IEEE 802.3 Ethernet Working Group Communication

From: IEEE 802.3 Working Group[1]

Subject: IEEE 802.3 Industry Connections NEA Ad Hoc Ethernet Bandwidth Assessment Part II

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Approval: Agreed to by IEEE 802.3 Ethernet Working Group by email ballot, 03 April, 2020.

It has been observed by participants in the IEEE 802.3 Ethernet Working Group that the bandwidth requirements of different application spaces are growing at different rates. In order to maintain an ongoing understanding of industry bandwidth trends, the IEEE 802.3 Industry Connections New Ethernet Applications (NEA) Ad Hoc undertook an effort with a scope to focus on gathering information that would enable an assessment of the bandwidth needs for Ethernet wireline applications.

The attached assessment is the culmination of the open 2019 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

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[1]This document solely represents the views of the IEEE 802.3 Working Group, and does not necessarily represent a position of the IEEE, the IEEE Standards Association, or IEEE 802.

IEEE 802.3 BWA Part II Ad Hoc Report, April 2020

IEEE 802.3™ Industry Connections Ethernet Bandwidth Assessment Part II

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/bwa2/BWA2_Report.pdf

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Executive summary

The release of this Ethernet bandwidth assessment completes a year-long effort by the IEEE 802.3 Industry Connections New Ethernet Applications Ad Hoc (NEA 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 2012 IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment (BWA), which observed that the 58% CAGR noted by the 2007 IEEE 802.3 HSSG was still a reasonable assumption for networking applications going forward from 2012.

The data used for this assessment came from a variety of different presentations and information available to the industry, which looked at a variety of application spaces including servers, data center networks, mobile networks, and telecom networks, while also exploring information regarding users, networks, applications, such as video, and access methods and rates.

Relative to observed traffic in 2017, analysis and extrapolation of submitted data indicates a broad diversity in the bandwidth growth rates of the various applications explored, ranging in 2025 from 2.3× to 55.4× the traffic levels of 2017.

Assuming a new project to define the next rate of Ethernet begins in 2020, and takes 5 years to complete (2025), growth rate curves based on either 800GbE or 1.6TbE were also generated and compared to the submitted data. Assuming no other architectural changes in deployment, this overlay demonstrated a significant growth lag between 800GbE and the observed growth curves. However, the 4× growth curve generated by a 1.6TbE solution would also lag all observed growth curves, except "Peering Traffic". Furthermore, all of the underlying factors that drive a bandwidth explosion, including (1) the number of users, (2) increased access rates and methods, and (3) increased services all point to continuing growth in bandwidth.

While these are the forecasted bandwidth capacity requirements, 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:

1.6TbE	1.6 Tb/s Ethernet
100GbE	100 Gb/s Ethernet
10GbE	10 Gb/s Ethernet
1GbE	1 Gb/s Ethernet
200GbE	200 Gb/s Ethernet
25GbE	25 Gb/s Ethernet
400GbE	400 Gb/s Ethernet
40GbE	40 Gb/s Ethernet
50GbE	50 Gb/s Ethernet
800GbE	800 Gb/s Ethernet
ASN	autonomous system networks
BW	bandwidth
BWA	bandwidth assessment
CAGR	compound annual growth rate

CDN	content delivery network
EB	exabyte
EPON	Ethernet passive optical network
GB	gigabyte
HD	high-definition
HSSG	Higher Speed Study Group
IoT	Internet of Things
IP	Internet Protocol
IXP	Internet exchange point
LAN	local area network
M2M	machine-machine
SD	standard definition
SP	service provider
UHD	ultra-high definition (4K)
VOD	video on demand

2. Introduction

2.1 Overview

In early 2011, shortly after the ratification of the IEEE Std 802.3ba-2010 40GbE and 100GbE standard, the IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc (BWA Ad Hoc) was formed. The output of this effort was the first Ethernet Bandwidth Assessment (BWA) [1]. This proactive effort provided insight into industry bandwidth trends that would impact Ethernet wireline applications. As noted in the first assessment, "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”.

Nonetheless, the assessment proved useful, and its findings helped justify the initiation of the IEEE 802.3 400Gb/s Ethernet Study Group in July 2013, which led to the development of the IEEE Std P802.3bs-2017 200GbE and 400GbE standard that was ratified in December 2017. Based on the usefulness of the first effort, the NEA Ad Hoc initiated the second Ethernet BWA in September 2018. Similar in scope to the first BWA, this proactive effort seeks to assess current industry bandwidth trends that will impact future Ethernet wireline applications.

Note—From a historical perspective the first Ethernet BWA did help in the initiation of an effort to develop a higher speed Ethernet beyond 100GbE (the highest Ethernet rate at the time of the publication of the first Ethernet BWA). However, like the first Ethernet BWA effort, the second assessment is focused on gathering information, and not on recommendations or the creation of a call-for-interest for the next speed of Ethernet beyond 400GbE.

To gather this information, the NEA Ad Hoc sought out contributions from individuals from various application areas, sought input from various industry standards groups and organizations [2][3][4], and made a public request for information [5]. The following individuals presented their information to the ad hoc at various meetings and teleconferences in 2018 and 2019:

- John D'Ambrosia, Futurewei
  "Introduction - Ethernet Bandwidth Assessment, Part II" [6];
  "Available Industry Data" [7];
  "Review of Networks in PeeringDB" [8];
  "Email Summary [9] of Published Reports on Broadband Findings" [10][11][12];
  “Email - Inclusion of Mobile Network Data Submitted to the B10K Study Group” [13];
- Wenyu Zhao, CAICT," Broadband Development Status and Trend in China" [14];
- Steve Carlson, High Speed Design, Inc, "Trends in Automotive Networks" [15];
- Mark Laubach, Broadcom, "Future EPON Bandwidth Needs" [16];
- Vladmir Kozlov, LightCounting, "Traffic Growth in Telecom Networks and Mega DataCenters" [17];
- Mark Nowell, Cisco, "CISCO VNI Forecast Update" [18];
- Christoph Dietzel, "The European IXP Scene" [19];
- Guo, Liang, "Next Generation Data Center Connections in China" [20];
- Baron Fung, Sameh Boujelbene, Shin Umeda, Dell'Oro, "Data Center Ethernet Switch and Server Bandwidth Assessment for IEEE" [21];

All submitted information should be considered a snapshot of the perceived bandwidth requirements at the time of submission to the NEA Ad Hoc or the publication of the referenced report.

2.2 Assessment limitations

Given the nature of the Ethernet BWA, there are a number of limitations faced during the course of its development:

- The information gathering period was limited to twelve months in order to limit the possibility of data becoming outdated and potentially inaccurate.
- The Ethernet BWA is limited by the data that has been contributed, including the topics and range of data forecast.
- 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.
- Information technologies may be used by a company to either 1) support their business, or 2) to provide an “information technology” based product. Given the close relationship between bandwidth and the financial success of the company, there is limited direct bandwidth data from end-users available.

3. Key findings

3.1 Introduction

As noted in the 2007 IEEE 802.3 Higher Speed Study Group (HSSG) Tutorial [23], 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.) and the bandwidth demand of these services. 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.

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

To fully explore the current state of industry bandwidth demand, contributions regarding bandwidth demand or any of the factors noted in Equation (1) were pursued.

3.2 Users

From 2017 to 2022, it is forecasted that device connections will grow from 18 billion to 28.5 billion devices and connections [18]. As noted in Equation (1), the "bandwidth explosion" that a given network may experience is directly related to the number of users accessing a network. When considering "Users", individuals should not be the only type of user considered, as machine-machine (IoT / M2M) communications suggested by Internet of Things (IoT) applications is also something to review.

3.2.1 Individual Users

One trend presented indicated that the number of Internet users will grow from 3.4 billion in 2017 to 4.8 billion in 2022 [18]. This forecast is supported by data from Internet World Stats (see Table 1) which indicated that as of March 31, 2019, there was already an estimated 4 383 810 343 users, representing only 57% of the world population at that point in time. This leaves an additional ~3.3 billion individuals that could be connected to the Internet.

Table 1—Internet Usage [7]

(as of 3/31/19)	Total World	Top 20 Countries	Rest of World
Population	7 716 223 209	5 187 499 066	2 565 984 143
Internet Users	4 383 810 342	3 117 533 898	1 229 027 955
Internet Usage	57%	60%	48%

This trend is also exhibited by the Top 20 countries per number of Internet users as of March 31, 2019. Data for the Top 20 Countries is shown in Table 2.

Table 2—Top 20 Countries Internet Usage [7]

#	Country	Population 2000 Est	Population 2019 Est	Internet Users 31/12/00	Internet Users 31/3/19	Internet Growth 2000-2019	Usage 2019
1	China	1 283 198 970	1 420 062 022	22 500 000	829 000 000	3 584%	58%
2	India	1 053 050 912	1 368 737 513	5 000 000	560 000 000	11 100%	41%
3	United States	281 982 778	329 093 110	95 354 000	292 892 868	207%	89%
4	Brazil	175 287 587	212 392 717	5 000 000	149 057 635	2 881%	70%
5	Indonesia	211 540 429	269 536 482	2 000 000	143 260 000	7 063%	53%
6	Japan	127 533 934	126 854 745	47 080 000	118 626 672	152%	94%
7	Nigeria	122 352 009	200 962 417	200 000	111 632 516	55 716%	56%
8	Russia	146 396 514	143 964 709	3 100 000	109 552 842	3 434%	76%
9	Bangladesh	131 581 243	168 065 920	100 000	92 061 000	91 961%	55%
10	Mexico	101 719 673	132 328 035	2 712 400	85 000 000	3 033%	64%
11	Germany	81 487 757	82 438 639	24 000 000	79 127 551	229%	96%
12	Turkey	63 240 121	82 961 805	2 000 000	69 107 183	3 355%	83%
13	Philippines	77 991 569	108 106 310	2 000 000	67 000 000	3 250 %	62%
14	Vietnam	80 285 562	97 429 061	200 000	64 000 000	31 900%	66%
15	UK	58 950 848	66 959 016	15 400 000	63 061 419	309%	94%
16	Iran	66 131 854	82 503 583	250 000	62 702 731	24 981%	76%
17	France	59 608 201	65 480 710	8 500 000	60 412 689	610%	92%
18	Thailand	62 958 021	69 306 160	2 300 000	57 000 000	2 378%	82%
19	Italy	57 293 712	59 216 525	13 200 000	54 789 299	315%	93%
20	Egypt	69 905 988	101 168 745	450 000	49 213 493	10 613%	49%

Note—Usage 2019 is the number of Internet users in 2019 divided by the estimated 2019 population.

A more in-depth analysis of Internet usage of the Top 20 connected countries (Table 2) is illustrated in Figure 1. The following observations are made -

- Observation #1 - From 2000 - 2019 there was rapid growth in connectivity of these countries, around 3.1 billion individual users were connected to the Internet.
- Observation #2 - only 8 of the 20 countries had at least 80% of their population connected as of March 31, 2019. Given that there are ~2 billion unconnected individuals in these 20 countries, there is a large number of individuals in the Top 20 countries for potential connection to the Internet.
- Observation #3 - China and India only have an estimated 58% and 41% of their populations connected as of March 31, 2019. Of the noted ~2 billion individuals in Observation #2, ~1.4 billion individuals are in China and India.

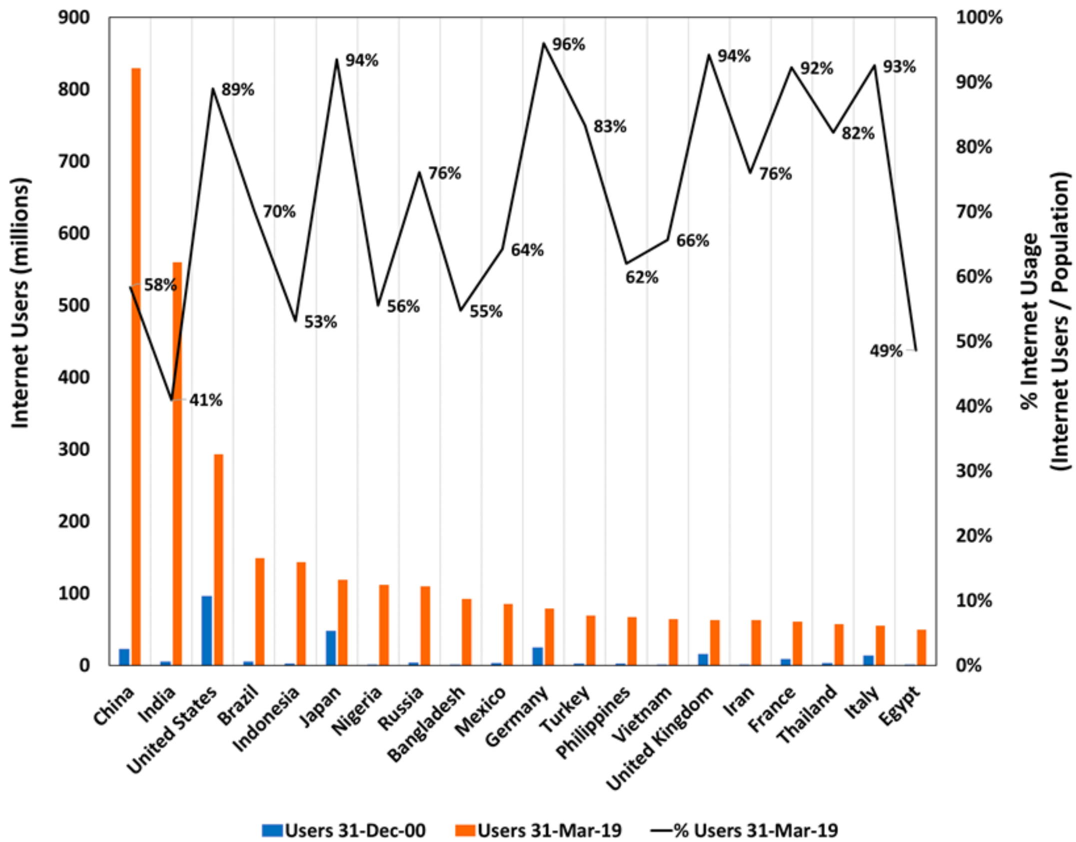

Figure 1—The Top 20 Countries with the Highest Number of Internet Users [7]

The Internet World Stats website also presented data on a "Regional" basis, estimated for March 31, 2019, which is illustrated in Figure 2. Figure 2 also highlights the relationship between the number of users in a region to the global number of users ("Global Penetration by Region"). This highlights that there is a very diverse picture when assessing bandwidth demand due to Internet connectivity on a regional basis, and how it contributes to the global picture. Only North America and Europe have greater than 80% of its population connected to the Internet. The other noted regions could experience the bandwidth explosion from all three factors noted in Equation (1), while the bandwidth explosion of North America and Europe would be driven by 1) increased access methods and rates and 2) increased services.

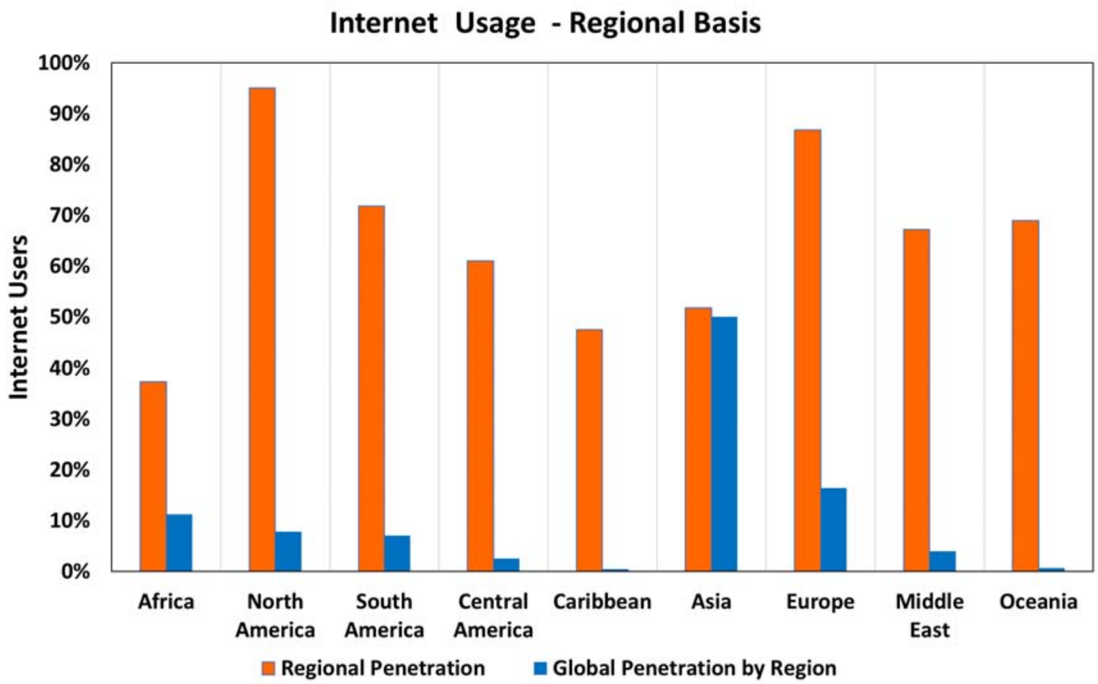

Figure 2—Internet Penetration [7]

3.2.2 Machine-Machine Communications

Connections for machine-machine (IoT / M2M) communications need to be considered, as the number of devices is forecasted to experience a 19% CAGR and grow from ~6 billion in 2017 to ~15 billion in 2022 [18].

Figure 3 breaks down the estimated IoT / M2M connections for IoT growth by vertical application. Note that topics associated with a "Connected Car" are discussed in 3.4.1. Figure 4 breaks down the global IoT / M2M connections on a regional basis. While the estimated shares vary on a regional basis, the estimated CAGRs are consistent at approximately 20%.

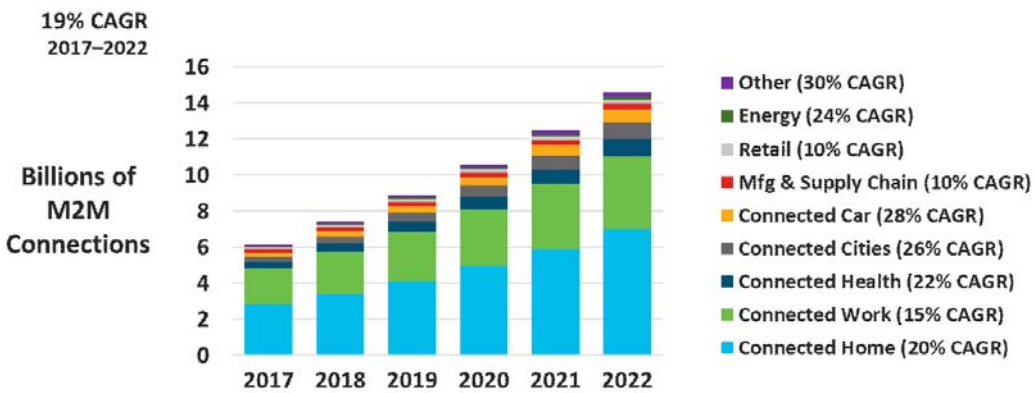

Figure 3—Global IoT / M2M Connections / IoT Growth by Vertical [18]

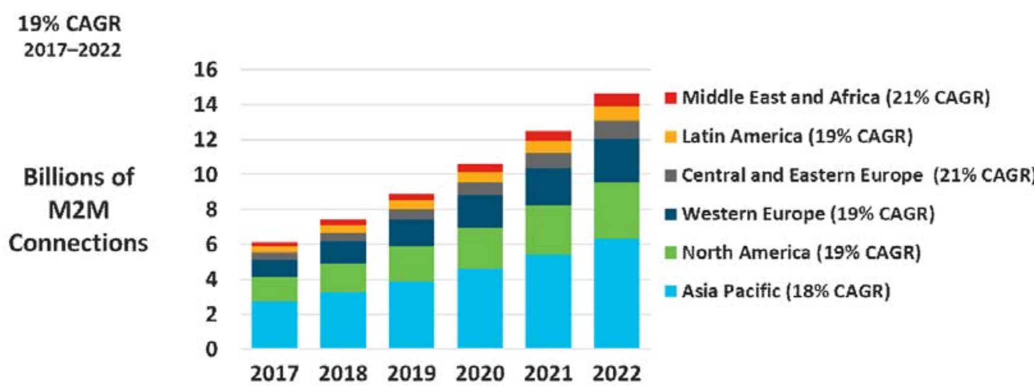

Figure 4—Global IoT / M2M Connections [18]

3.3 Access Methods and Rates

A user may use more than just a single method or device to access the Internet. This section looks at the various methods of Internet connection, as well as the growth in data rates where available of the various connection methods.

3.3.1 Overview

In today's world there are multiple ways that a user may connect to the Internet. Figure 5 illustrates the various methods, as well as the forecasted growth, for individual users to connect, as well as IoT / M2M connections.

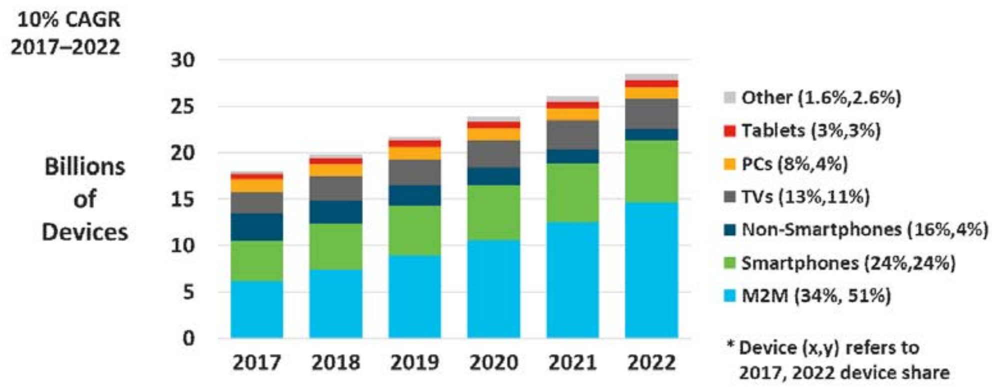

Figure 5—Global Device / Connection Growth by Type [18]

Table 3 provides insight into the global contribution of IP traffic on average of the various methods of interconnection. The following observations are made -

- Observation #1 - Despite accounting for 51% of global devices and connections, IoT / M2M traffic only accounts for 1,730 MB per month in 2022, or about 1% of all average traffic forecasted in this table.
- Observation #2 - the largest forecasted growth is for smartphones and ultra-high definition (4K) TV at 411% and 377%, respectively, suggesting that these are areas to further explore.

Table 3—Global Average IP Traffic Per Device [18]

MB / Month	2017	2022	Growth
IoT / M2M	610	1 730	184%
Smartphone	5 110	26 100	411%
Tablet	10 380	31 140	200%
Laptop /PC	35 950	59 250	65%
Ultras High Definition (4K) TV *	7 520	35 840	377%

* - includes IP VoD Traffic

When considering industry bandwidth needs, the number of users alone does not present a complete picture and cannot be considered. A single user may have multiple devices, with each device potentially on the same or different networks. Table 4 indicates the average number of devices per capita and household.

Table 4—Devices / Connections Per User [18]

	2017	2022	Growth
Average # of Devices / Connections per Capita	2.4	3.6	50%
Average # of Devices / Connections per Household*	6.4	9.0	41%

* - only includes consumer devices and connections

Table 5 highlights that the corresponding average traffic per user for the 2017 - 2022 timeframe will experience nearly 200% growth per user and household.

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Table 5—Average Global Internet Bandwidth Usage [18]

	2017	2022	Growth
Average Traffic per User per Month	29 GB	85 GB	193%
Average Traffic per Household per Month	82 GB	240 GB	193%

Figure 6 highlights the amount of global traffic per different device type. It is important to note again that the amount of traffic on smartphones and TVs suggests additional attention to these areas.

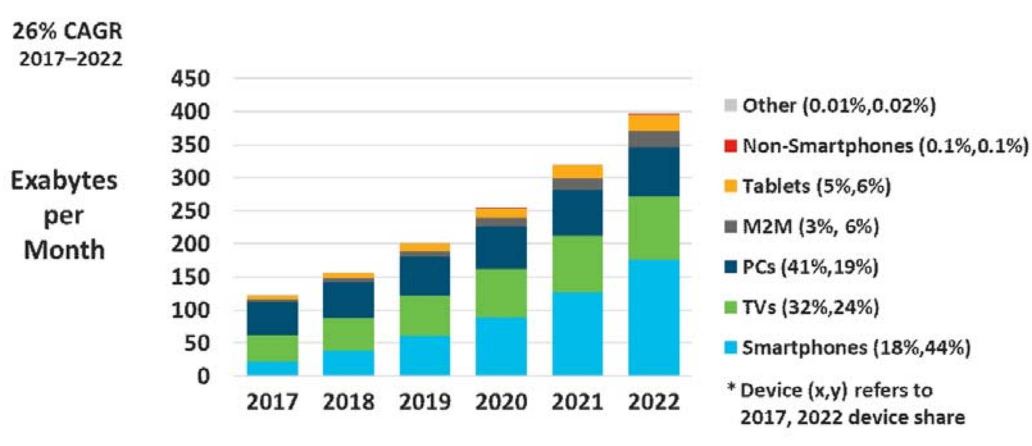

Figure 6—Global IP Traffic by Device Type [18]

There is a risk, however, in looking at average traffic, as networks need to be designed to address peak traffic. As shown by Figure 7, there is a growing difference between average Internet traffic and busy hour Internet traffic. From 2017 to 2022, busy hour traffic is projected to grow from over 1 Pb/s to over 6 Pb/s, while average hour Internet traffic is expected to grow from ~0.3 Pb/s to ~1 Pb/s.

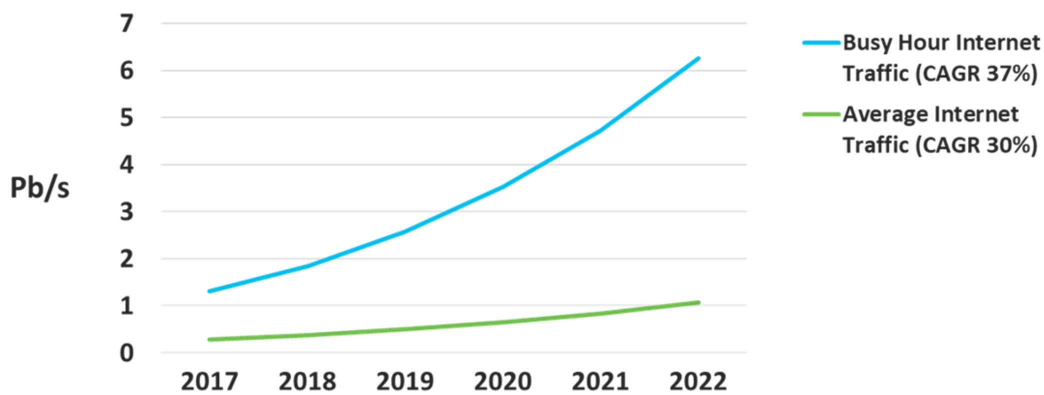

Figure 7—Global Busy-Hour vs Average Hour Internet Traffic [18]

3.3.2 Different Access Networks

Table 6 provides a summary forecast of fixed broadband, Wi-Fi (average) and Cellular (average) rates for the 2017 to 2022 time period on a global and regional basis. The following observations are noted:

- Observation #1 - For 2022 the following available data rates are noted for each network type:
  - Fixed Broadband - 20.2 Mb/s to 98.8 Mb/s
  - Wi-Fi - 11.2 Mb/s to 83.8 Mb/s
  - Cellular - 15.3 Mb/s to 50.5 Mb/s
- For 2022 Asia Pacific is expected to have the highest fixed broadband date rate, North America the highest Wi-Fi data rate, and Europe the highest cellular data rate.
- For 2022 North America is expected to have the highest Wi-Fi data rate and the second highest date rate for both Fixed Broadband and Cellular.

Table 6—Forecast of Access Methods [18]

	Fixed Broadband				Wi-Fi (Average)				Cellular (Average)		
In Mb/s	2017	2022	CAGR		2017	2022	CAGR		2017	2022	CAGR
Global	39.0	75.4	14.1%		24.4	54.2	17.3%		8.7	28.5	26.8%
By Region											
Asia Pacific	46.2	98.8	16.4%		26.7	63.3	18.8%		10.6	28.8	22.1%
Latin America	11.7	28.1	19.2%		9.0	16.8	18.8%		4.9	17.7	29.3%
North America	43.2	94.2	16.9%		37.1	83.3	17.7%		16.3	42.0	20.8%
Western Europe	37.9	76.0	14.9%		25.0	49.5	14.6%		16.0	50.5	25.8%
Central and Eastern Europe	32.8	46.7	7.3%		19.5	32.8	11.0%		10.1	26.2	21.0%
Middle East & Africa	7.8	20.2	21.0%		6.2	11.2	12.6%		4.4	15.3	28.3%

3.3.2.1 Broadband

The following additional data on China's fixed broadband capabilities was provided [14]:

- As illustrated in Figure 8, the number of fixed broadband users reached 350 million (328 million were fiber broadband users) in 2017.
- Figure 9 illustrates the growth of various access rates (20 Mb/s, 500 Mb/s, and 100 Mb/s and above) for broadband users from 2014 to 2018.
- Figure 10 highlights the growth in average download rate of fixed broadband users in China from 2015 Q2 through 2018 Q2 for a 52% CAGR.

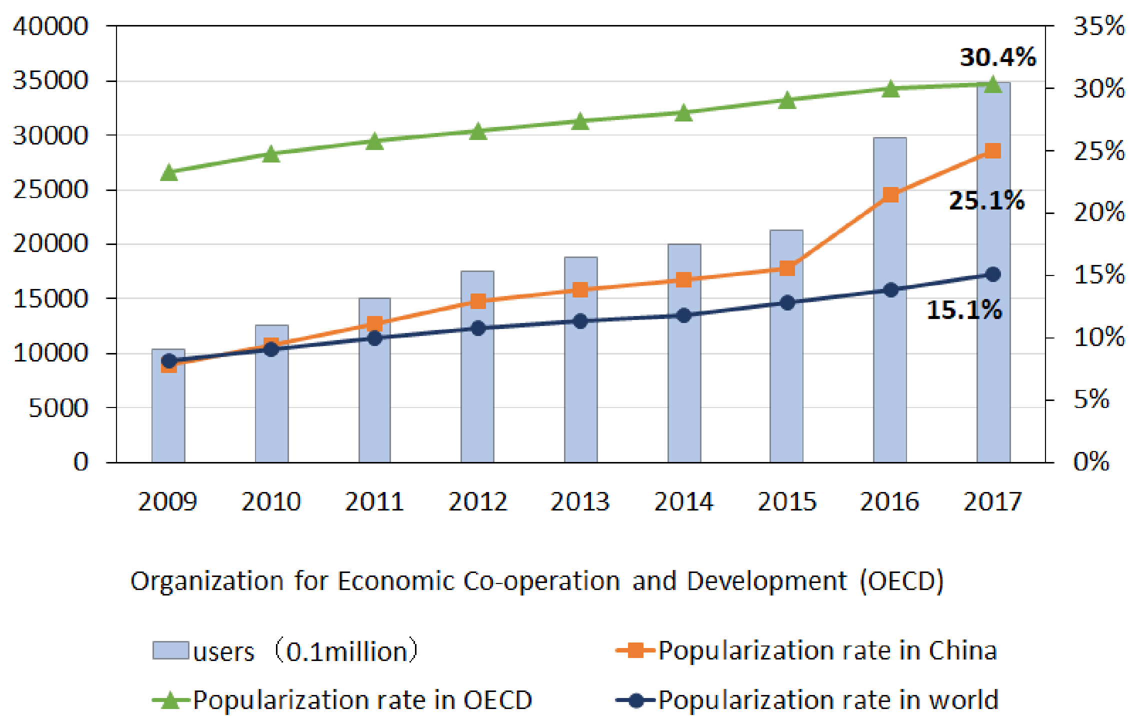

Figure 8—Fixed Broadband User Status [14]

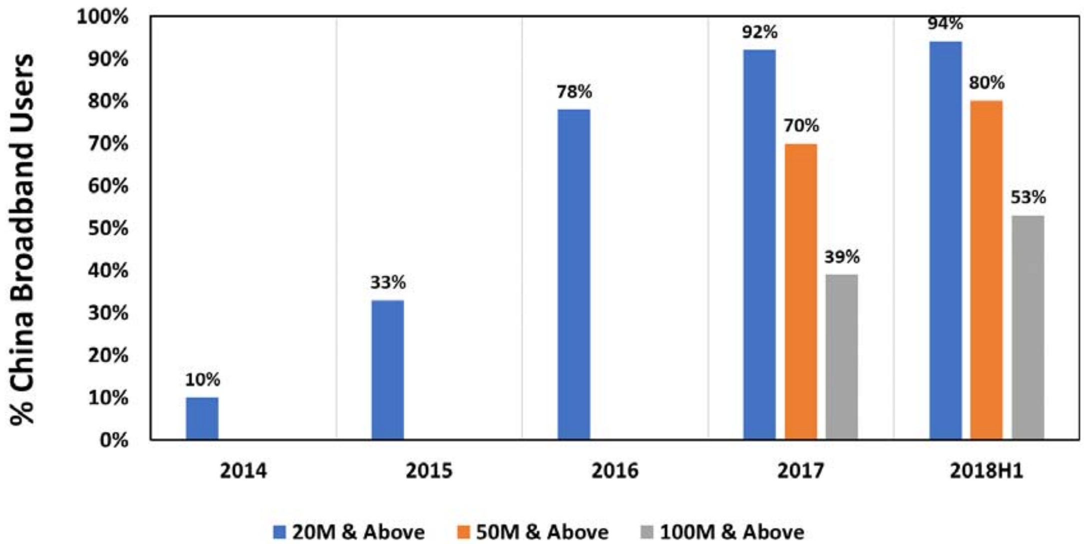

Figure 9—China Broadband Access Rates [14]

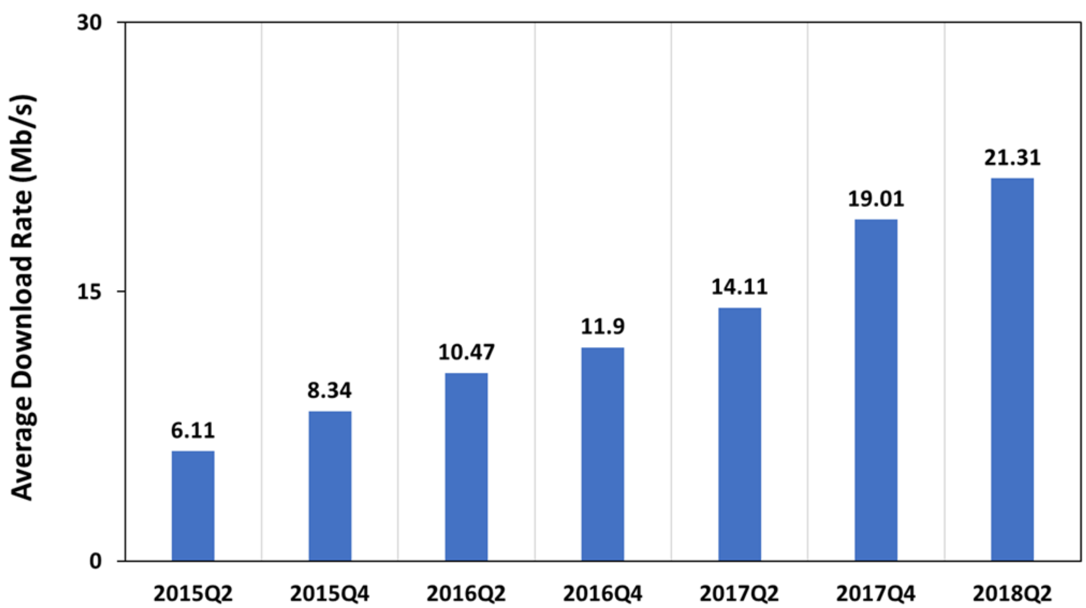

Figure 10—Average Download Rate of Fixed Broadband Users in China (Mb/s) [14]

3.3.2.2 Wi-fi

Monitoring the growth of Wi-Fi hotspots will provide insight into the potential growth of accessing the Internet via Wi-Fi. Figure 11 highlights Wi-Fi hotspot deployment on a regional basis. While there is a 35% CAGR globally for the period of 2017 to 2022, there is a significant variation ranging from 17% to 75% on a per region basis. It is interesting to note that per Table 6 the global average Wi-Fi speed will grow from 24.4 Mb/s to 54.2 Mb/s for a CAGR OF 17.3%.

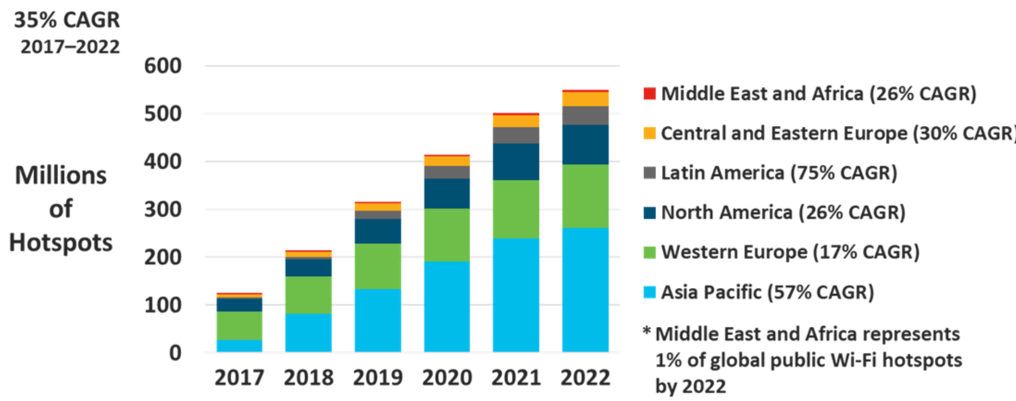

Figure 11—Global Public Wi-Fi Hotspots [18]

3.3.2.3 Cellular / Mobile Networks

With the current industry anticipation of the rollout of 5G, there was a wealth of information on mobile networks presented from various sources to the NEA Ad Hoc.

The following observations were made:

- As shown in Figure 12, the ITU-R forecasted that the number of mobile subscriptions will grow from 10.7 billion to 17.1 billion for the 2020 to 2030 timeframe, which corresponds to a 4.8% CAGR.
- Figure 13 graphs data (minimum, maximum, average) from Akamai, which looked at data on the average connection speeds from approximately 90 countries over the 5-year period from 2013 to 2017. The term connection rate was used with no reference to whether is was download or upload. In 2013 the average connection speed for the countries considered ranged from 0.4 Mb/s to 8.6 Mb/s. By 2017 the average connection speed for the countries considered ranged from 2.8 Mb/s to 26 Mb/s. The average rates for 2013 to 2017 ranged from 2.3 Mb/s to 10.7 Mb/s for a CAGR of 15%.
- Figure 14 shows data on average download rates of 4G users in China, supporting the range calculated from the Akamai data plotted in Figure 13.
- As noted previously, there can be a substantial difference between average and peak data rates. Figure 15 graphs data (minimum, maximum, average) from Akamai, which looked at data on the peak connection speeds from approximately 90 countries over the 2-year period from 2014 to 2016. In 2014 the peak connection speeds for the countries considered ranged from 5.0 Mb/s to 114.2 Mb/s. By 2016 the peak connection speed for the countries considered ranged from 11.7 Mb/s to 171.6 Mb/s. The average rates for 2014 to 2016 ranged from 21.7 Mb/s to 49.0 Mb/s for a CAGR of 23%.

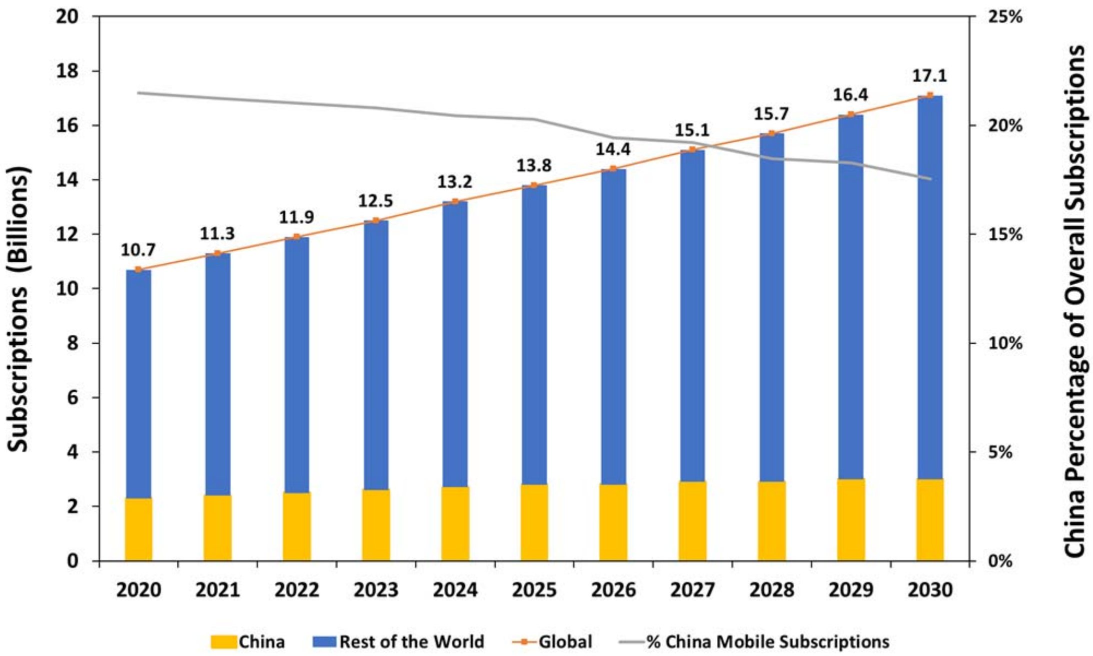

Figure 12—Estimation of Mobile Subscriptions [13]

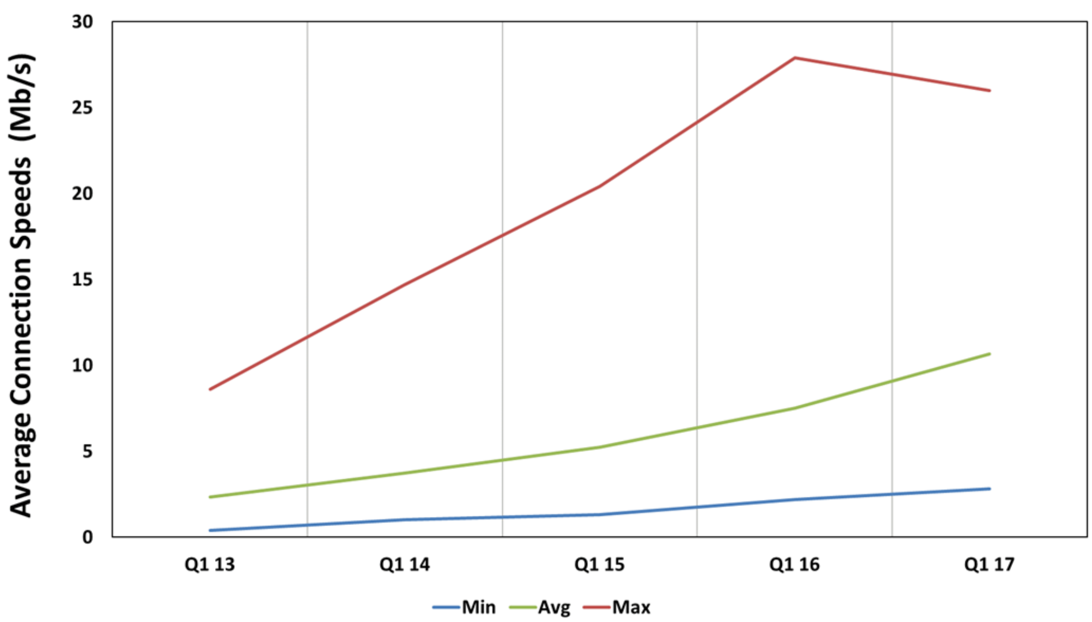

Figure 13—Average Connection Speeds on Mobile Networks [7]

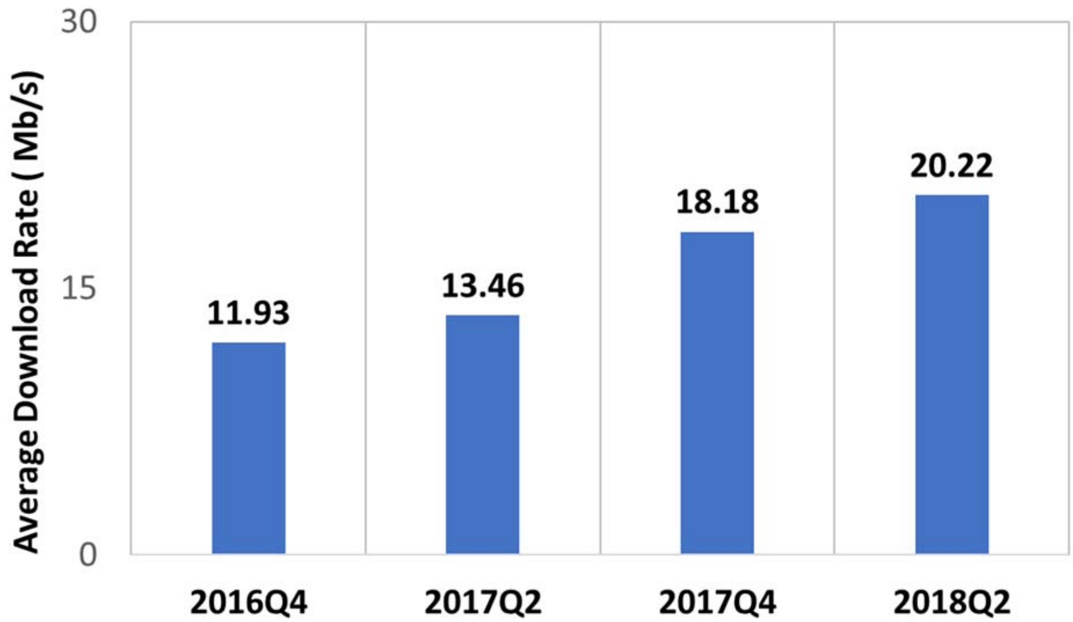

Figure 14—Average Download rate of 4G users in China (Mb/s) [14]

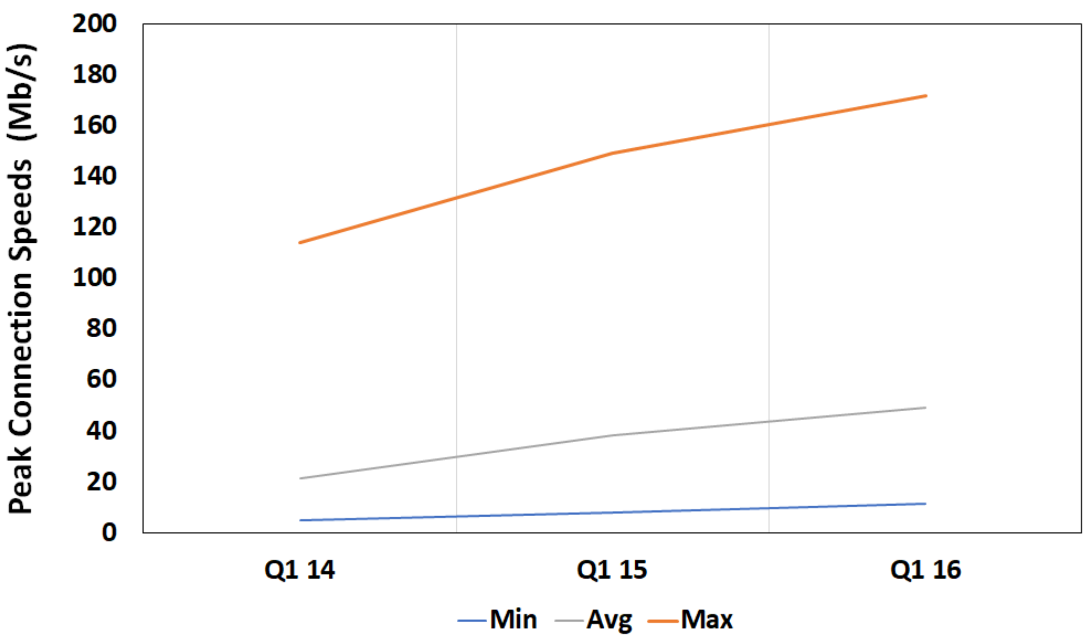

Figure 15—Peak Connection Speeds on Mobile Networks [7]

3.3.2.4 EPON

This section addresses material presented to the NEA Ad Hoc in support of EPON's future bandwidth requirements [16]. There is currently work underway in the IEEE P802.3ca Project that is defining 25 Gb/s and 50 Gb/s EPON solutions, based on 25 Gb/s serial solutions. During the course of this project a presentation was submitted that asserted that existing 10G-EPON solutions will satisfy industry needs until 2025. It was noted that China (Southeast Asia) is very likely the largest growth market for EPON, and further suggested that future deployments in China would focus on 100 Gb/s services based on 50 Gb/s serial rates.

A future Call-For-Interest to start a 50 Gb/s serial EPON project for 50 Gb/s and 100 Gb/s was suggested for the 2020 / 2021 timeframe.

3.4 Increased Services & Applications

As noted in Equation (1), Increased Services & Applications is one of the factors that can drive a bandwidth explosion. Understanding application traffic share can provide insight into usage and provide further guidance. Data gathered from Sandvine from October 2018 [24] related to Global Application Traffic Share from a download perspective is shown in Figure 16 and an upload perspective is shown in Figure 17 [7]. Additional data from Sandvine from February 2019 [25] related to Mobile Download Application Traffic Share is shown in Table 7 [7].

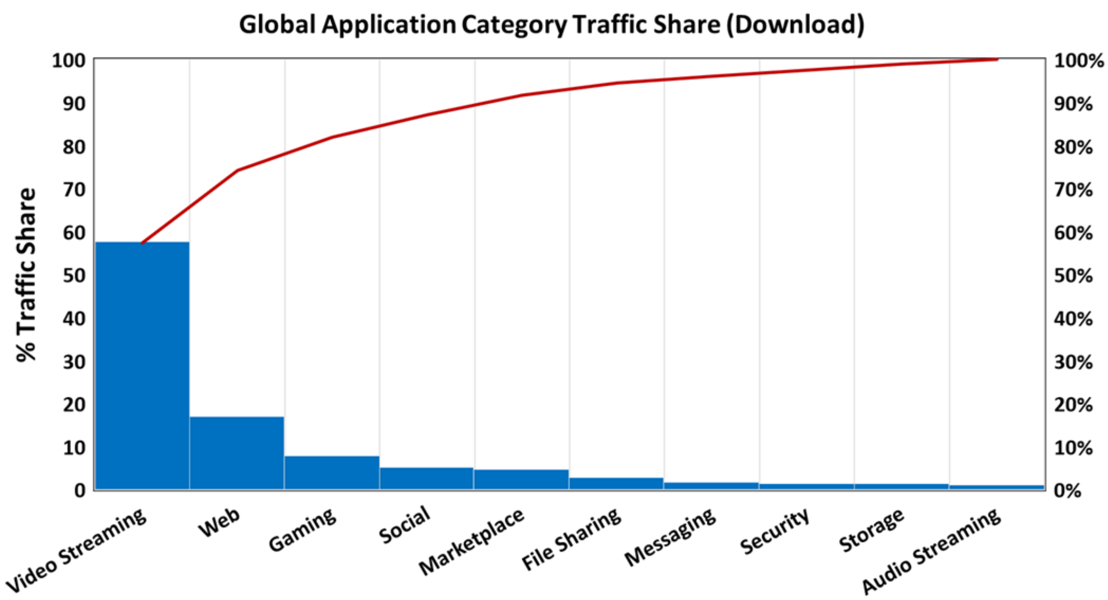

Figure 16—Global Mobile Application Traffic Share (Download) [7]

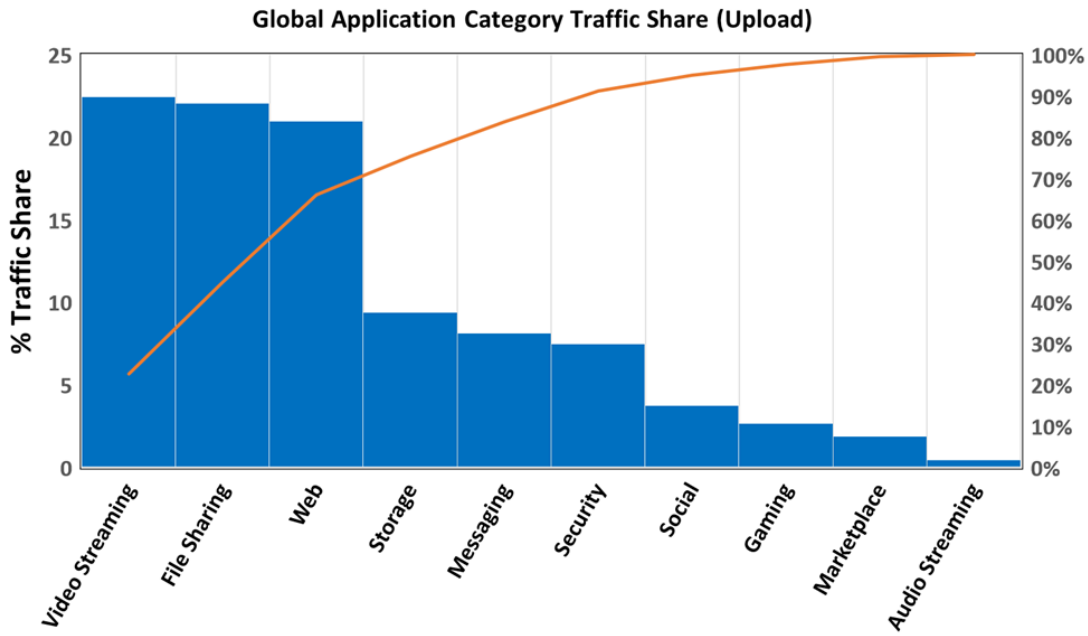

Figure 17—Global Mobile Application Category Traffic Share (Upload) [7]

Table 7—Mobile Application Download Traffic Share [7]

Application	Global	North America	Latin America	Europe	Middle East	Asia-Pacific
YouTube	37%	15%	17%	25%	37%	38%
Facebook	8%	7%	13%	5%	8%	11%
Snapchat	8%	5%		2%	11%	
Instagram	6%	14%	15%	8%	6%	4%
Web Browsing	5%	11%	8%	6%	3%	6%
WhatsApp	4%		12%		5%	
Facebook Video	4%	6%	11%	6%		11%
Netflix	2%	6%	2%	7%	3%	
App Store	2%	3%			2%	
Google Play	2%		3%			2%
iCloud		2%				
Google		4%	4%			
Spotify			1%			
HTTP Media Stream				3%		1%
QUIC				2%		3%
Itunes Store				2%		
PlayStation Download					2%	
Tik Tok					2%	
Line						3%

From this data the influence of video is obvious. To further understand the impact that different services and applications are having on bandwidth growth, it is prudent to also look at forecasted bandwidth growth.
Figure 18 is a forecast of Global IP Traffic Growth for the 2017 to 2022 time period, which illustrates growth from 122 EB per month to 396 EB per month for a 26% CAGR. Figure 19 segments the forecasted data by application with Internet video and IP VOD / Managed IP Video consuming 75% of data, or approximately 90 EB per month, in 2017 to 82% of data, or approximately 325 EB per month in 2022. This corresponds to a 29% CAGR over this time period. This data further justifies that additional consideration be given to video.

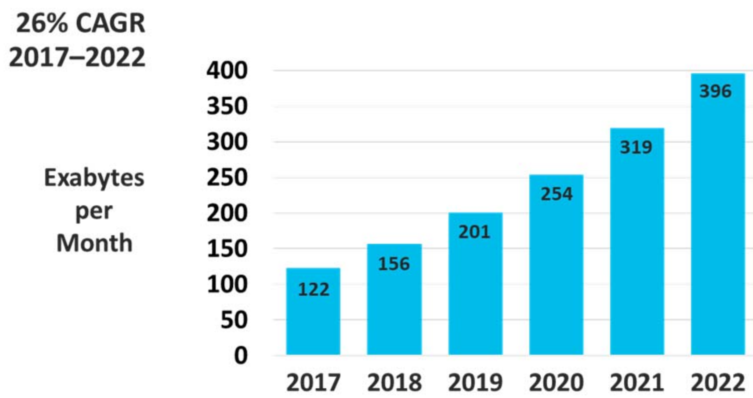

Figure 18—Global IP Traffic Growth [18]

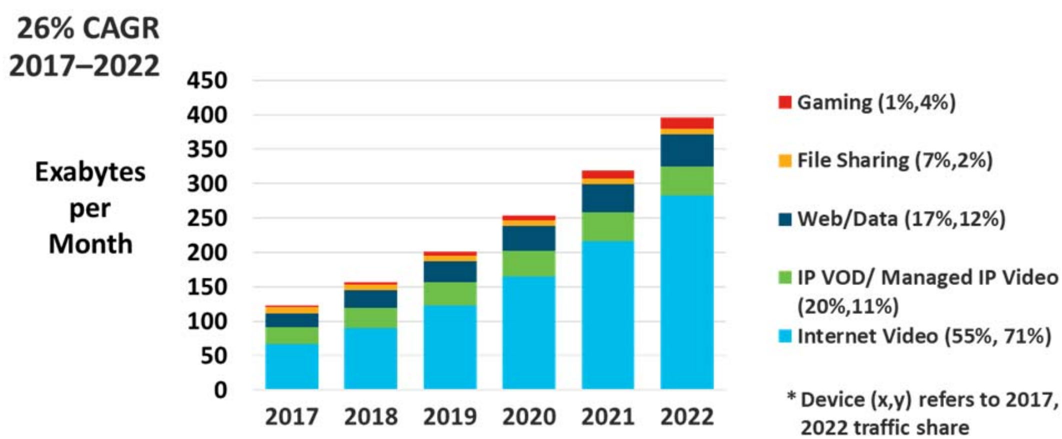

Figure 19—Global IP Traffic by Application Type [18]

3.4.1 Video

The impact of video in driving bandwidth was recognized by the two previous efforts within the IEEE 802.3 Ethernet Working Group when it considered increasing the Ethernet data rate beyond 10 Gb/s in 2006 and 100 Gb/s in 2013. During the course of this assessment the potential large growth of ultra-high definition TV was recognized as justification for exploring the bandwidth demands of video further. Figure 20 highlights that TVs are not the only devices that must be considered when contemplating the impact that video will have on bandwidth demand. It is important to note that by 2022 televisions only represent 24% of the total number of video capable devices.

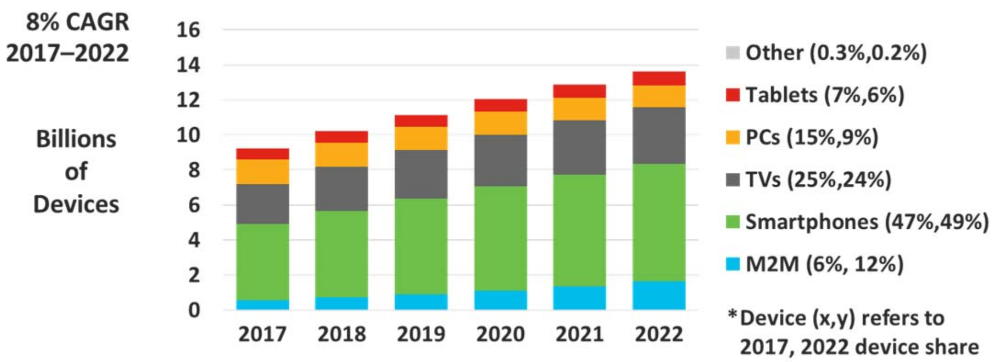

Figure 20—Global Video Capable Device Growth by Type [18]

There is another aspect of televisions that can't be ignored, and that is the video definition. Standard definition (SD) represents 2 Mb/s, high-definition (HD) represents 5 Mb/s to 7.2 Mb/s, while ultra-high-definition (UHD) represents 15 Mb/s to 18 Mb/s. Therefore, the number of connected 4K TV sets (shown in Figure 21) with their inherent ability and potential to use UHD needs to be considered as part of any BWA.

It is anticipated that in the future, support of video beyond UHD, such as 8K/12K/16K, will further accelerate bandwidth growth.

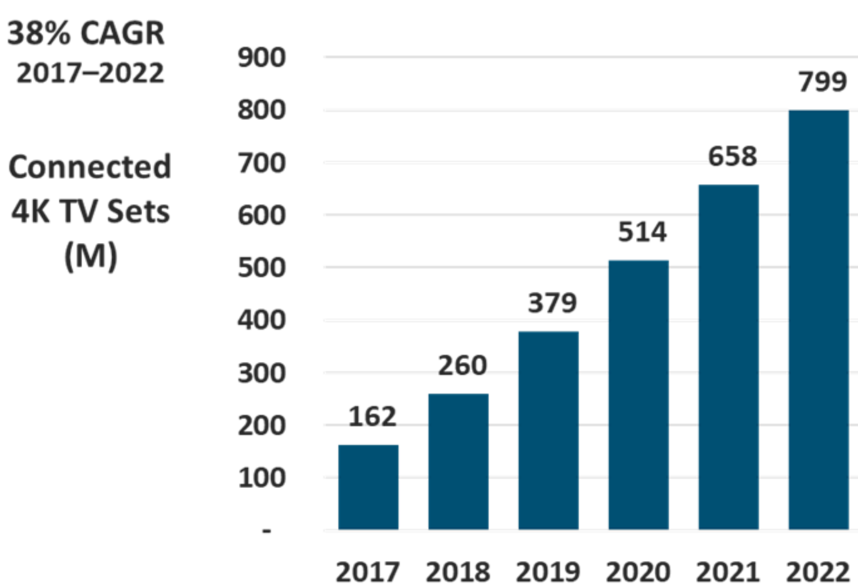

Figure 21—4K TV Sets [18]

Figure 22 highlights the impact of video definition on IP growth. While standard definition represents 50% of IP video data in 2017, it remains relatively flat to 2022, and represents 21% of IP video data. HD video on the other hand grows from approximately 40 EB per month in 2017 to 180 EB per month in 2022 for an approximate 35% CAGR over the 2017 to 2022 period. In 2017 UHD video will comprise ~3 EB per month and grows by a CAGR of ~90% to nearly 72 EB per month in 2022.

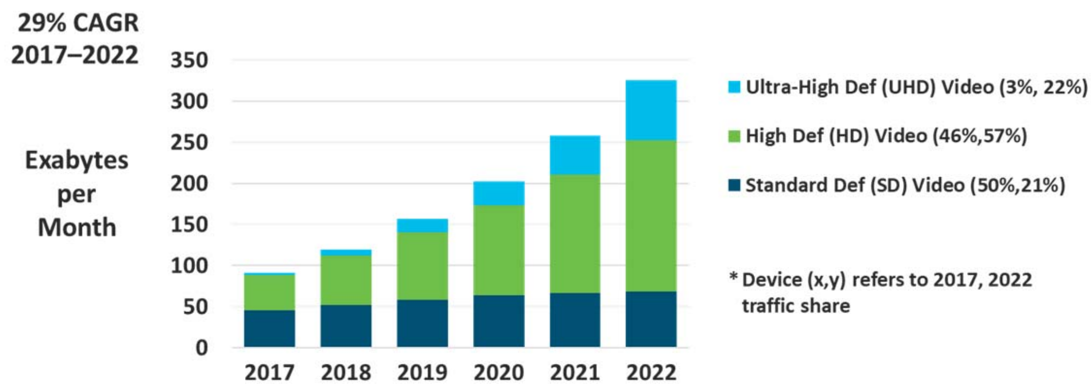

Figure 22—Impact of Definition on IP Video Growth [18]

3.4.2 Virtual / Augmented Reality

Figure 23 illustrates the forecast of traffic growth associated with virtual and augmented reality. This application space is projected to experience a 65% CAGR over the 2017-2022 time frame, resulting in 4 EB per month of traffic.

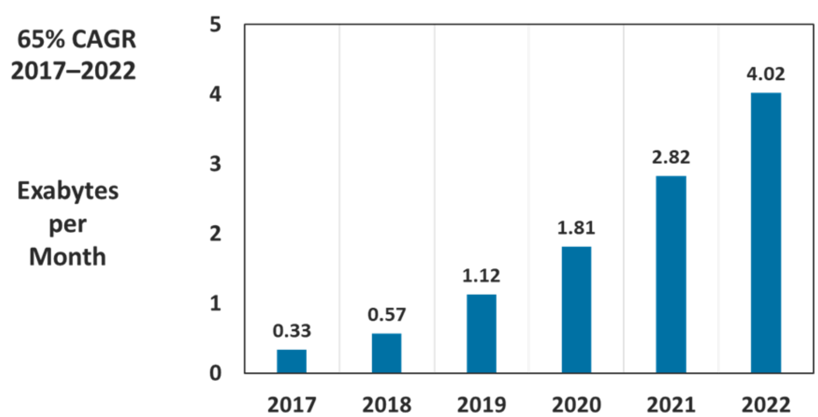

Figure 23—Virtual and Augmented Reality Traffic [18]

3.4.3 Automotive

As shown in Figure 24, for connected cars, there are three networks / connections to consider: 1) the network inside the car (the application space being addressed by Automotive Ethernet); 2) Car-to-car connection; and 3) the car-to-cloud connection (which has potential impact on mobile backhaul traffic). From an Ethernet perspective, the wired network inside the car and the wired infrastructure supporting the car-to-cloud connection are of interest.

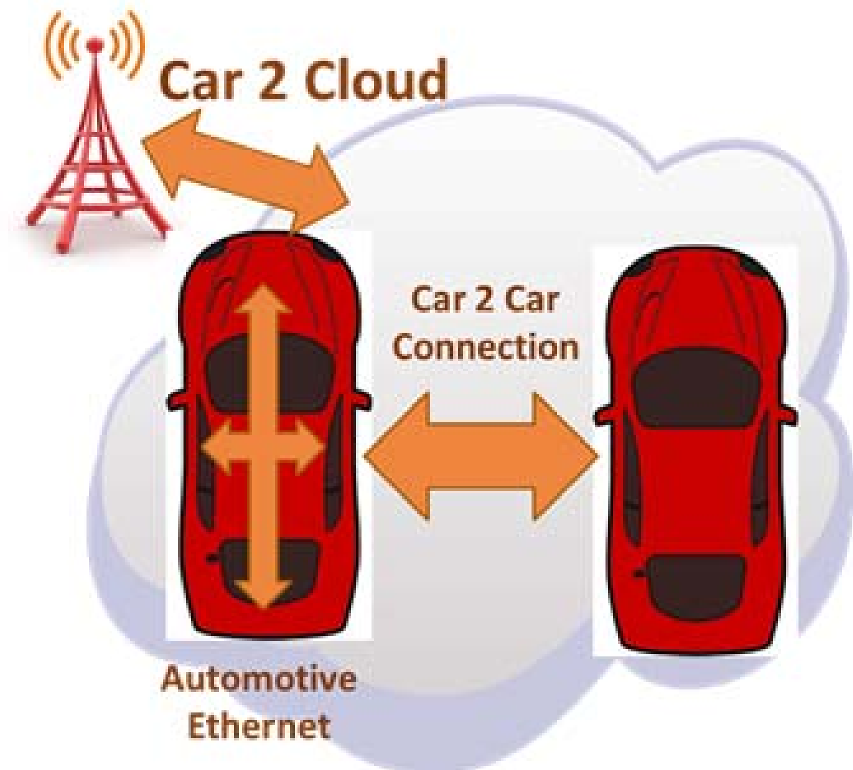

Figure 24—Connected Cars [6]

Table 8 summarizes the target applications of Automotive Ethernet and the necessary data rates. In 2018, global automobile sales were around 80 million passenger cars (cars, light trucks, SUVs). After 2026, it is expected that the average number of Ethernet ports per car will be greater than 100. Based on these assumptions, it is forecasted that the total number of Ethernet ports could be ~ 800 million/year by the mid-2020s.

Table 8—Automotive Ethernet Trends [15]

Time	2012	2016	2019
Data Rate	1 Gb/s	2.5 Gb/s - 10 Gb/s	> 10 Gb/s (25/50 Gb/s)
Target Applications	Advanced Driver Assist Systems (ADAS) • Adaptive cruise control • Lane-departure warnings • Adaptive braking • Medium-resolution cameras • Infotainment • Ethernet backbones between Electronic Control Units (ECU) • Level 0 to Level 2 autonomous driving	High-performance ADAS More high-resolution, high-frame cameras Faster backbones Infotainment, Wi-Fi and cellular backbone Sensor fusion (cameras, radar, LIDAR, sonar) Level 1 to Level 3 autonomous driving	Ultra-high resolution cameras Redundant backbone for zonal architecture Flight data recorder Infotainment, Wi-Fi and cellular backbone Software migration between zonal ECUs Sensor fusion (cameras, radar, LIDAR, sonar) Level 3 to Level 5 autonomous driving Level 5 is a fully driverless car

This forecast does not provide any insight into the bandwidth demands of the car-to-cloud connection. Figure 25 forecasts the amount of global wireless traffic generated by various embedded applications from 2010 to 2020 in automobiles. Note the growth of entertainment and Internet access, which is assumed to be influenced by some sort of video. Unfortunately, no new data was presented during the course of this Ethernet BWA. Furthermore, no information related to the wireless connection to the car was provided. Given the forecasted number of passenger cars, as well as the wireless connection, the car-to-cloud connection is potentially a large bandwidth demand, however an accurate estimate is not possible due to the lack of information related to the types of applications and associated bandwidth demands.

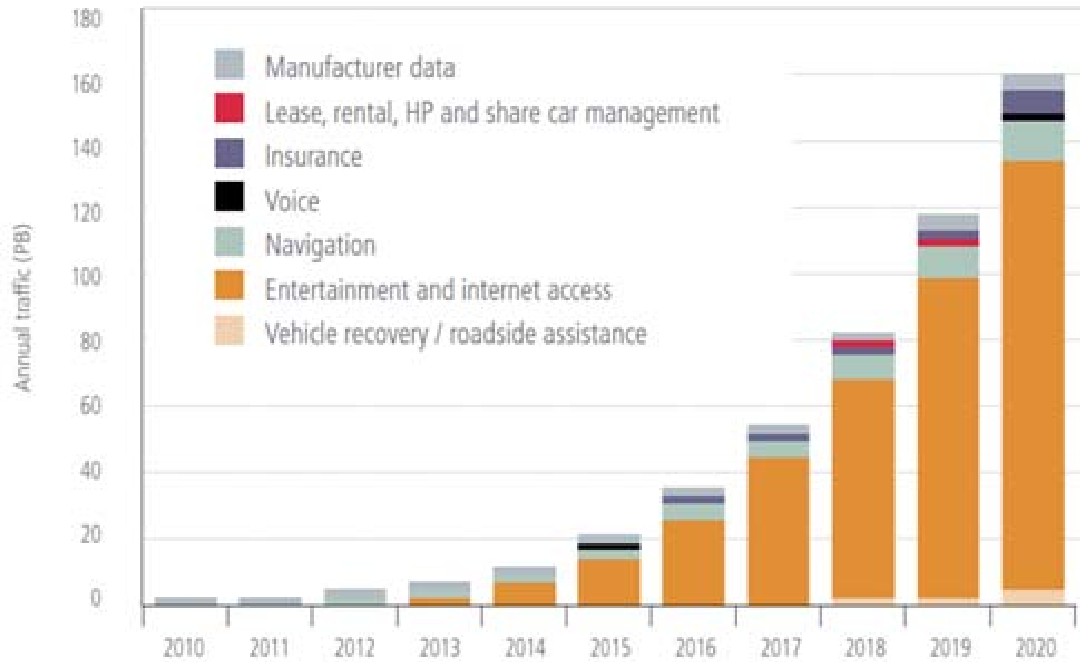

Figure 25—2011 Forecast for Global Wireless Traffic (Embedded Mobility by Application) [6]

3.5 Bandwidth Growth

This section documents data presented to the Ethernet BWA regarding bandwidth growth. Before moving forward, it is important to note that the data presented is representative of the application it addresses.

Figure 26 highlights global IP traffic growth by region. For the 2017 to 2022 time period, the CAGRs per associated regions varied anywhere from 21% to 41%.

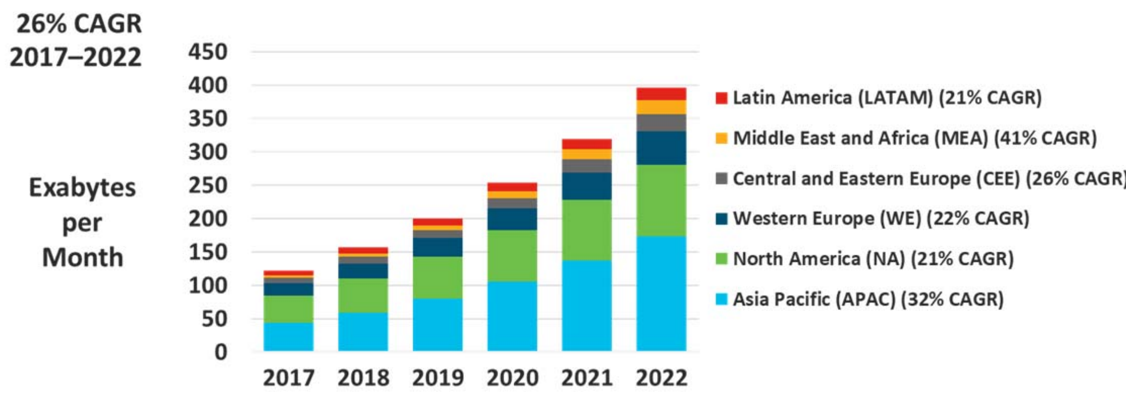

Figure 26—Global IP Traffic Growth by Region [18]

Figure 27 demonstrates the broad variation in observed bandwidth growth patterns. As shown, for the 2011 to 2023 time period, the growth rate of Internet traffic has slightly declined, while the rate of growth for global mobile traffic has declined by over 60%. Conversely, as reported by CINIC, the rate of growth for China mobile data significantly increased from the 2011 to 2018 from 50% to 200% but fell to 100% for 2019.

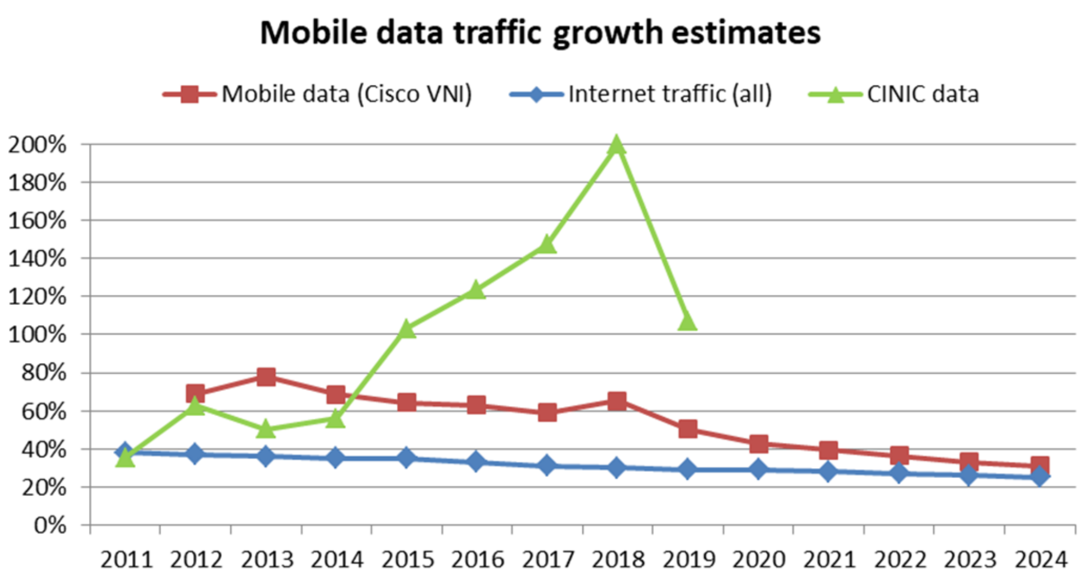

Figure 27—Comparison of Growth Rates [17]

3.5.1 Data Centers

Supporting the bandwidth demand for data centers has justified the start of many Ethernet standardization and industry multi-source agreement efforts targeting I/O module form factors. Understanding the future trajectory of their bandwidth demand, therefore, is a priority. Before considering the bandwidth demand, it is useful to understand what is happening with server deployments. Figure 28 is a forecast of enterprise and cloud server unit shipments. Figure 29 is a forecast of data center Ethernet switch capacity shipments.

Figure 28 highlights the percentage decline in servers based on <= 10 Gb/s from 2014 to 2023, while 25 Gb/s to 50 Gb/s servers will grow to be approximately 60% of servers shipped by 2023. Shipments for servers supporting 100 Gb/s or greater are forecasted by 2023 to represent 25% of all server shipments.

Figure 29 shows the forecast for the annual port capacity shipped on Data Center Ethernet switches in exabits per second. The corresponding exponential growth in capacity shipments is undeniable, as the bandwidth capacity shipped exhibits a CAGR of 44% from 2014 to 2023.

Light Counting provided the data in Figure 30, which forecasts the bandwidth growth in data center traffic and optical shipments from 2011 to 2024. It is interesting to note the forecasted decrease in growth rates over the time period.

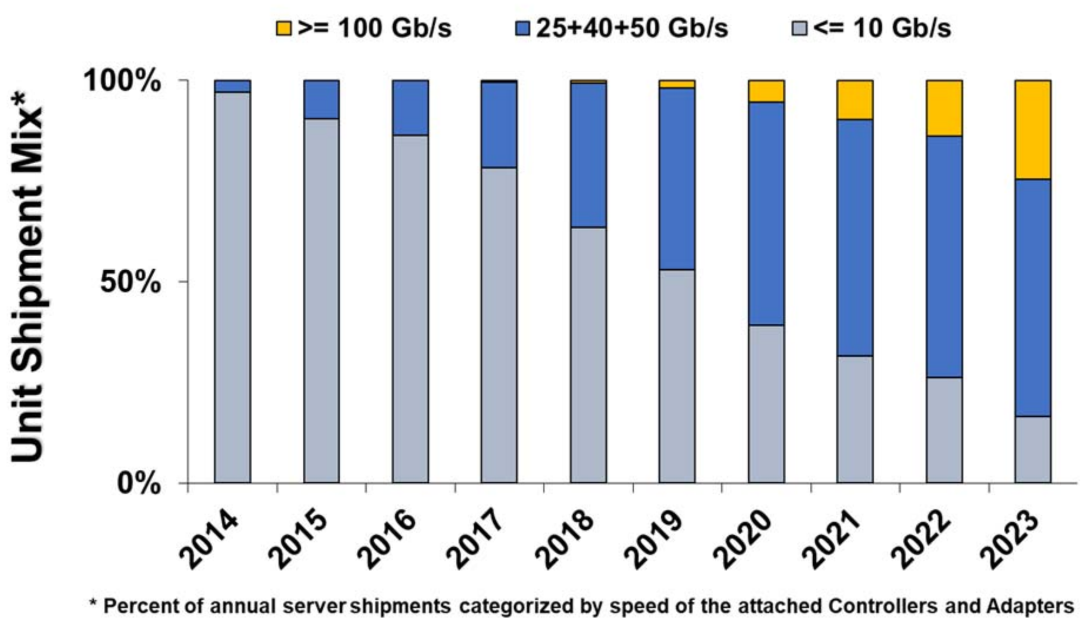

Figure 28—Enterprise and Cloud Server Unit Shipments [21]

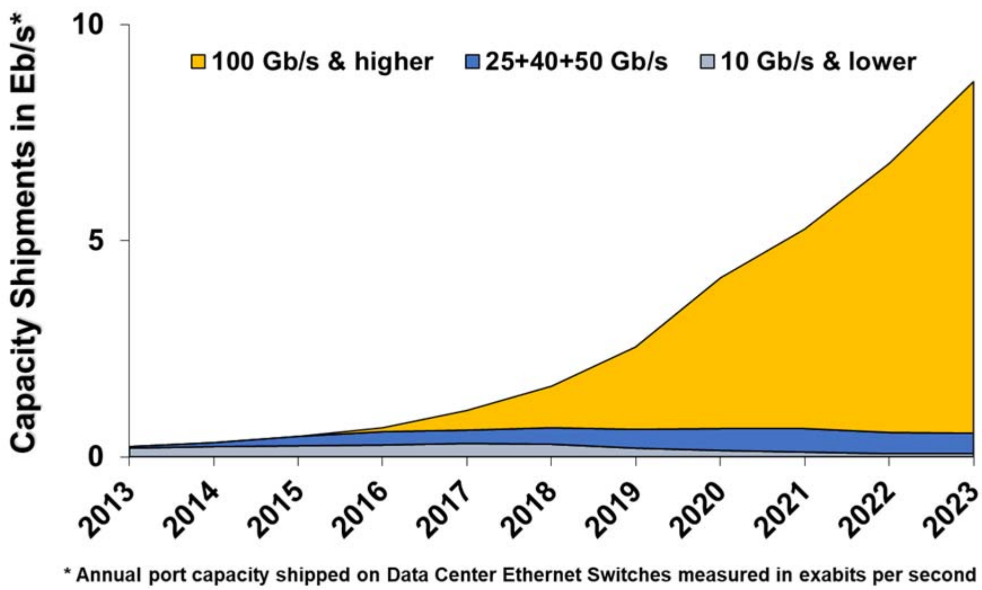

Figure 29—Data Center Ethernet Switch Capacity Shipments [21]

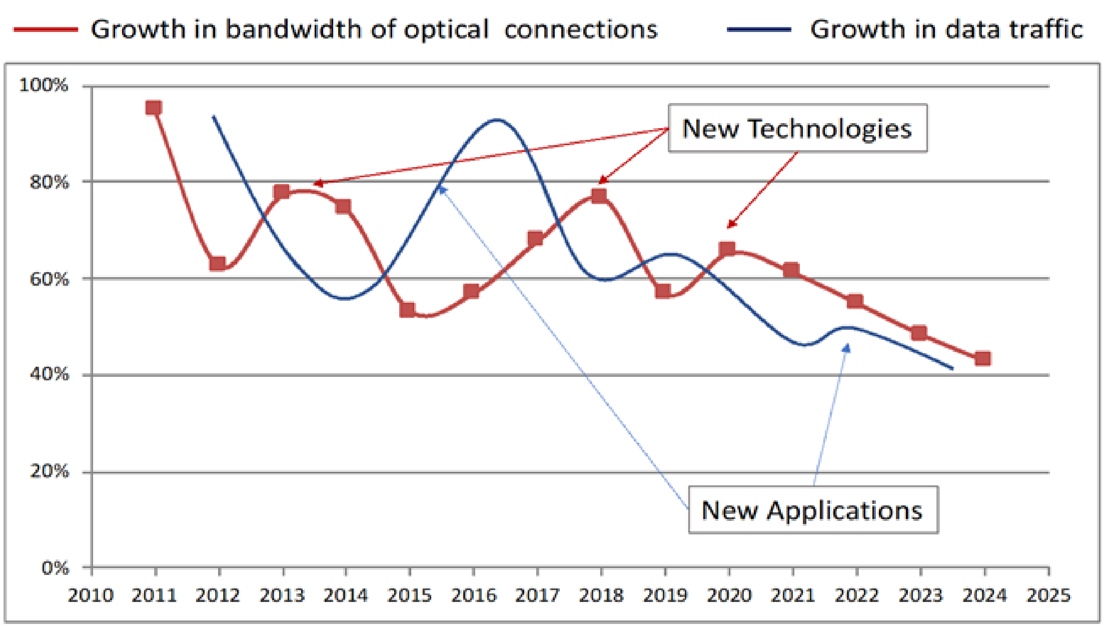

Figure 30—Data Center Data Traffic and Bandwidth of Connectivity [17]

This data is thought to be representative of internal east-west traffic in the data centers themselves, but it is believed that there will be a rise in traffic leaving the data centers themselves. There was no data presented defining such a relationship. Online public peering data for seven hyperscalers, available at PeeringDB, was reviewed, as of August 23, 2019 [8]. For the seven hyperscalers considered there were nine ASN's (Autonomous System Networks). The public peering capacity ranged anywhere from 1.1 Tb/s to 15.3 Tb/s for a total of 55.7 Tb/s. Figure 31 provides a profile of the peering connections and the associated number of network connections at the noted capacities. It is unclear what will happen to this profile with increased data center traffic.

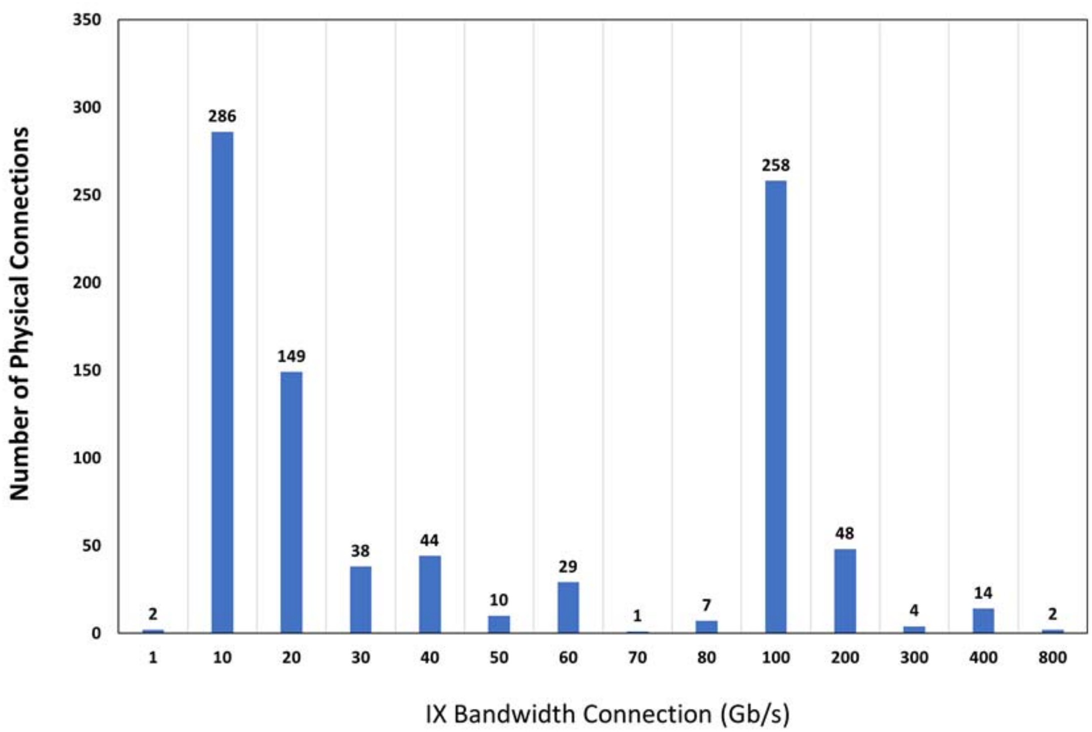

Figure 31—Hyperscaler Data Centers in PeeringDB [8]

3.5.2 Content Delivery Networks (CDN)

Figure 32 forecasts the growth of traffic associated with content delivery networks. As noted, for the 2017 to 2022 period, CDN traffic is forecasted to experience a 30% CAGR.

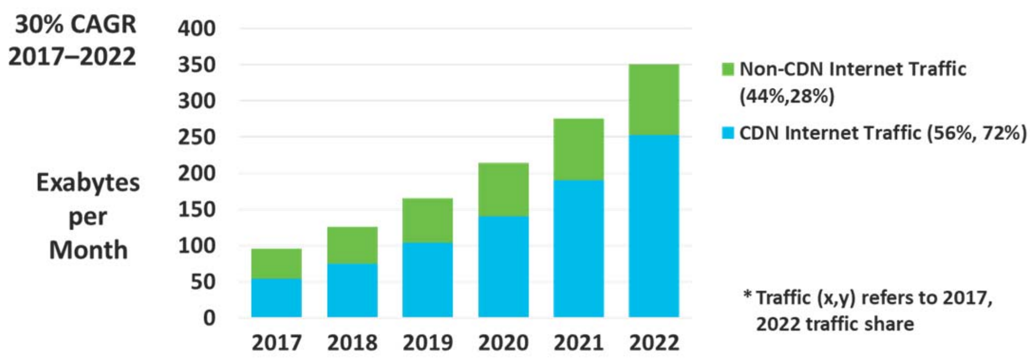

Figure 32—Global Content Delivery Network (CDN) Traffic [18]

3.5.3 Mobile Networks

Figure 33 is an estimate of mobile traffic consumed per subscription per month globally. The estimate uses a method based on the estimated results of global mobile traffic divided by global mobile subscriptions (IoT / M2M traffic was not included). In 2020 the amount of traffic per month is 5.3 GB and is forecasted to grow to 257.1 GB by 2030 for a CAGR of 47%. Figure 34 is an estimate of mobile traffic including IoT / M2M traffic per month. In 2020 the amount of traffic is 62 EB per month and is forecasted to grow to 5016 EB by 2030 for a CAGR of 55%.

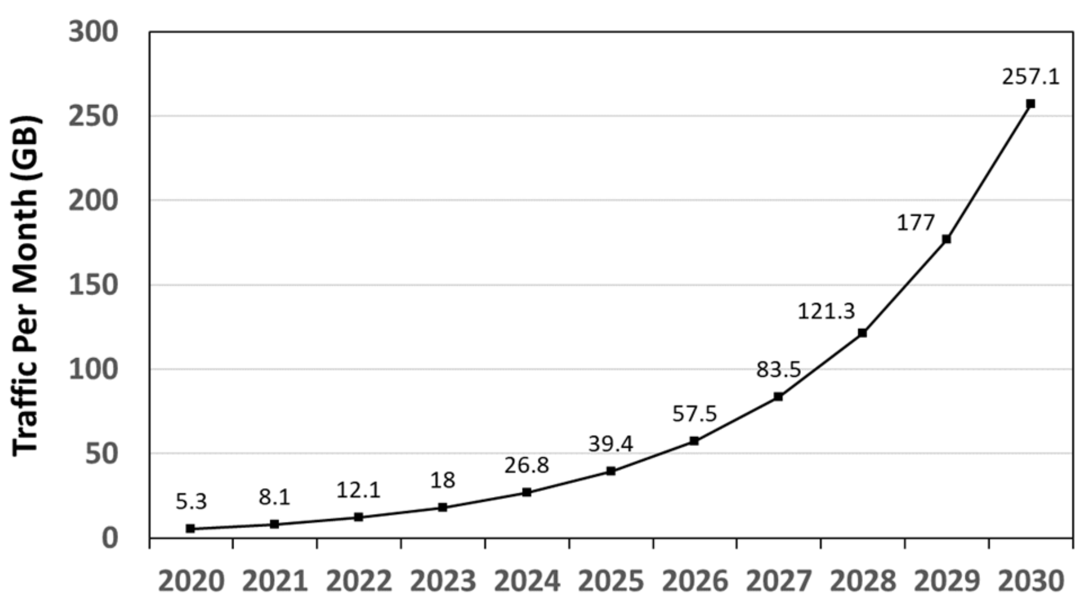

Figure 33—Estimations of global mobile traffic per subscriptions per month from 2020 to 2030 (IoT / M2M not included) [22]

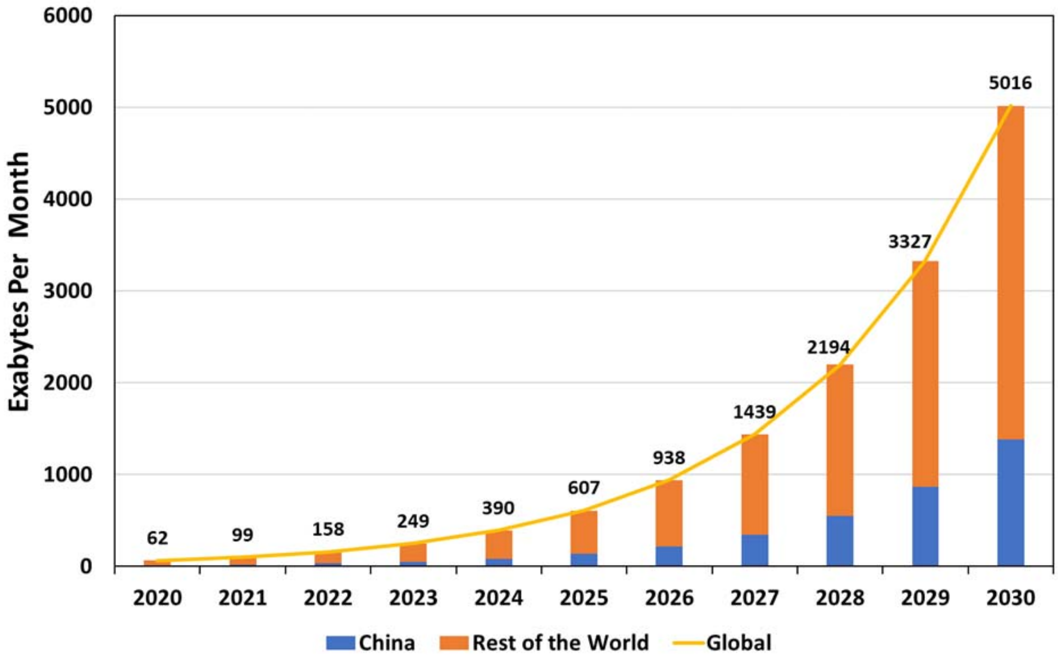

Figure 34—Estimation of mobile traffic in 2020-2030 (IoT / M2M traffic included) [22]

3.5.4 Service Provider Networks

Figure 35 was provided by LightCounting, and illustrates two very important trends that need to be considered. First, Internet traffic has grown at a consistent year to year growth rate, though there has been a slight downward trend over the 1999 to 2023 period considered. The second trend is the cyclical update in DWDM network bandwidth capacity that has occurred.

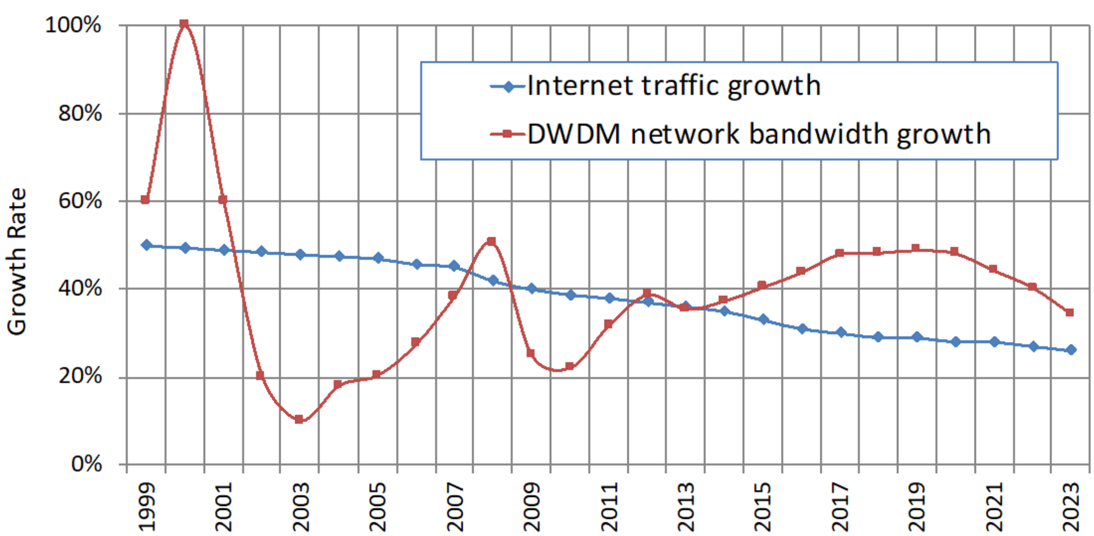

Figure 35—Growth in Network Bandwidth vs Growth in Traffic [17]

Figure 36 shows data presented regarding the predicted backbone and metro growth for China Telecom's network, showing a CAGR of 40%. It was reported that China Mobile and China Unicom have similar rates. The increase in metro traffic over backbone should also be noticed.

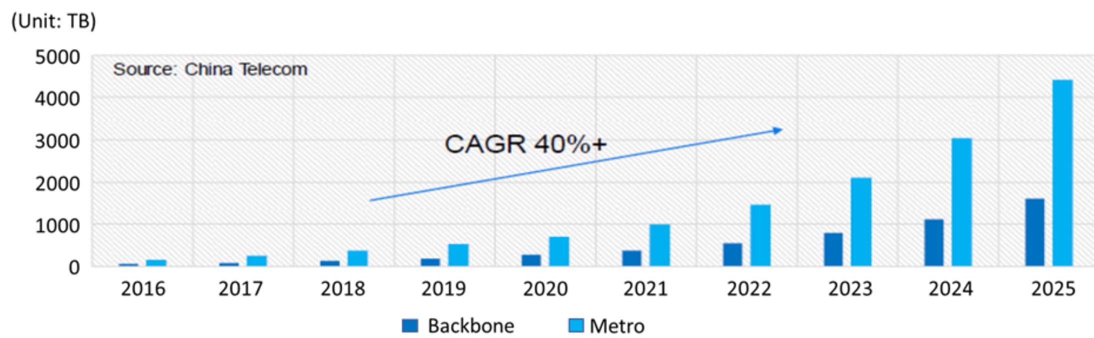

Figure 36—Predicted Traffic on China Telecom's Network [14]

The growth of traffic for Content Delivery Networks was explored in 3.5.2, which noted a 30% CAGR for the 2017 to 2022 period. It was noted that metro-capacity of service provider networks is growing faster than core-capacity and will account for a third of total service provider network capacity by 2022. See Table 9. The negative numbers shown in Table 9 highlight that “Core-Regional” and “Core-Cross-Country” will account for less of the service provider network capacity in 2022 as compared to 2017.

Table 9—Service Provider Network Capacity [18]

	2017	2022	Change
Within Metro	27%	33%	6%
Core-Regional	25%	24%	–1%
Core-Cross-Country	48%	43%	–5%

3.5.5 Internet Exchanges

Data from Euro-IX from its members who provide Internet Exchange Points was submitted. This data is an update to data submitted to the original Ethernet BWA in 2011.

As shown in Table 10, the number of IPXs has nearly doubled in the past 8 years, highlighting the growing need for peering.

Table 10—Global IXP Development by Region [19]

Region	IX-F Member	2011	2019	Growth
Europe	Euro-IX	132	218	65%
APAC	APIX	60	159	165%
Africa	AF-IX	22	43	95%
LATAM	LAC-IX	27	76	181%
North America		80	134	68%
Global		312	630	96%

It was noted that seven of the top 10 IXPs in the world (by peak data rate) are in Europe. Of the Top 10 European IXP's, six of them have more than 5 Tb/s traffic (by peak data rate).

Figure 37 [19] highlights the port counts for Euro-IX and connected capacity by port speed for the 2013 to 2018 period (2016 data missing). The impact of 100GbE on connected capacity is evident, as nearly 60% of the noted connected capacity is attributed to 100GbE, which is a small portion of the overall port count.

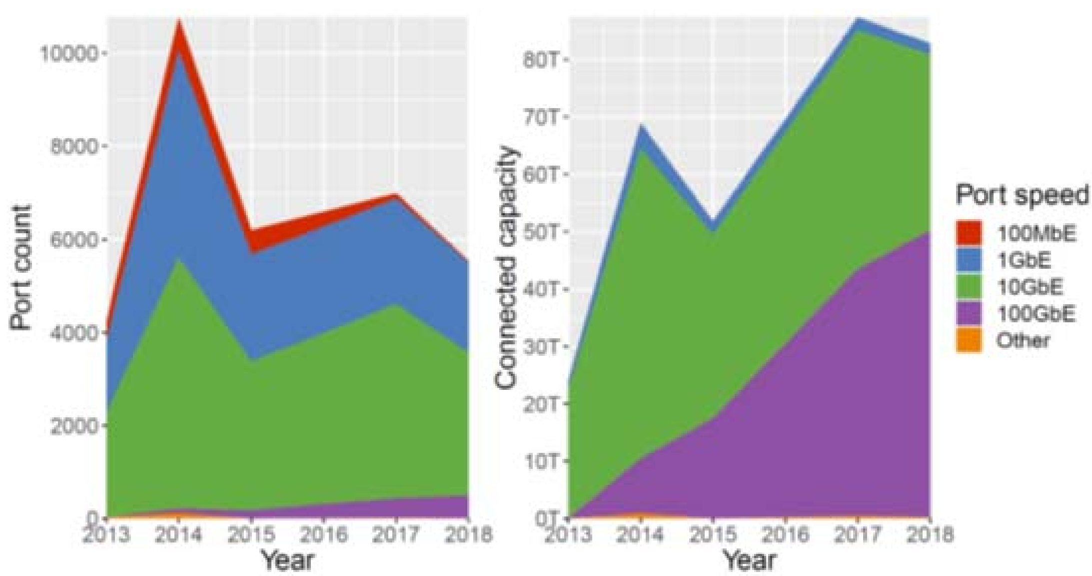

Figure 37—Euro-IX Port Speed Trends [19]

Figure 38 highlights the peak data rates by region from 2008 to 2019. It should be noted that this is an aggregate of all IXPs in each region for each IXP region shown. The European region is significantly greater than each of the other regions.

Figure 38—Peak Data Rates by IXP Region [19]

Figure 39 provides trend analysis of the Euro-IX peak data. It should be noted that for Euro-IX from 2008 to mid 2012 the peak data was on a 4.8 Gb/d curve, and then switched to a 12.2 Gb/d trendline. If it continues at this trend line the forecasted peak capacity would be at ~50 Tb/s in 2022.

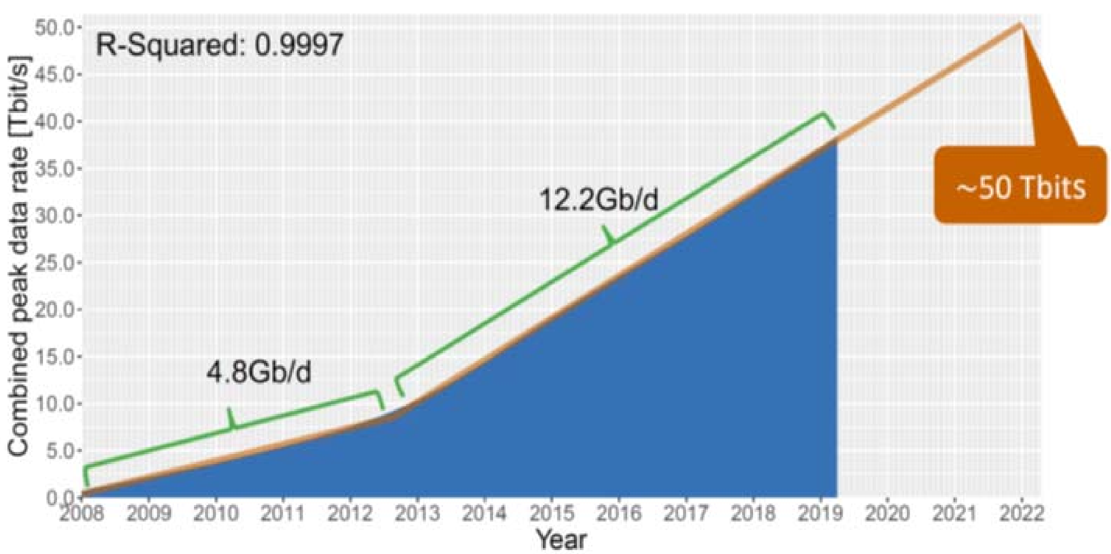

Figure 39—Euro-IX IXP Peak Data Rate Trend [19]

3.5.5.1 Case Study - DE-CIX

The same data provided for Euro-IX was also provided for DE-CIX which is one of the largest IXPs in Europe. Figure 40 provides the DE-CIX port speed distribution with the connected capacity shown in Figure 41. Figure 42 shows the DE-CIX peak data rate, while Figure 43 shows the DE-CIX trend analysis. Based on this analysis DE-CIX is looking at a peak data rate of ~8.8 Tb/s by 2022.

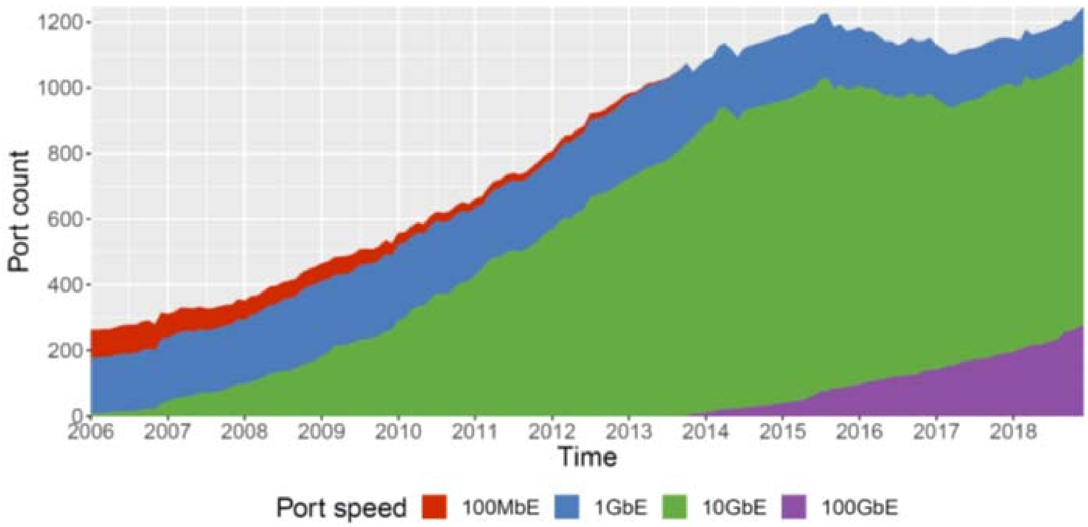

Figure 40—DE-CIX Port Speed Distribution [19]

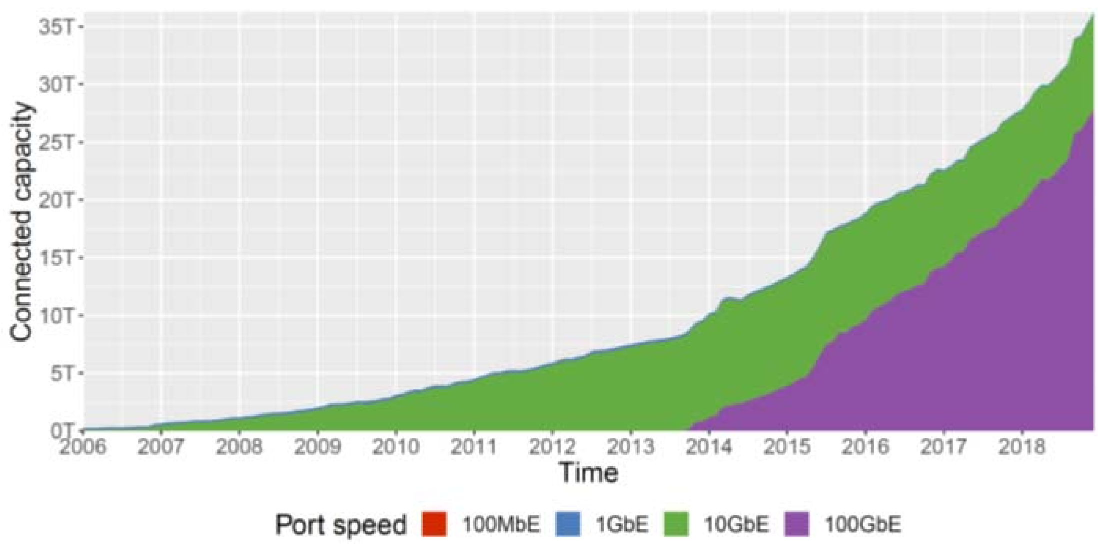

Figure 41—DE-CIX Connected Capacity by Port Speed [19]

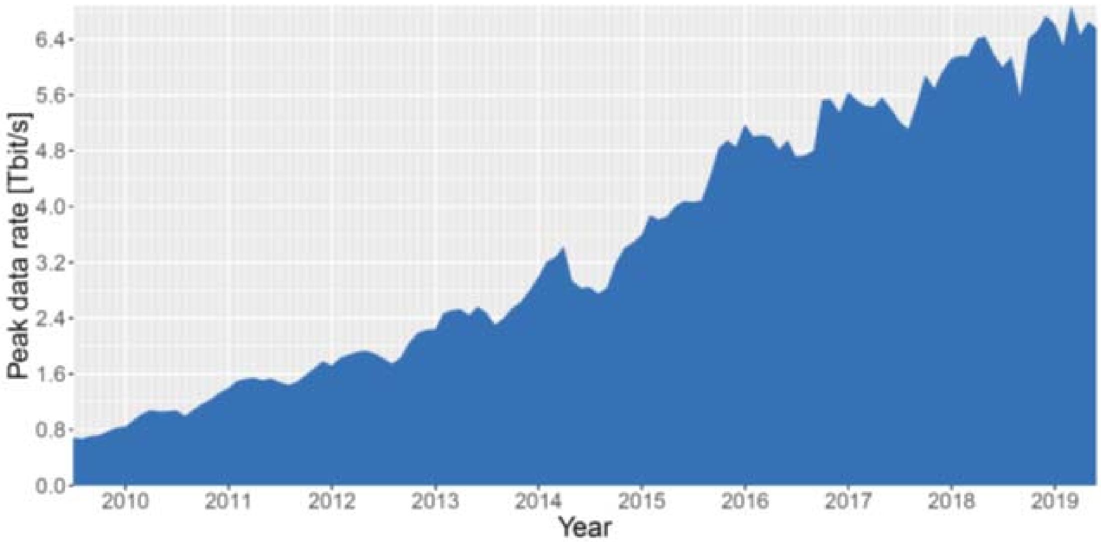

Figure 42—DE-CIX Peak Data Rate [19]

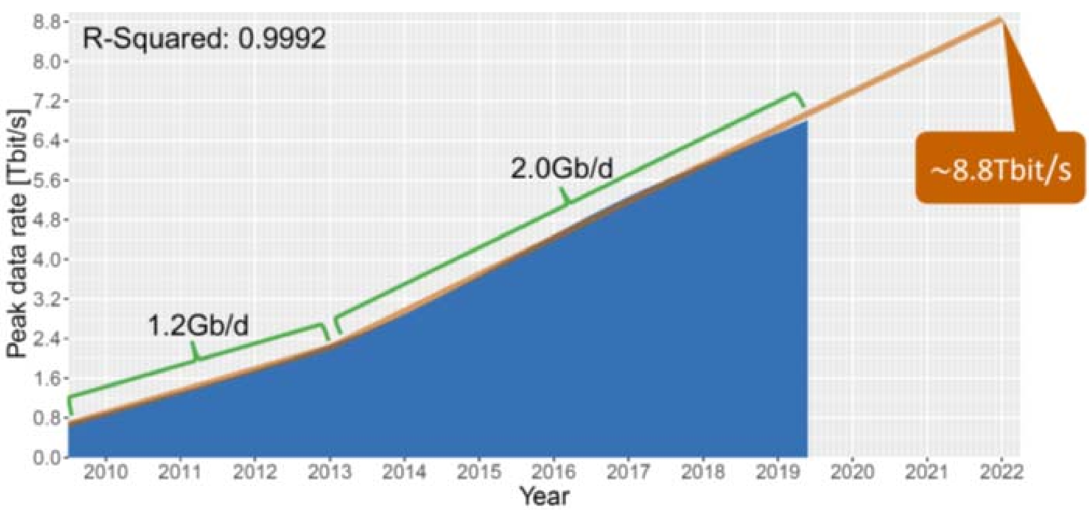

Figure 43—DE-CIX Peak Data Rate Trend [19]

3.5.5.2 Public Peering

An analysis of all ASNs in the PeeringDB Network Database, as of July 1, 2019 was performed. The data was examined by network type, traffic, and region.

For "traffic" only 60% of the ASNs reported their ASN's associated traffic. It should also be noted that the traffic categories provided are specified by PeeringDB.

Figure 44a and Figure 44b look at the traffic associated with various network types. While there is no forecast of data growth, it is clear from the data that "Network Service Providers" and "Cable/DSL/ISP" had the largest amount of traffic in nearly all traffic categories from 100 Mb/s and up, with "Content" usually rounding up the top three positions. Networks ranging from 100 Mb/s to 10 Gb/s accounted for ~40% of all ASNs.

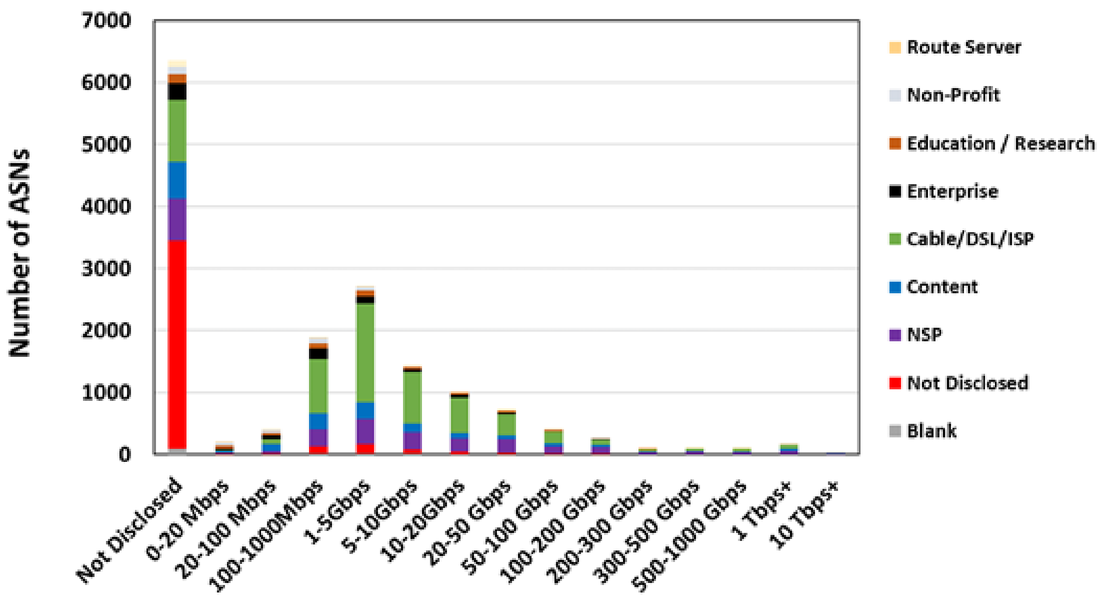

Figure 44a—Traffic Per Network Type [8]

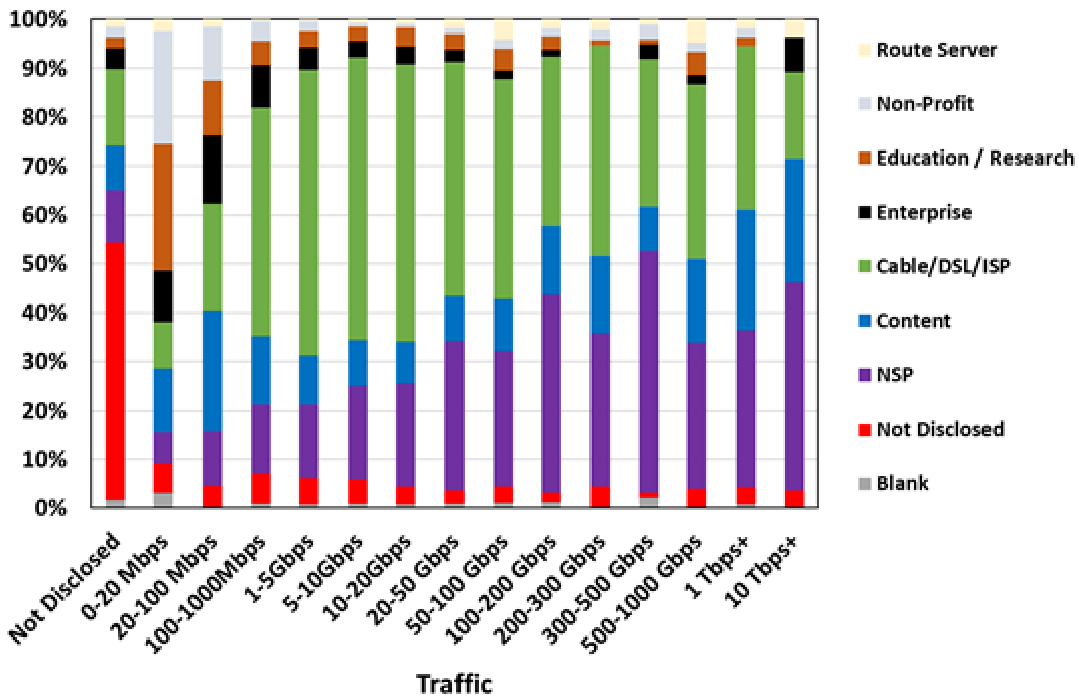

Figure 44b—Traffic Per Network Type [8]

Figure 45a and Figure 45b look at traffic on a regional basis. It should be noted that in addition to the prior comments of this data, the "Regional" category is not well defined, but typically means that a given ASN is not covering the full region to which it belongs but only a sub-region. Global networks were the highest for 1 Tb/s+ in traffic, while regional was clearly a large number of networks across all speeds.

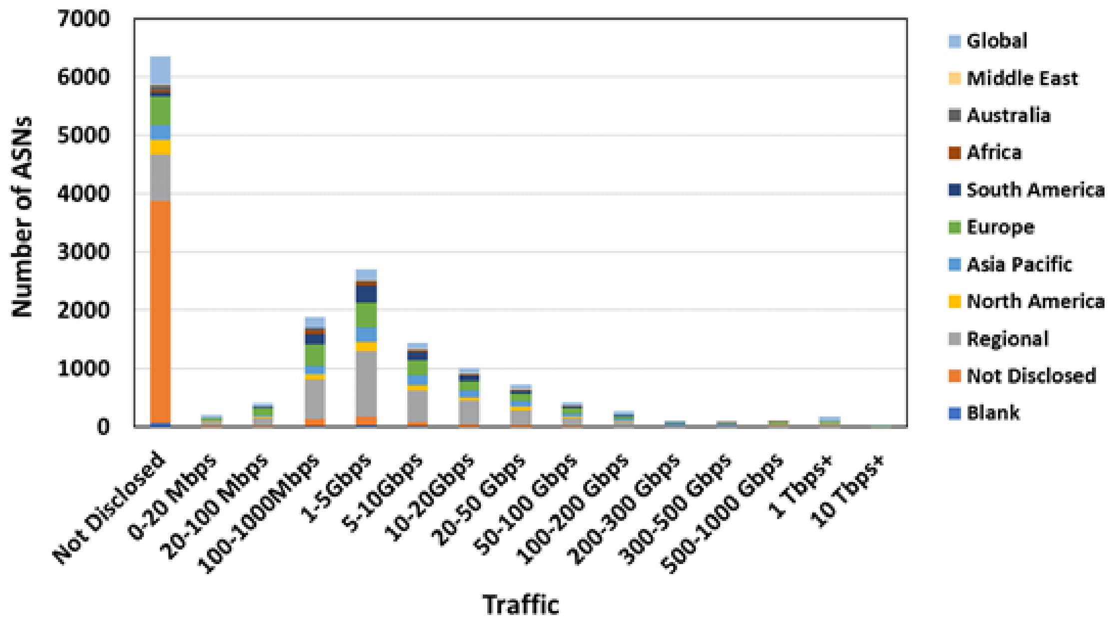

Figure 45a—Traffic Per Region [8]

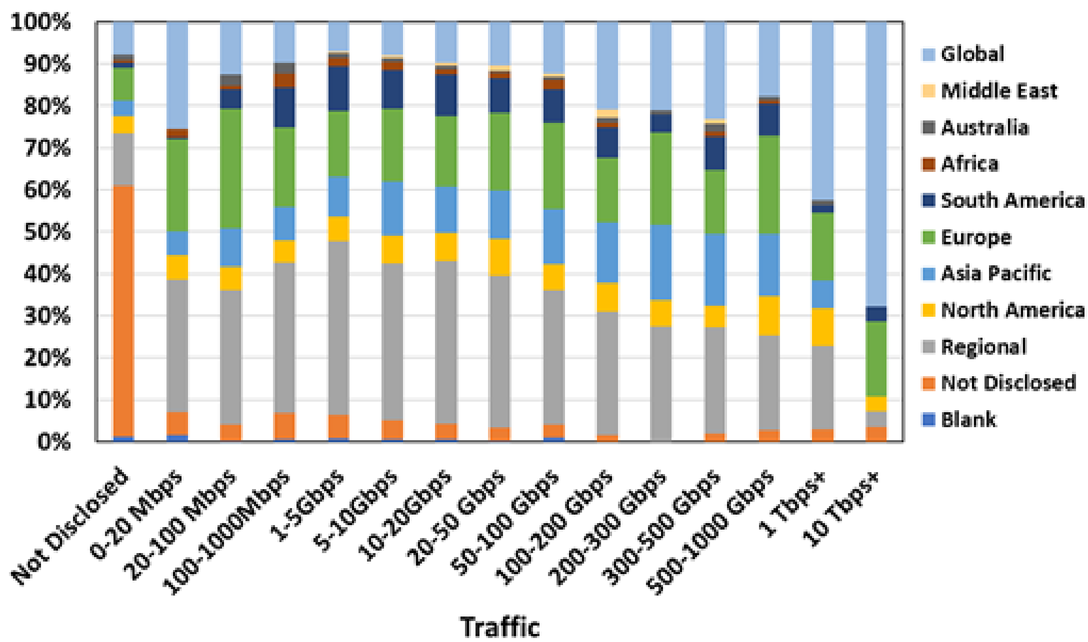

Figure 45b—Traffic Per Region [8]

Figure 46a and Figure 46b look at the network types on a regional basis. From this data it is noted that North America has a small number of ASNs reported. Given other data in the Ethernet BWA, it is suspected that North American ASNs may either have been reported as "Non Disclosed" or "Regional." The other observation is that North America and Europe had similar network distributions, as did South America and Africa.

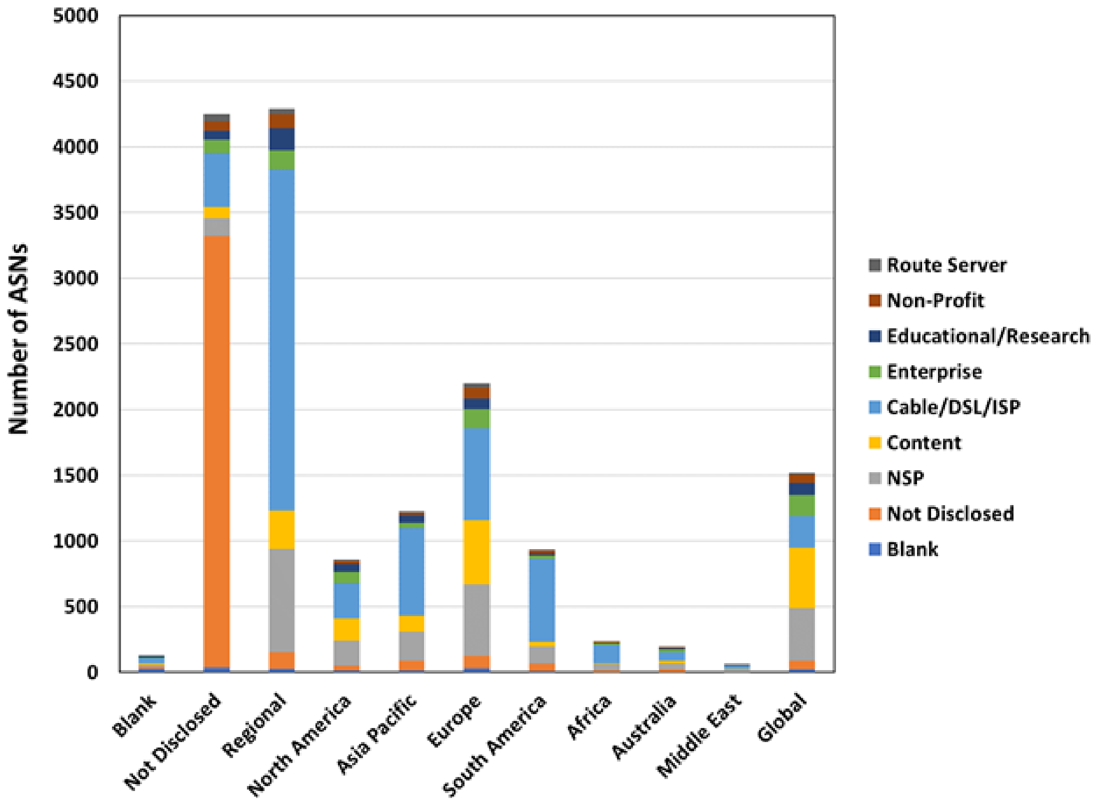

Figure 46a—Network Distribution per Region [8]

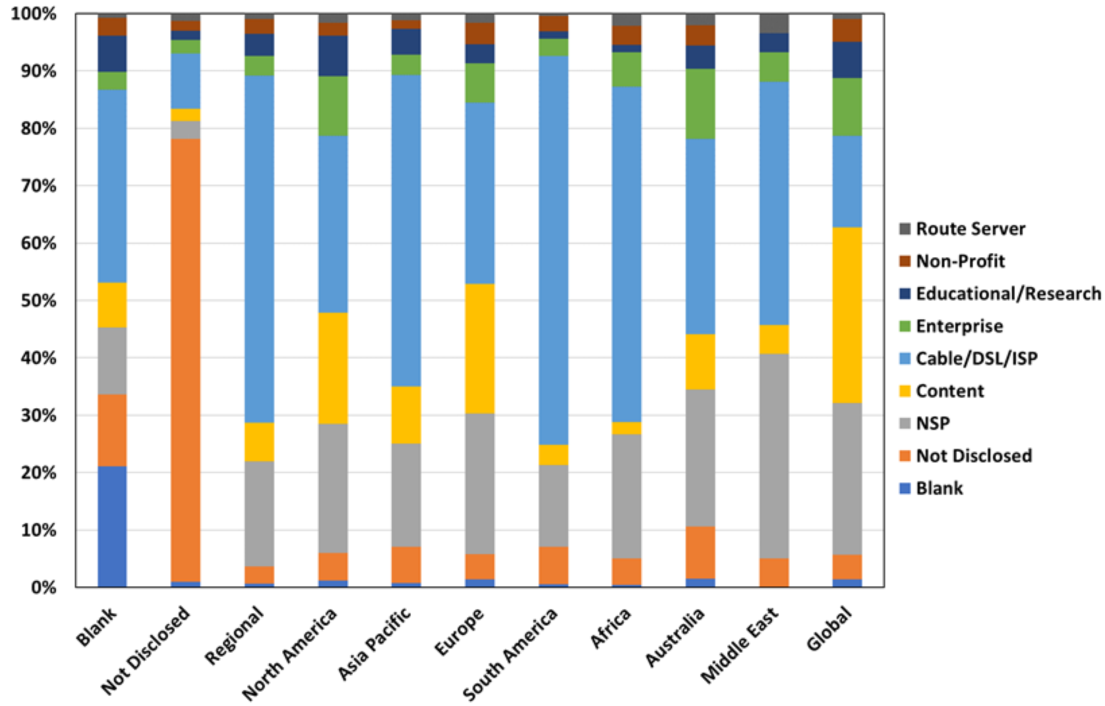

Figure 46b—Network Distribution per Region [8]

4. Assessment

4.1 Overview

The data submitted to the second Ethernet BWA was considerably broader than the data submitted to the first assessment. While there is a considerable amount of data regarding network usage, there is also a significant amount of data related to users, their usage habits, different access rates, different applications, and geographical basis. While all of the data is relevant to different application spaces that leverage or may leverage Ethernet, the breadth of the available data provides insight into the challenge of a bandwidth forecast for a basic technology like Ethernet.

This Assessment section, like the "Key findings" on page 13, will leverage Equation (1), and explore the various findings of each factor of the equation, as well as the noted "bandwidth explosion" product. Before reviewing the findings, it will be a useful exercise to review any data that compares to the forecast made by the first Ethernet BWA, as well as other prior forecasts, to understand potential limits to prior forecasts.

4.2 Prior Forecasts

The 2012 IEEE 802.3 Industry Connections Ethernet BWA produced the following forecast for the bandwidth demand of various application spaces. See Figure 47.

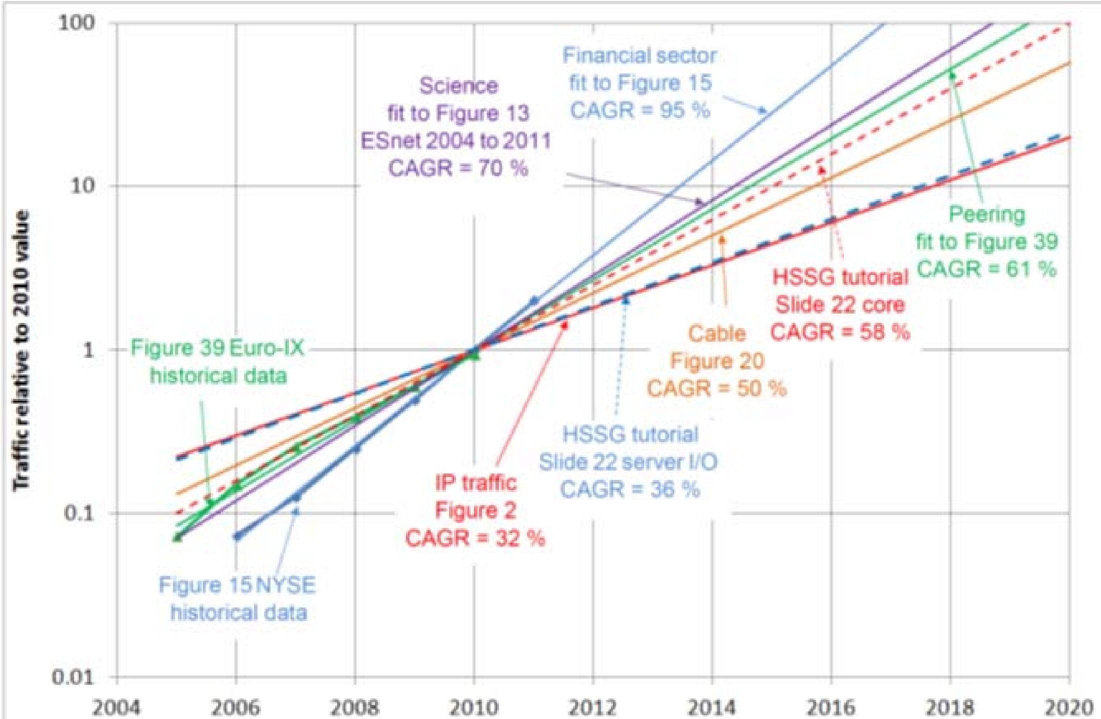

Figure 47—2012 IEEE 802.3 Ethernet BWA Forecast [1]

For the second BWA, data was provided that corresponded to 1) IP Traffic and 2) Peering. As shown by Table 11 the corresponding 2012 forecasts were slightly optimistic, but it should be noted that the comparison was for a period 6 years out.

Table 11—2012 Ethernet Bandwidth Forecast Accuracy

For 2018	Forecast	Actual
IP Traffic	~200 EB / month	156 EB / month
Peering	~187.5 Tb/s	~32.5 Tb/s

Additional comparisons provided by LightCounting provide additional insight into potential market trends that may potentially explain deviations between forecasted and actual data. Figure 48 compares forecasted and actual data for DWDM ports. As shown, while the overall count was relatively close, the predicted mix between 40GbE and 100GbE was off. However, it is clear that demand for 40GbE ramped up and fell quicker than predicted in the forecast, while 100GbE didn't ramp up as initially suggested, but then outpaces expectations. Exceeding expectations is also a potential, as shown by Figure 49, where demand for both 40GbE and 100GbE far exceeded the forecast. This is also shown by comparison data provided in the Cisco VNI update, where global demand exceeded the forecast, but was within 10%. See Figure 50.

To summarize, forecasting can be very challenging, but also provide an exercise to identify and understand the underlying trends that can impact market demands.

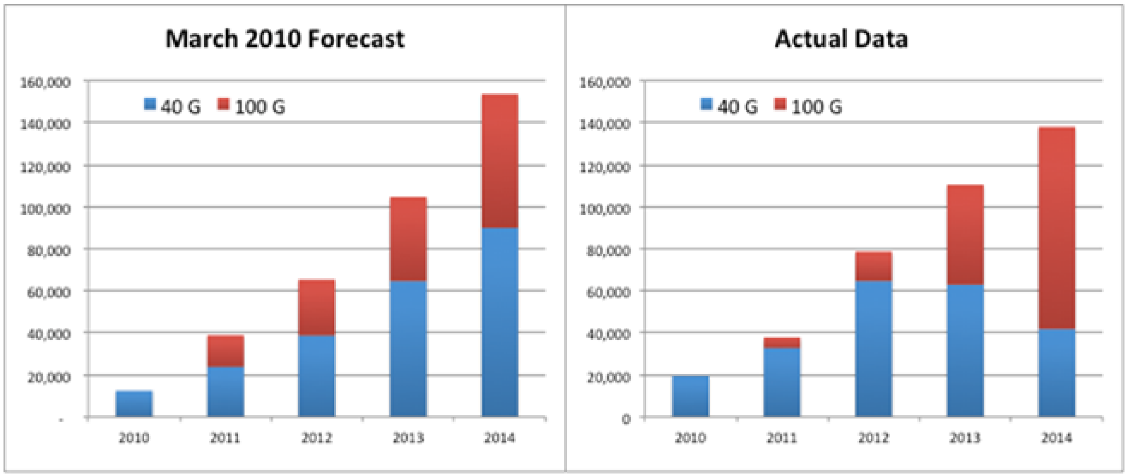

Figure 48—Comparison Between Forecast and Actual Data for DWDM Ports [17]

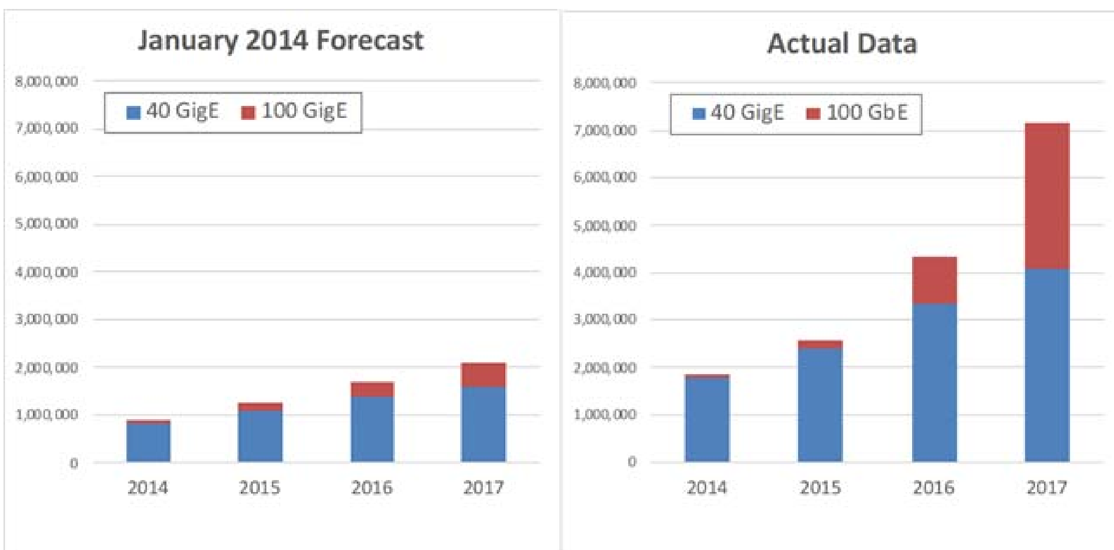

Figure 49—Comparison Between Forecast and Actual Data for Transceivers for Mega Datacenters [17]

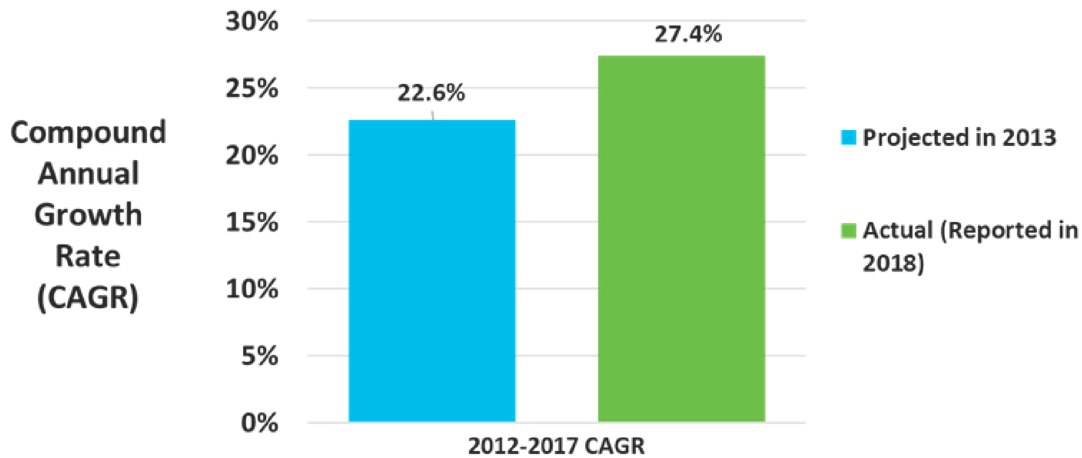

Figure 50—VNI Projections and Actuals (Global) [18]

4.3 Users

When considering Internet users around the world, it is important to understand that the number of users and usage rate vary greatly from country to country. This is highlighted by Figure 1, which looked at usage in the Top 20 countries in the world, based on the number of Internet users. Observations from this data suggest -

- China and India have a significant number of Internet users when compared to the other 18 countries, but the respective usage rate is still relatively low, as China is only at a 58% usage rate and India had the lowest of all 20 countries at 41%. This suggests that these two countries could see significant bandwidth growth based on the number of users (including the number of devices per user), access abilities and rates, and application demand.
- Eight of the top 20 countries (United States, Japan, Germany, Turkey, United Kingdom, France, Thailand and Italy) had usage rates greater than 80%. This high degree of usage suggests that increased bandwidth demand could come from an increase in the number of devices per user, access abilities and rates, and application demand.
- It should be noted that only 57% of the world population, as of March 31, 2019, was connected to the Internet. This leaves potential bandwidth demand to be created as the remaining ~3.4 billion people get connected to the Internet.
- Machine-machine connections are forecasted to experience a 19% CAGR over the 2017 to 2022 timeframe with greater than 14 billion connections anticipated by 2022.
- While the number of personal vehicles being sold is understood (currently annual sales is 80 million vehicles), the potential bandwidth demands of connected cars and autonomous vehicles are not.

4.4 Access Methods and Rates

The second factor to contribute to a bandwidth explosion is the number of different ways a user can access the Internet and the rate of the given connection. Data regarding the number of devices globally to interconnect to the Internet shows by 2022 there will be ~29 billion devices connecting to the Internet, which, if the CAGR remains at 10% will grow to approximately 38 billion by 2025. Furthermore, the number of devices per capita and household continue to grow, up to 3.6 and 9 by 2022 respectively. Combined, these factors will drive average traffic per user and household up to 85 Gb / month and 240 Gb / month by 2022 respectively. Furthermore, there is a significant difference between average and busy hour traffic, as these two rates are growing at different CAGRs over the 2017 to 2022, 37% and 30% respectively. By 2022, there is a

5.9× difference between busy hour and average traffic, growing to 6.9× by 2025. This is significant to network providers who must build networks to meet peak traffic demand.

Different access methods also show no sign of letting up, as on a global basis fixed broadband speeds will increase by 14.1%, Wi-Fi by 17.3%, and Cellular by 26.8%. It is important to note that the rates of increase vary greatly on a by country and regional basis. It is also important to note that there is a significant difference between peak connection and average connection speeds. For example, by 2022, the maximum peak speed for mobile networks will be >6× the average connection speed. This type of variation will lead to broad variability in the speeds mobile networks are required to support.

EPON, popular in China, is also showing a future upgrade path , as work is underway to develop 25 Gb/s and 50 Gb/s EPON. Furthermore, the project has already heard requests to develop 50 Gb/s serial EPON to support 50 Gb/s and 100 Gb/s Ethernet by 2025.

4.5 Increased Services & Applications

Over the past 15 years, video has been recognized as a leading contributor to the bandwidth explosion that many networks are experiencing. Submitted data showed that nearly 58% of download traffic is related to video streaming. Furthermore, from a global perspective, as well as each individual region, the number 1 application driving traffic share was YouTube, a video streaming application.

The evolution of video definition can not be ignored either. Standard definition (SD) represents 2 Mb/s, high-definition (HD) represents 5 Mb/s to 7.2 Mb/s, while ultra-high-definition (UHD) represents 15 Mb/s to 18 Mb/s. From 2017 to 2022 the number of 4K TV set connections is forecasted to grow with a 38% CAGR. As UHD content becomes available and market adoption accelerates, the increased presence of 4K TVs and content will drive a significant push in bandwidth by 2022 and beyond.

Other applications, such as virtual / augmented reality and connected cars represent potential bandwidth drivers. For the 2017 to 2022 period virtual / augmented reality will drive traffic growth to a 65% CAGR, so that by 2022, there is 4.02 EB per month of traffic. Connected / autonomous vehicles are a great unknown at this time. Limited data was shared regarding the application space with no new bandwidth forecasts shared. It is noted that this assessment is based solely on the contributions noted in 2.1. It is recognized that there are other areas, such as high performance computing and artificial intelligence, that could have significant bandwidth demand in the future.

4.6 Bandwidth Growth

Bandwidth demand is application dependent. Furthermore, newer applications that are adopted rapidly will exhibit greater growth rates. Readers are encouraged to review “Bandwidth Growth”, see 3.5 for further insight into the bandwidth demands of individual application spaces.

Given the variety of submitted data, the submitted bandwidth curves were normalized to their 2017 value and overlaid on top of each other to compare their relative growth rates. See Figure 51.

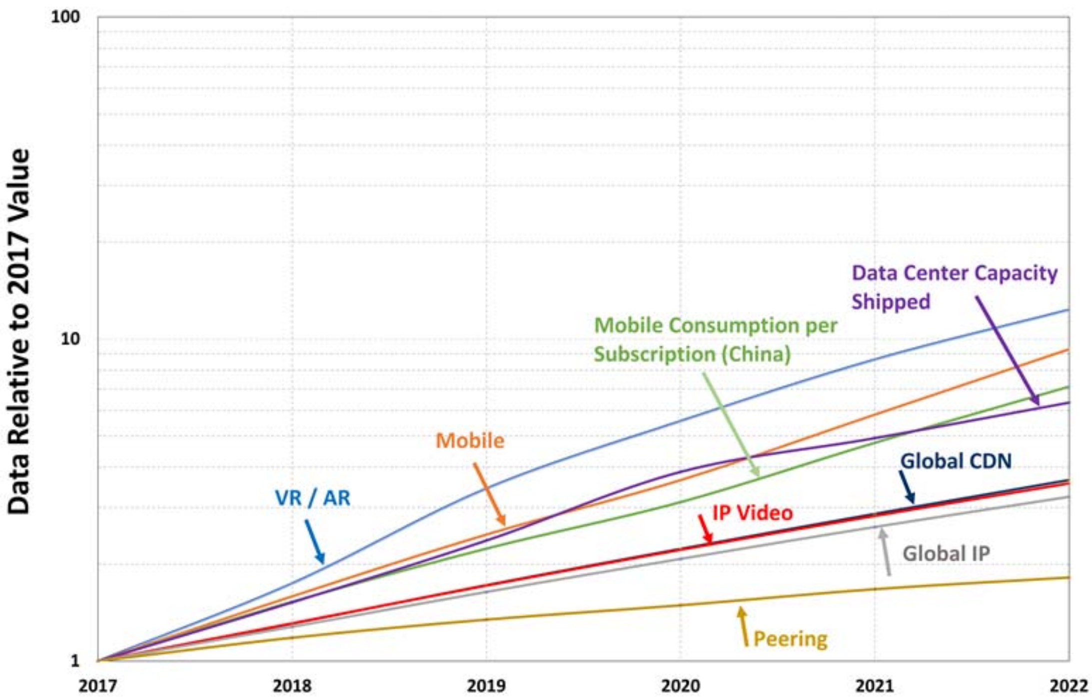

Figure 51—Bandwidth Curves (2017-2022)

Note—"Mobile Traffic Consumption Per Subscription (China)" and "Mobile Traffic" were exponentially fitted to provided data to calculate the 2017 through 2019 values.

Given the anticipated publication of this report in 2020, it was felt that a forecast 2 years beyond the publication date was insufficient, and a 5-year forecast would be more beneficial. To create the series of forecast curves shown in Figure 51, the following steps were taken:

- The forecast for "Global IP Traffic", "IP Video", "Virtual/ Augmented Reality Traffic", and "Global Content Delivery Network Traffic" were extended to 2023-2025 based on the reported CAGR for each parameter.
- The forecast for "Peering Traffic" was extended to 2023-2025 based on an exponential fit of provided data.
- The forecast for "Data Center Switching Capacity Shipped" was extended for 2024-2025, based on the calculated CAGR of the provided data for 2017-2023.

Two possible futures for Ethernet beyond 400 Gb/s are commonly discussed: 800 Gb/s Ethernet and 1.6 Tb/s Ethernet. Based on prior experience, a project to develop either data rate would take 5 years and would complete in 2025 if started in 2020. Normalizing 400 Gb/s to the year it was standardized (2017), 800 Gb/s is noted as a 2× increase over 400 Gb/s in 2025, and 1.6 Tb/s is noted as a 4× increase over 400 Gb/s in 2025. To enable a comparison to the noted forecast curves, dashed lines were added between the introduction of 400 Gb/s in 2017 and each new data rate in 2025.

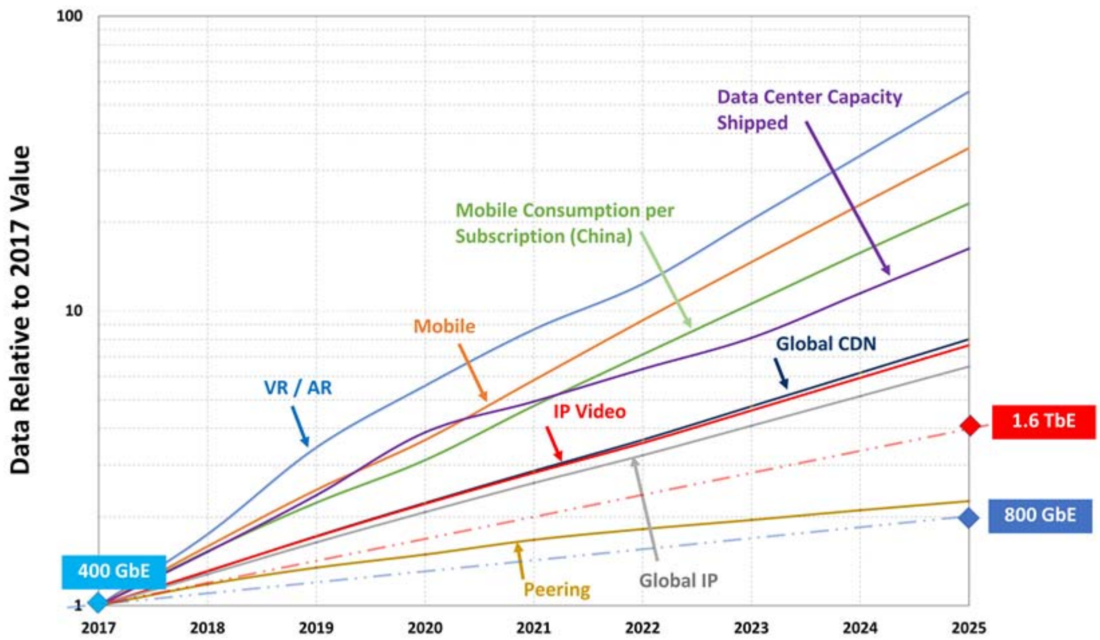

Figure 52—Bandwidth Curves (2017-2025)

Figure 52, excluding the two Ethernet curves, highlights the growing diversity between applications growth rates, ranging anywhere from 2.3× to 55.4× the traffic in 2025 each application saw in 2017. The values for 2017, 2022, and 2025 plotted in Figure 52 are tabulated in Table 12. It is important to note how the two Ethernet curves are lagging in growth rates, compared to the growth rates of the other application spaces.

Table 12—Tabulation of Bandwidth Growth Values in 2017, 2022, and 2025

	2017	2022	2025
800GbE	1		2×
Peering Traffic	1	1.8×	2.3×
1.6TbE	1		4×
Global IP Traffic	1	3.2×	6.5×
IP Video	1	3.6×	7.6×
Global Content Delivery Network Traffic	1	3.7×	8×
Data Center Switching Capacity Shipped	1	6.4×	16.3×
Mobile Traffic Consumption Per Subscription (China)	1	7.1×	23.2×
Mobile Traffic	1	9.3×	35.7×
Virtual / Augmented Reality Traffic	1	12.3×	55.4×

As noted in the first Ethernet BWA, whether these projections are realized or not will depend, among other things, on the ability to continually drive the cost per bit falling with time. This is the challenge to the Ethernet community, given the assumed use of Ethernet in the respective application space. Furthermore, in addition to this, the question of whether this increased traffic is serviced by the introduction of new rates above 400 Gb/s or by increasing numbers of the existing interfaces will depend on the ability of the higher rates to provide a sufficiently cost effective solution.

5. Summary

Relative to observed traffic in 2017, the submitted data to the 2020 Ethernet BWA indicates a broad diversity in the bandwidth growth rates of the various applications explored, ranging in 2025 from 2.3× to 55.4× the traffic levels of 2017.

Assuming a new project to define the next rate of Ethernet begins in 2020, and takes 5 years to complete (2025), growth rate curves based on either 800GbE or 1.6TbE were also generated and compared to the submitted data. Assuming no other architectural changes in deployment, this overlay demonstrated a significant growth lag between 800GbE and the observed growth curves. However, the 4× growth curve generated by a 1.6TbE solution would also lag the observed growth curves. Furthermore, all of the underlying factors that drive a bandwidth explosion: 1) the number of users; 2) increased access rates and methods; and 3) increased services all point to continuing growth in bandwidth.

While these are the forecasted bandwidth capacity requirements, 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 and the time scales in which a new Ethernet rate(s) and the associated technologies might be delivered.

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