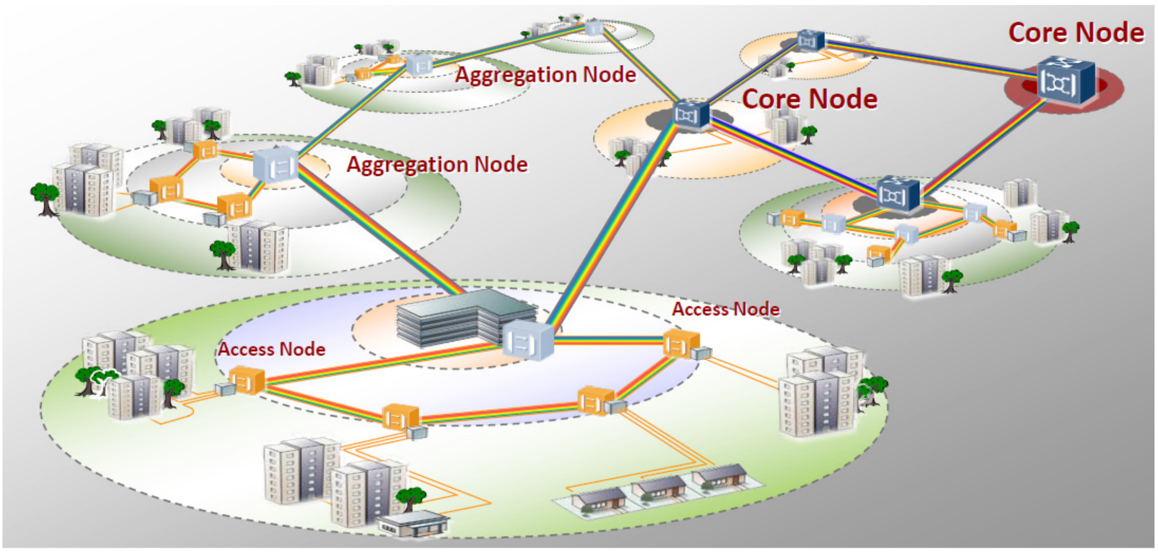

Figure 24—Network classification

Figure 25 and Figure 26 [13] show the projected bandwidth needs of operators from China in Aggregation Nodes and Core Nodes respectively. As the networks of three Chinese operators are not the same, the bandwidth per wavelength in an Aggregation Node or a Core Node shows some variation.

The bandwidth per wavelength in an Aggregation Node is expected to converge around 100G in 2015 and is expected to be in the range of 200G to 400G in 2020.

The bandwidth per wavelength in a Core Node is expected to be in the range of 100G to 400G in 2015 and is expected to be in the range of 400G to 1T in 2020.

Figure 25—Bandwidth needs per wavelength in an Aggregation Node - China

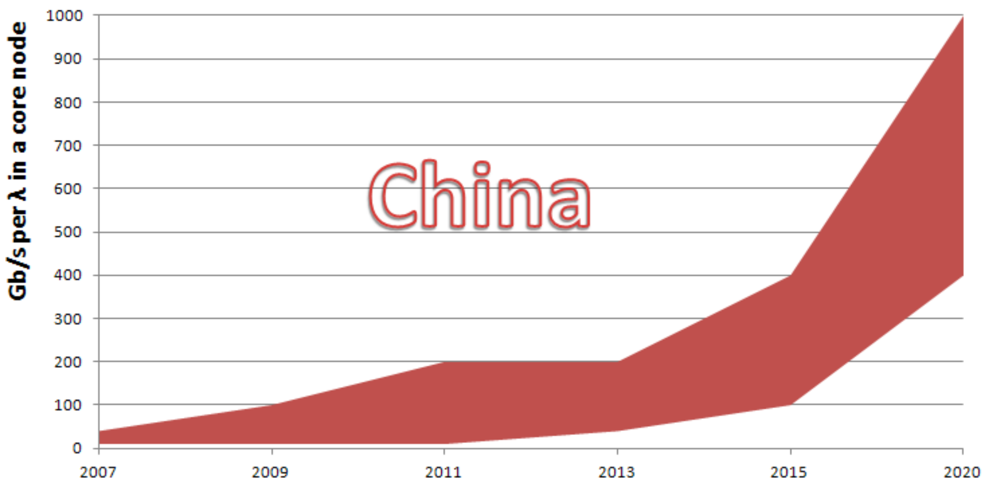

Figure 26—Bandwidth needs per wavelength in a Core Node - China

Figure 27 and Figure 28 [13] show the projected bandwidth needs of operators from Asia in Aggregation Nodes and Core Nodes respectively. As the development levels of Asian countries are so different, the bandwidth per wavelength in an Aggregation Node or a Core Node varies significantly from 2011 onwards.

The bandwidth per wavelength in an Aggregation Node is expected to be in the range of 40G to 100G in 2015 and is expected to be in the range of 100G to 400G in 2020.

The bandwidth per wavelength in a Core Node is expected to be in the range of 100G to 400G in 2015 and is expected to be in the range of 400G to 1T in 2020

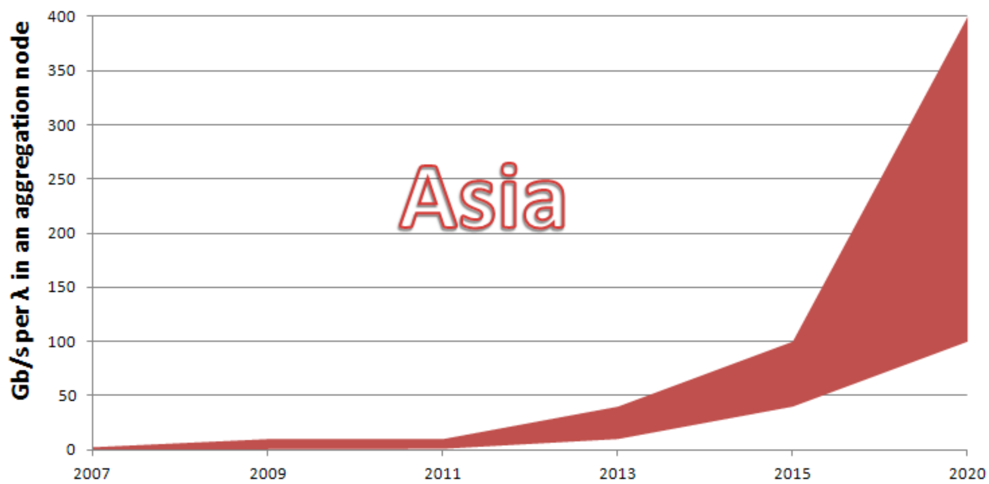

Figure 27—Bandwidth needs per wavelength in an Aggregation Node - Asia

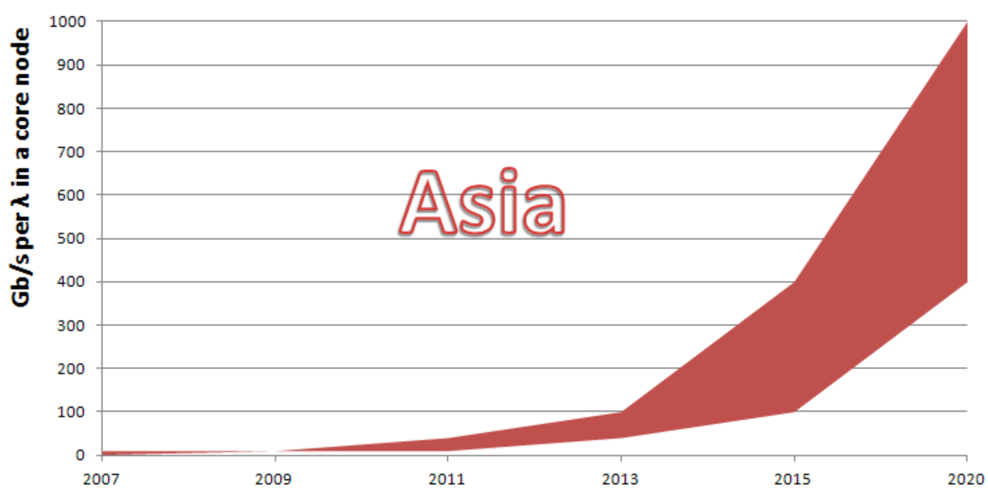

Figure 28—Bandwidth needs per wavelength in a Core Node - Asia

Figure 29 and Figure 30 [13] show the projected bandwidth needs of operators from Africa in Aggregation Nodes and Core Nodes respectively. Due to the large difference in economic development, Africa shows a much lower rate of increase for bandwidth demand than Asia.

The bandwidth per wavelength in an aggregation node is expected to be up to 40G in 2015 and is expected to be up to 100G in 2020.

The bandwidth per wavelength in an core node is expected to be up to 200G in 2015 and is expected to be up to 400G in 2020.

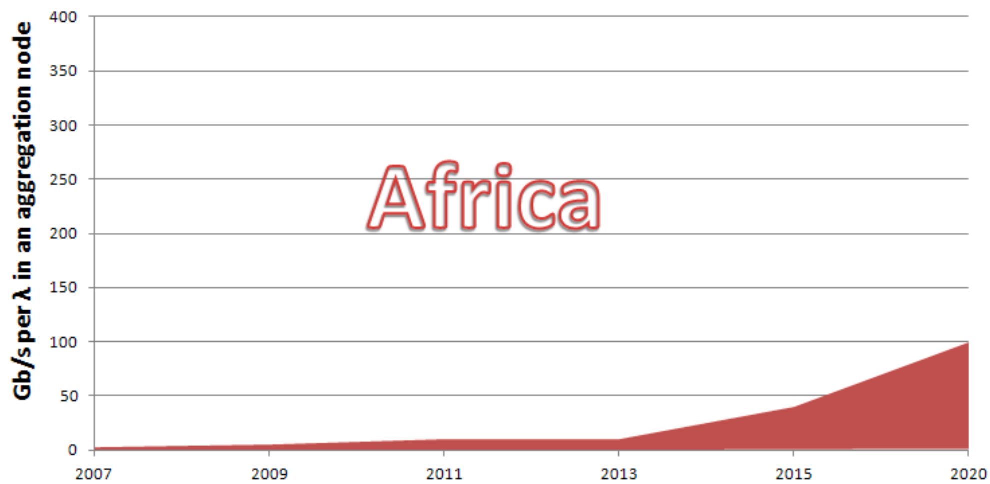

Figure 29—Bandwidth needs per wavelength in an Aggregation Node - Africa

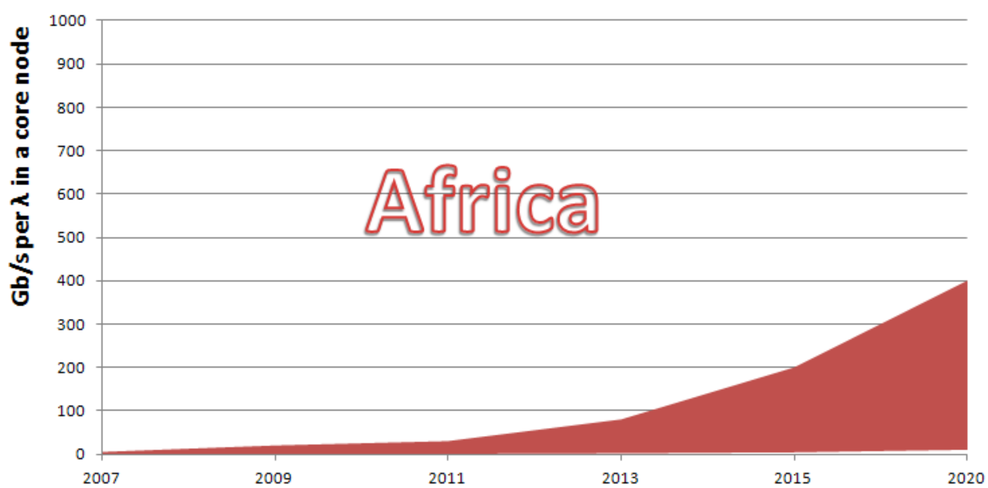

Figure 30—Bandwidth needs per wavelength in a Core Node - Africa

3.9 European peering

The European Internet Exchange Association (Euro-IX) is made up of 60 affiliated IXP entities: 46 from Europe (27 countries) and 14 from the rest of the world operating a total of 160 IXPs worldwide [14]. A map showing the location of Euro-IX affiliated and soon to be affiliated IXPs is shown in Figure 31.

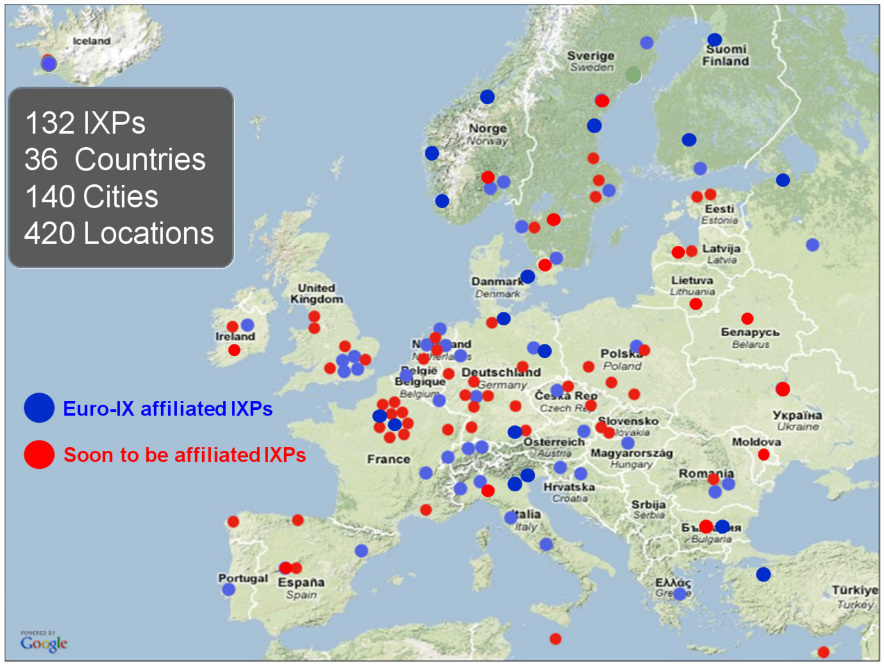

Figure 31—Euro-IX IXP locations

The formal definition of an Internet Exchange Point (IXP) (for example used in RIPE-451) is:

> A physical (Ethernet based) network infrastructure operated by a single entity whose purpose it is to facilitate the exchange of Internet traffic between ISPs. There must be a minimum of three ISPs connected.

ISP in this context is any company that sends and/or receives Internet IP traffic.

The global distribution of IXPs [14] is shown in Table 12.

Table 12—Global distribution of IXPs

Region	Number of IXPs	% of total
Europe	132	41 %
Asia/Pacific	60	19 %
Africa	22	7 %
Latin America	27	8 %
North America	80	25 %
Global	321	

Over the last five years, the costs of Ethernet ports from the Euro-IX members have seen significant reductions [14] as shown in Table 13 and the usage of each port type has changed [14] as shown in Figure 32.

Table 13—Euro-IX european members average relative monthly Ethernet port costs

Port	2005	2010	Decrease
10 Mb/s	1	0.2	80 %
100 Mb/s	1	0.45	55 %
1 Gb/s	1	0.53	47 %
10 Gb/s	1	0.44	56 %

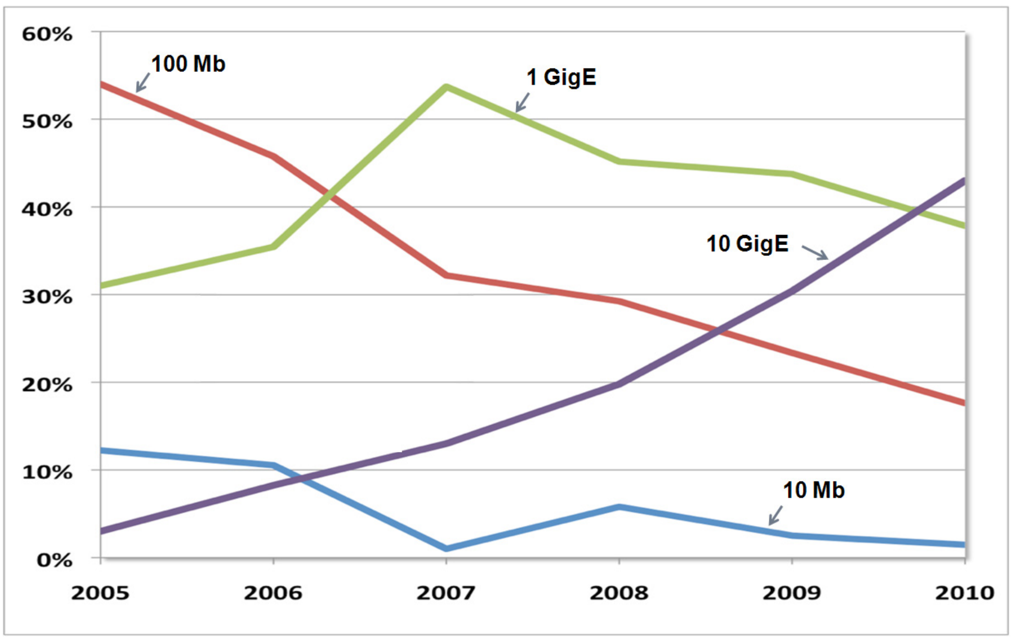

Figure 32—Euro-IX european member port usage trends

The combined Euro-IX european member IXP traffic shows a significant variation during the day [14]. On a typical day in September 2011 the average was 4.08 Tb/s, the maximum was 6.80 Tb/s and the minimum was 1.29 Tb/s which is a peak to trough ratio of 5.27.

This peak traffic rose from 4.9 Tb/s at the end of September 2010 to 7.2 Tb/s at the end of September 2011 which is a 49% increase in 12 months [14]. See Figure 33.

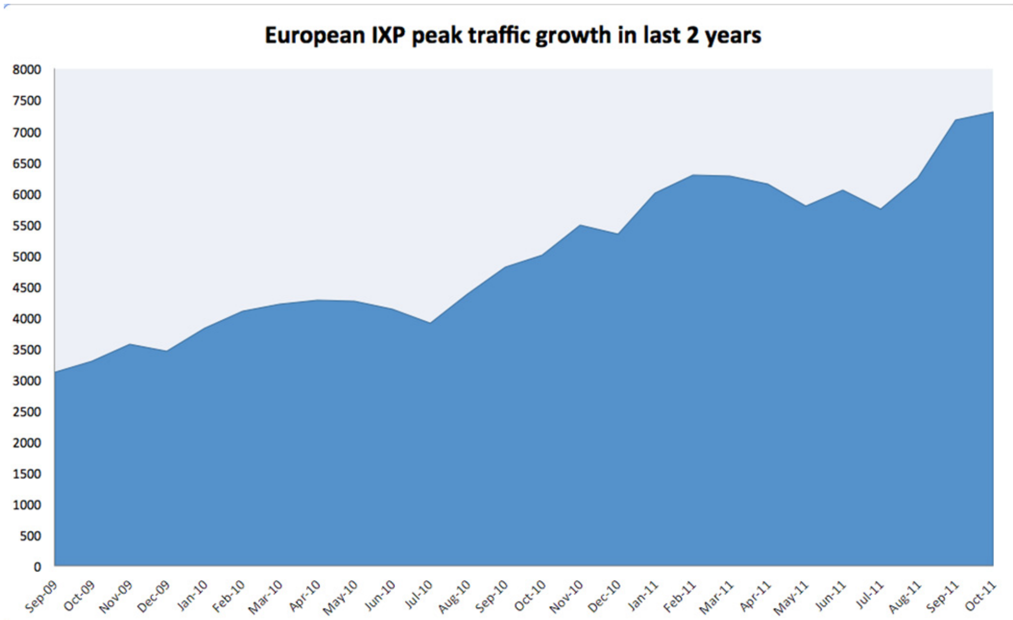

Figure 33—Euro-IX european member peak traffic growth

In addition to this steady growth in peak traffic, individual IXPs also see occasional spikes due to special events (such as sport) [14]. Figure 34 shows the traffic at the LONAP (London) IXP on a normal weekday when the peak traffic was 8.5 Gb/s. Figure 35 shows the traffic through the same IXP on a Wednesday when there was a football match between England and Slovenia during the 2010 World Cup when the peak traffic rose to 29.5 Gb/s.

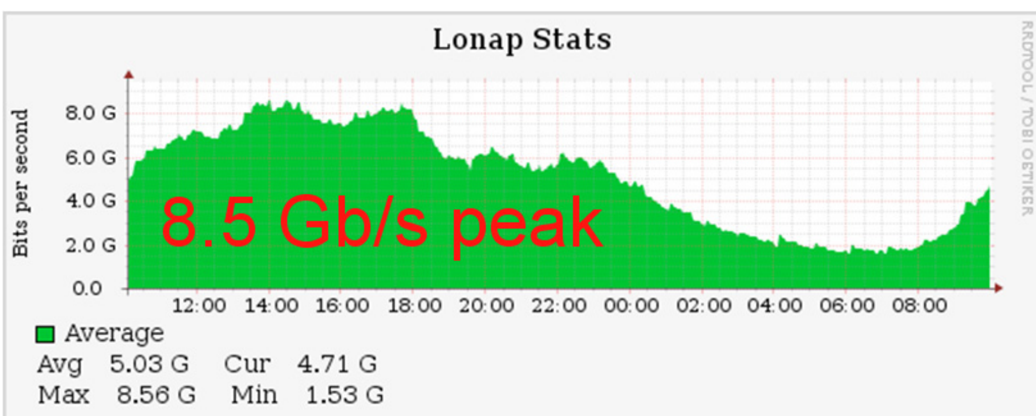

Figure 34—LONAP (London) traffic on a ‘normal’ weekday

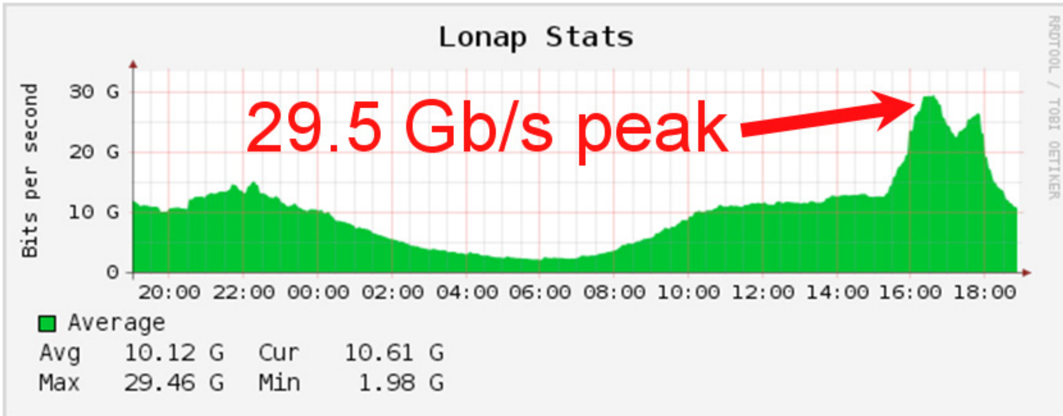

Figure 35—LONAP (London) traffic during the World Cup 2010 England vs. Slovenia

The annual IXP peak traffic growth rates show some variation according to the size of the IXP and also according to region [14]. The Global annual IXP peak traffic growth rates in 2010 shown by IXP size are given in Figure 36, shown by region within Europe are given in Figure 37 and shown by global region are given in Figure 38.

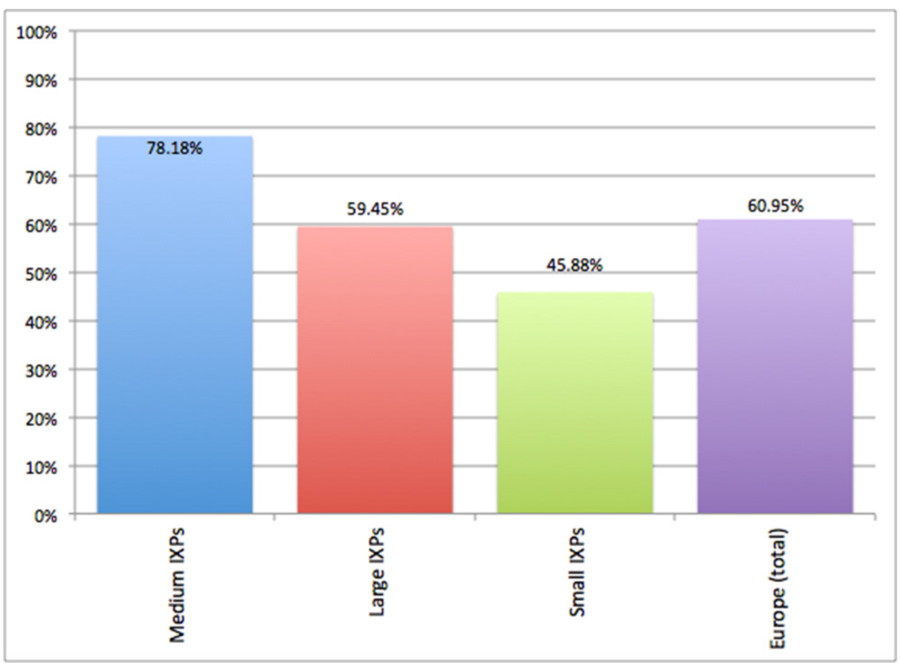

Figure 36—Global annual IXP peak traffic growth rates by IXP size 2010

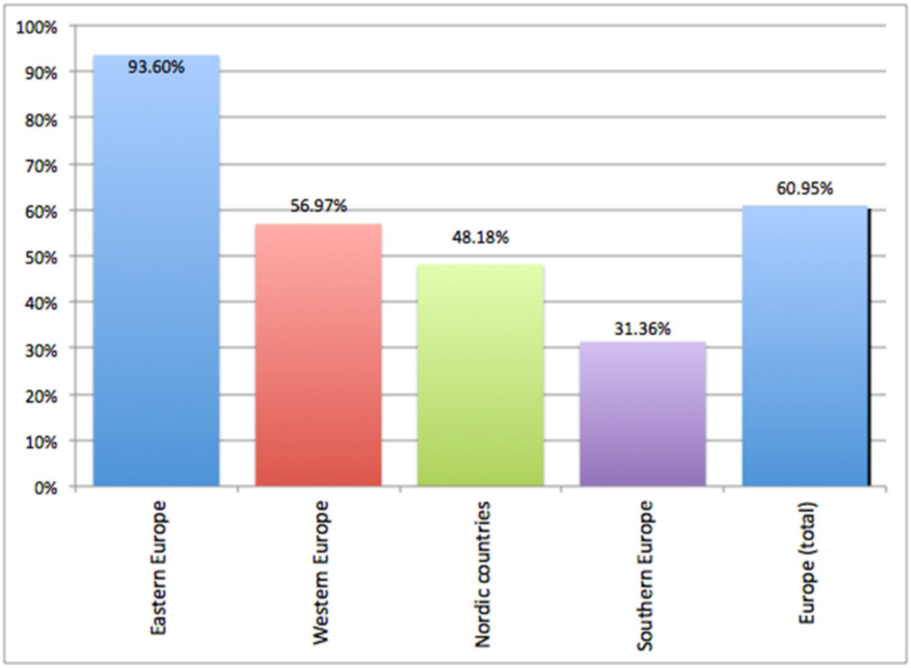

Figure 37—European annual IXP peak traffic growth rates by region 2010

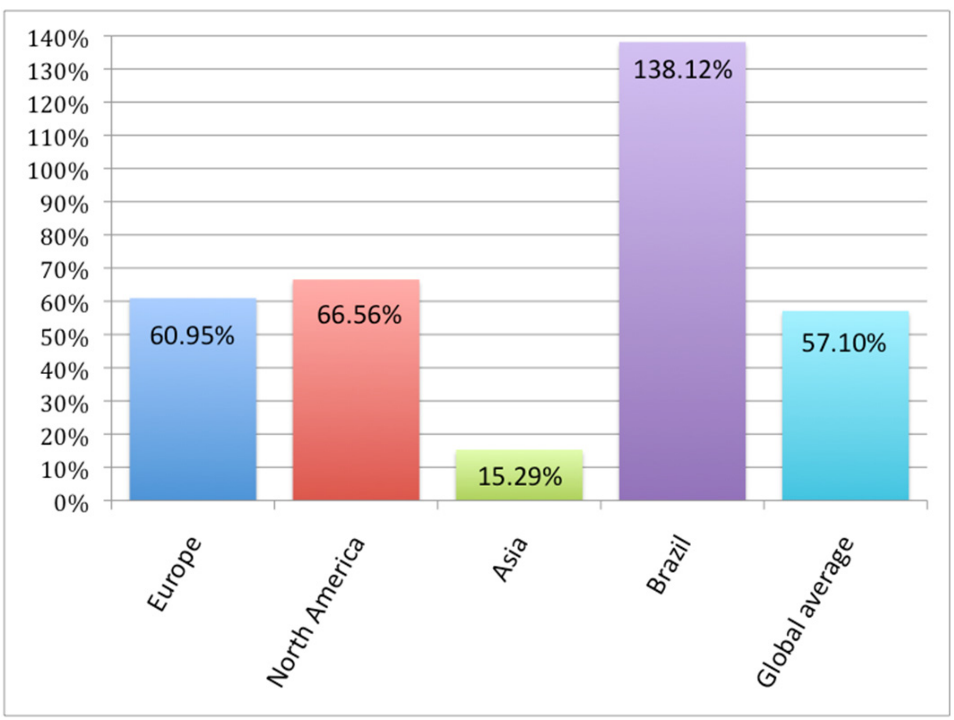

Figure 38—Global annual IXP peak traffic growth rates by region 2010

Fitting an exponential trendline to the data from the end of August 2005 to the end of August 2010 shows that the IXP peak traffic increase during this period was 12 times. See Figure 39.

If this trend continues, this would result in IXP peak traffic of 47 Tb/s by 2015. See Figure 39.

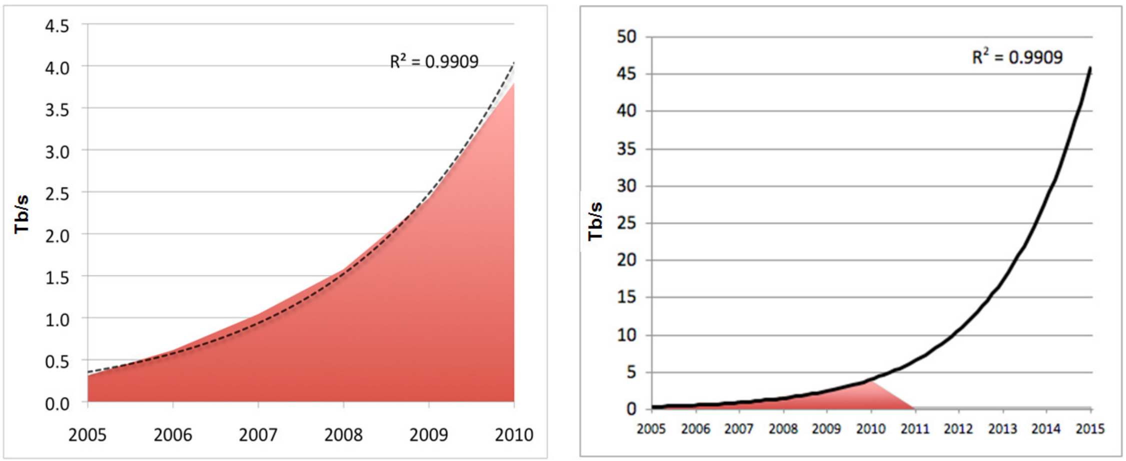

Figure 39—Five year peak European IXP traffic projection

4. Assessment

4.1 Peripheral growth trends

The key findings section of this report includes information on the growth trends for a variety of peripheral devices that create data that is transmitted over Ethernet networks. In particular, these are:

- 3.2 Visual Networking Index
- 3.7 Cable data
- 3.3 Storage growth
- 3.4.1 Server bandwidth scenarios

As discussed in 3.2, the number of Internet users is steadily increasing, the rate that each of those users can download (and upload) data is steadily increasing and there is a trend towards those users accessing increasing amounts of video content via the Internet. These factors combined are predicted to cause a 32 % CAGR for global IP traffic as shown in Figure 2. Similarly, in 3.7 it is shown that the trend for the maximum permitted downstream bandwidth for cable users has shown a CAGR of 50 % for the past 29 years (see Figure 19), the average downstream bandwidth has a similar slope (see Figure 20) and the cable industry is developing future platforms to enable this trend to continue.

Data storage is also growing with a CAGR of about 50 % (see 3.3 for details). While this does not directly relate to the rate of increase of Ethernet traffic, there is a trend towards data being maintained within a cloud or being “touched” by cloud computing service providers, which does relate to Ethernet traffic increase.

Most Ethernet traffic involves a server at one or other end of the link. Section 3.4.1, and in particular Table 6 gives a view of how the I/O bandwidth for servers is expected to grow over the next few years. To relate this information to Ethernet bandwidth demand requires knowledge of server deployment rates, the mix of the various server types and the average utilisation of the server interfaces, but since for all server types there is at least a factor of 10 increase in I/O bandwidth predicted within the next five years, this appears to be adequate to keep up with predicted Ethernet bandwidth demand growth.

4.2 Network growth trends

The growth trends of various segments of the Ethernet ecosystem are reported on in the following sections:

- 3.4.3 Data center bandwidth scenarios
- 3.4.4 Global data centers
- 3.5 Data intensive science
- 3.6 Financial sector
- 3.8 Optical Transport Network
- 3.9 European peering

As discussed in 3.4.3 and 3.4.4, Ethernet interfaces are widely used within data centers and there is a significant trend for interface rates to move from the lower speeds towards higher ones (see Figure 11).

Two sources of network data explored in the key findings section are data intensive science in 3.5 and the financial sector in 3.6. For data intensive science, the data accepted by the ESnet network over the past eleven years is shown in Figure 13. A fit to this curve over the period 2004 to 2011 shows a CAGR of 70 %. Similarly, data for traffic growth from one data center in the financial sector is shown in Figure 15 and a fit to this gives a CAGR of 95 %.

For long haul networks the current highest rate (OTU4) is sized to accommodate 100Gb Ethernet. Section 3.8 predicts a need for OTN rates per wavelength (and hence Ethernet rates) of 400 Gb/s starting in 2015 and 1 Tb/s starting in 2020 (see Figure 26 and Figure 28).

The traffic growth trend of one segment of the Internet Exchange Point (IXP) community is explored in 3.9. An exponential fit to the data from the end of August 2005 to the end of August 2010 shows a CAGR of 64 % (see Figure 39).

4.3 Variation factors

The growth trends discussed in 4.1 and 4.2 above are the average for the sector being discussed. It is recognized, however, that within each sector there is often significant variation in the growth rate by region or market segment.

In 3.2 global IP traffic is forecast to show a CAGR of 32 %. However, the predicted growth varies from 26 % in North America to 52 % in the Middle East and Africa as shown in Table 4 and also varies according to access technology from 24 % for fixed/wired to 92 % for mobile data as shown in Figure 2.

The growth in broadband speeds between 2010 and 2015 predicted in Table 3 shows a regional variation from a factor of 2.5 (20 % CAGR) in the Middle East and Africa up to a factor of 4.6 (36 % CAGR) in Asia Pacific.

Within the data centers discussed in 3.4.4, Figure 12 shows a different distribution of link speeds depending on whether the segment is finance and insurance, government or health.

For the Optical Transport Network (OTN), information is given in Figure 25 to Figure 30 on the predicted bandwidth per wavelength needs that shows significantly higher needs in China and Asia than for Africa.

In 3.9 a CAGR of 64 % is predicted for the European IXPs. As shown in Figure 36, the growth in IXP peak traffic in 2010 varied from 45.88 % in small IXPs to 78.18 % in medium IXPs with large IXPs in between at 59.45 %. The regional variation in growth within Europe in 2010 is shown in Figure 37 with the lowest being 31.36 % in Southern Europe and the highest 93.6 % in Eastern Europe. Figure 38 shows even wider variation globally, with the lowest being 15.29 % in Asia and the highest 138.12 % in Brazil.

4.4 Summary

The growth in global demand for Ethernet bandwidth that will be seen in the coming years is expected to be due to a combination of the factors considered in the sections above together with (of course) some additional factors that have not been considered here. Perhaps the most important of the latter factors is the ability of the Ethernet community to keep the cost per bit falling with time in such a way that the exponential rise in traffic does not result in unsupportable costs. This cost ultimately limits the ability to deliver the bandwidth necessary to satisfy the various applications, which influences these applications' impact on bandwidth growth.

In an attempt to place all of the relevant growth factors on a single chart, the relative traffic increase of the various sectors studied normalized to 2010 (the year when IEEE Std 802.3ba™ was approved) are shown in Figure 40 (solid lines) together with the rate of increase of core networking assumed by the 2007 IEEE 802.3 Higher Speed Study Group (HSSG) Tutorial (dashed line) [18].

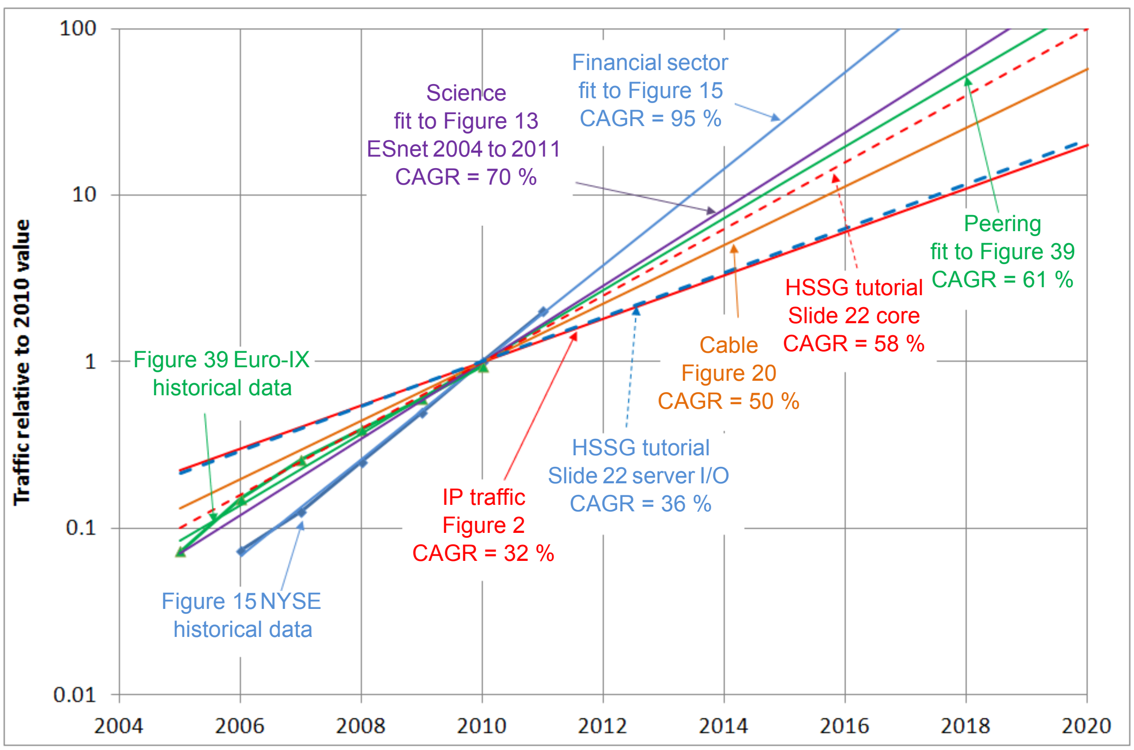

Figure 40—Relative traffic increase normalized to 2010

The most aggressive growth rates are shown by the financial sector and data intensive science (CAGR = 95 % and 70 % respectively), slower growth rates are seen for maximum bandwidth for cable users (although the number of users is also increasing) and for IP traffic (CAGR = 50 % and 32 % respectively) with the growth seen in Peering in the middle (CAGR = 64 %). The dotted red line showing the rate of increase of core networking assumed by the 2007 IEEE 802.3 HSSG (CAGR = 58 %) also appears in the middle of the group, suggesting that this assumption is still justified. It should be noted that end-station applications, such as cable users and server I/O, have slower growth rates, which indicates a continuation of the trend noted during the 2007 HSSG (CAGR = 36 %) and shown by the dotted blue line.

The various projections show traffic increasing to a factor of ten above the 2010 value from as early as 2013 to as late as 2018 with the previous HSSG assumption doing so by 2015. As noted above, whether or not these projections are realized or not will depend, among other things, on the ability of the Ethernet community to keep the cost per bit falling with time. In addition to this, the question of whether this increased traffic is serviced by the introduction of new rates above 100 Gb/s or by increasing numbers of the existing interfaces depends on the ability of the higher rates to provide a sufficiently cost effective solution.

5. References

[1] Muller, S., Bechtolsheim, A., Hendel, A. *HSSG Speeds and Feeds - Reality Check*
http://www.ieee802.org/3/hssg/public/jan07/muller_01_0107.pdf

[2] Lee, D. *Saturating 100G and 1T Pipes*
http://www.ieee802.org/3/hssg/public/mar07/lee_01_0307.pdf

[3] Seely, T. *Carrier Hurdles To Meeting 10GE Demand*
http://www.ieee802.org/3/hssg/public/mar07/seely_01_0307.pdf

[4] Bresser, A. *Requirements from an operator perspective*
http://www.ieee802.org/3/hssg/public/may07/bresser_01_0507.pdf

[5] IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc *Request for Information*
http://www.ieee802.org/3/ad_hoc/bwa/public/anslow_01a_0411.pdf

[6] Kipp, S. *Data Center Bandwidth Scenarios*
http://www.ieee802.org/3/ad_hoc/bwa/public/may11/kipp_01_0511.pdf

[7] Bach, A. *Bandwidth Demand in the Financial Industry - The Growth Continues*
http://www.ieee802.org/3/ad_hoc/bwa/public/jun11/bach_01a_0611.pdf

[8] Brown, K. *Server Bandwidth Scenarios - Signposts for 40G/100G Server Connections*
http://www.ieee802.org/3/ad_hoc/bwa/public/jul11/brown_01a_0711.pdf

[9] Cloonan, T. *Bandwidth Trends on the Internet... A Cable Data Vendor's Perspective*
http://www.ieee802.org/3/ad_hoc/bwa/public/sep11/cloonan_01a_0911.pdf

[10] Kipp, S. *Storage Growth and Ethernet*
http://www.ieee802.org/3/ad_hoc/bwa/public/sep11/kipp_01a_0911.pdf

[11] Nowell, M. *Cisco Visual Networking Index (VNI) Global IP Traffic Forecast Update; 2010–2015*
http://www.ieee802.org/3/ad_hoc/bwa/public/sep11/nowell_01_0911.pdf

[12] Pepeljugoski, P., Coteus, P. *Bandwidth needs in HPC taking into account link redundancy*
http://www.ieee802.org/3/ad_hoc/bwa/public/nov11/pepeljugoski_01_1111.pdf

[13] Huang, X. *Bandwidth Needs in Core and Aggregation nodes in the Optical Transport Network*
http://www.ieee802.org/3/ad_hoc/bwa/public/nov11/huang_01_1111.pdf

[14] Steenman, H. *The European Peering Scene*
http://www.ieee802.org/3/ad_hoc/bwa/public/nov11/steenman_01_1111.pdf

[15] Hansen, L. *Global Data Centres Presentation IEEE*
http://www.ieee802.org/3/ad_hoc/bwa/public/dec11/hansen_01_1211.pdf

[16] Dart, E. *Data Intensive Science Impact on Networks*
http://www.ieee802.org/3/ad_hoc/bwa/public/dec11/dart_01a_1211.pdf

[17] IEEE 802 LMSC Executive *Meeting minutes*, 12 November 2010
http://www.ieee802.org/minutes/2010-November/20101112-closing-minutes-v0.pdf#Page=127

[18] IEEE 802.3 Higher Speed Study Group Tutorial, *An Overview: The Next Generation of Ethernet*
http://www.ieee802.org/3/hssg/public/nov07/HSSG_Tutorial_1107.zip

[19] Cisco Visual Networking Index™,
http://www.cisco.com/go/vni

[20] IEEE 802.3 *Higher Speed Study Group Call-For-Interest*
http://www.ieee802.org/3/cfi/0706_1/CFI_01_0706.pdf

[21] IEEE 802.3 BWA ad hoc meeting notes, 29 June, 2011
http://www.ieee802.org/3/ad_hoc/bwa/public/jun11/notes_01_0611.pdf

[22] Cloonan, T. *Comment #25 against D1.0 of this report*
http://www.ieee802.org/3/ad_hoc/bwa/public/apr12/cloonan_01_0312.pdf