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THE FINDINGS OF THE  
IEEE 802.3 INDUSTRY CONNECTIONS  
NEW ETHERNET APPLICATIONS AD HOC:  
ETHERNET BANDWIDTH ASSESSMENT, PART II

**IEEE 802.3 NEW ETHERNET APPLICATIONS AD HOC  
TELECONFERENCE MEETING  
MARCH 23, 2020**

# PRESENTERS

- John D'Ambrosia
  - Chair, IEEE 802.3 New Ethernet Applications Ad Hoc
  - Futurewei Technologies, U.S. Subsidiary of Huawei
- Ray Nering
  - Cisco Systems

# AGENDA

- Introduction
- Findings
  - Users
  - Access Rates & Methods
  - Services
  - Bandwidth Explosion
- Summary

# DISCLAIMERS

- This presentation is a supplement to the IEEE Industry Connections Ethernet Bandwidth Assessment, Part 2, D1.2, which is pending final approval by the IEEE 802.3 Ethernet Working Group
- All contributed information was submitted prior to Oct 2019 and may have been dated at time of submission.
- All contributed information is solely the perspective of the respective contributors.
- The views expressed in the Assessment (pending approval) 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.



# INTRODUCTION

# THE 2007 HSSG TUTORIAL

## Why Higher Speed Ethernet?

Fundamental bottlenecks are happening everywhere

**Increased #  
of users**

+

**Increased  
access  
rates and  
methods**

+

**Increased  
services**

=

**Bandwidth  
explosion  
everywhere**



**As demonstrated  
by the number of  
ISPs: Comcast,  
AOL, YahooBB,  
NTT, Cox,  
EasyNet, Rogers,  
BT, ...**

**EFM, xDSL,  
WiMax,  
xPON,  
Cable, WiFi,  
3G/4G...**

**YouTube,  
BitTorrent,  
VOD,  
Facebook,  
Kazaa, Netflix,  
iTunes, 2<sup>nd</sup>  
life, Gaming...**

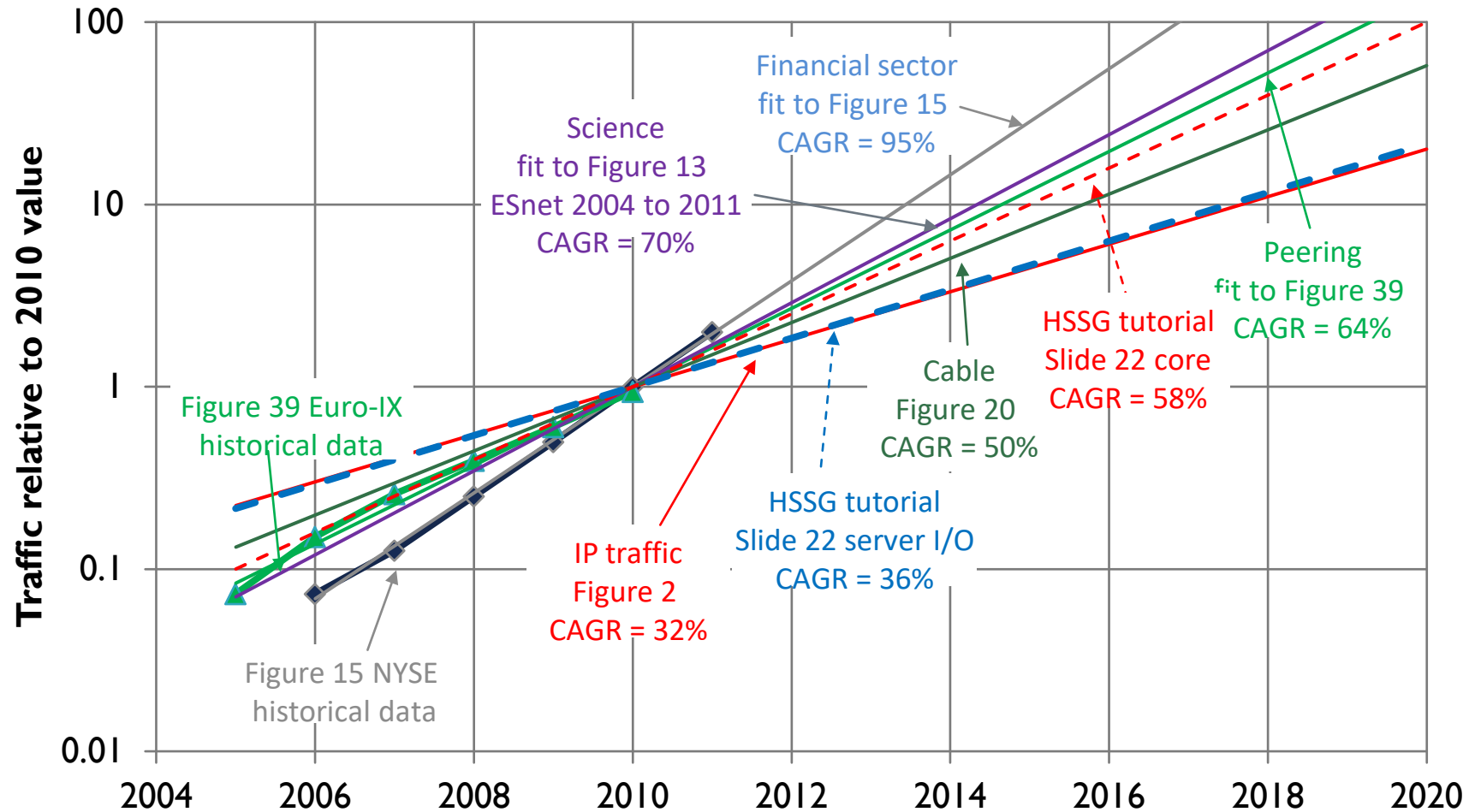
The  
basic  
equation  
has  
remained  
the same

IEEE 802.3 Higher Speed Study Group - TUTORIAL

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Source: 2007 HSSG Tutorial - [http://www.ieee802.org/3/hssg/public/nov07/HSSG\\_Tutorial\\_1107.zip](http://www.ieee802.org/3/hssg/public/nov07/HSSG_Tutorial_1107.zip)

# IEEE 802.3 ETHERNET BANDWIDTH ASSESSMENT (2012)



Source: 2012 Ethernet Bandwidth Assessment Tutorial - [http://www.ieee802.org/802\\_tutorials/2012-07/BWATutorial\\_DI\\_12\\_0716.pdf](http://www.ieee802.org/802_tutorials/2012-07/BWATutorial_DI_12_0716.pdf)

In September 2018 -  
“What are the bandwidth trends now?”



# ETHERNET BANDWIDTH ASSESSMENT WEB & REFLECTOR INFORMATION

- Charter and Scope
  - Evaluate Ethernet wireline bandwidth needs of the industry
  - Reference material for a future activity
  - The role of this ad hoc is to gather information, not make recommendations or create a CFI
- Webpage - [http://www.ieee802.org/3/ad\\_hoc/bwa2/index.html](http://www.ieee802.org/3/ad_hoc/bwa2/index.html)
- Reflector - [http://www.ieee802.org/3/ad\\_hoc/bwa2/reflector.html](http://www.ieee802.org/3/ad_hoc/bwa2/reflector.html)
- Public request for data - [http://www.ieee802.org/3/minutes/sep18/outgoing/IEEE\\_802d3\\_to\\_ALL\\_BWA\\_0918.pdf](http://www.ieee802.org/3/minutes/sep18/outgoing/IEEE_802d3_to_ALL_BWA_0918.pdf)

# ASSESSMENT LIMITATIONS

- **Assessment Duration: 18 months maximum**
  - One year for information gathering (Sept 2018 – Sept 2019)
  - All potential application spaces may not have been studied
  - Prevent data from becoming dated
  - Information provided snapshot at time of submission
- **Past trends may not be an accurate predictor of the future**
  - Emerging applications
  - Technology
  - Standardization Efforts
  - Will Ethernet cost per gigabit continue to decrease?
- **Underlying assumptions**
  - Market adoption
  - Continuation of applications that require increasing bandwidth

# ACKNOWLEDGEMENTS

- Charts and description reprinted with permission from Dell'Oro Group, Data Center Ethernet Switch and Server Bandwidth Assessment for IEEE by Sameh Boujelbene, Shin, Umeda, and Baron Fung, ©2019.
- Cisco VNI Forecast reprinted with permission from Cisco, Cisco Visual Networking Index (VNI) Complete Forecast Update, 2017–2022, 2018 Global Presentation, ©2018.



# FINDINGS

# INFORMATION GATHERING APPROACH

$$\begin{array}{ccccccc} \text{Increased} & & \text{Increased} & & \text{Increased} & = & \text{Bandwidth} \\ \text{\# of users} & \times & \text{access} & \times & \text{services} & & \text{Explosion} \\ & & \text{methods} & & & & \\ & & \text{and rates} & & & & \end{array}$$

Information gathering focused on each aspect of this equation

# USERS

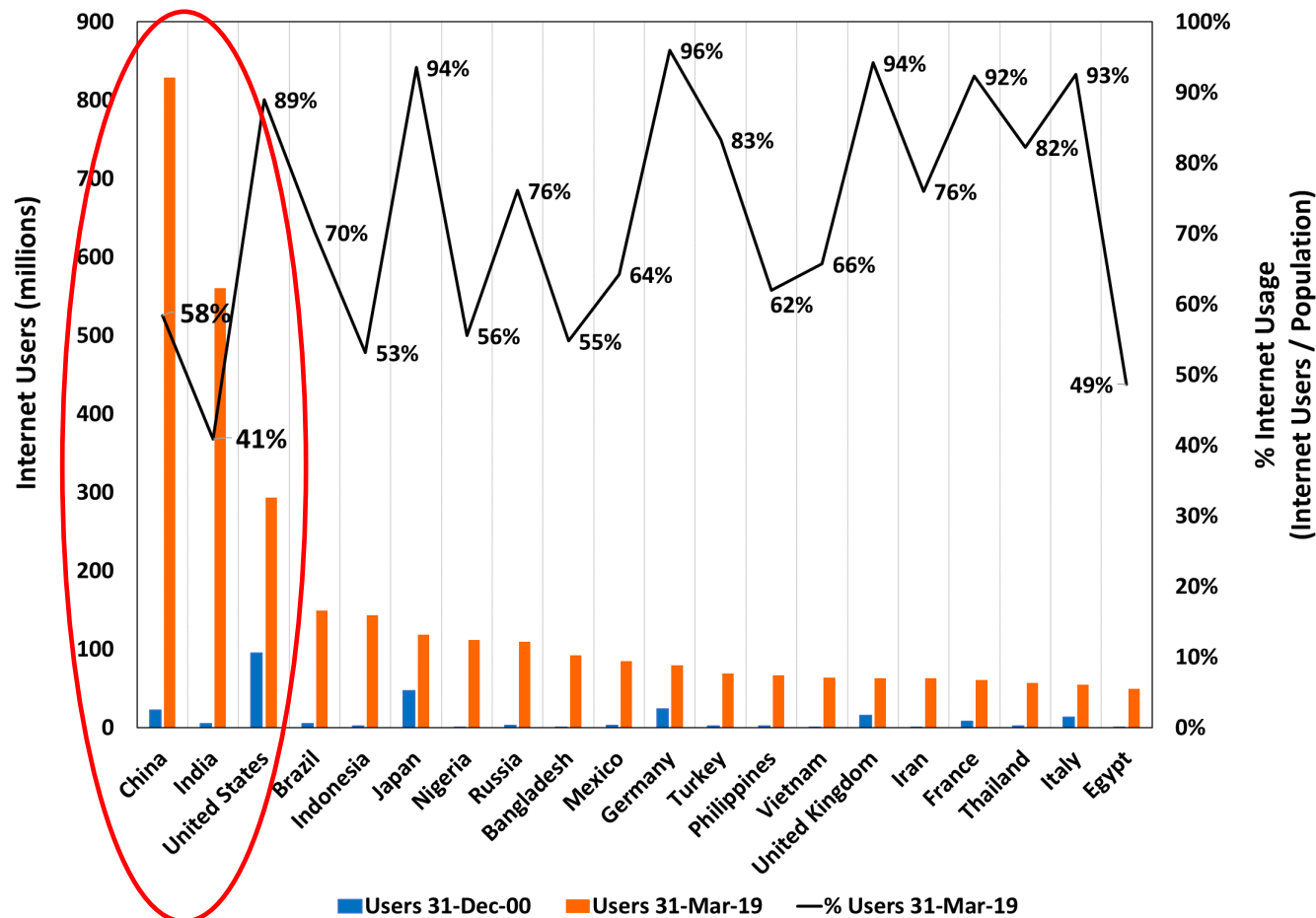
# INTERNET WORLD STATISTICS



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

Source: Internet World Stats (as of 31 March 2019)  
<https://www.internetworldstats.com/stats.htm>

# INTERNET USAGE – TOP 20 COUNTRIES



## Observations

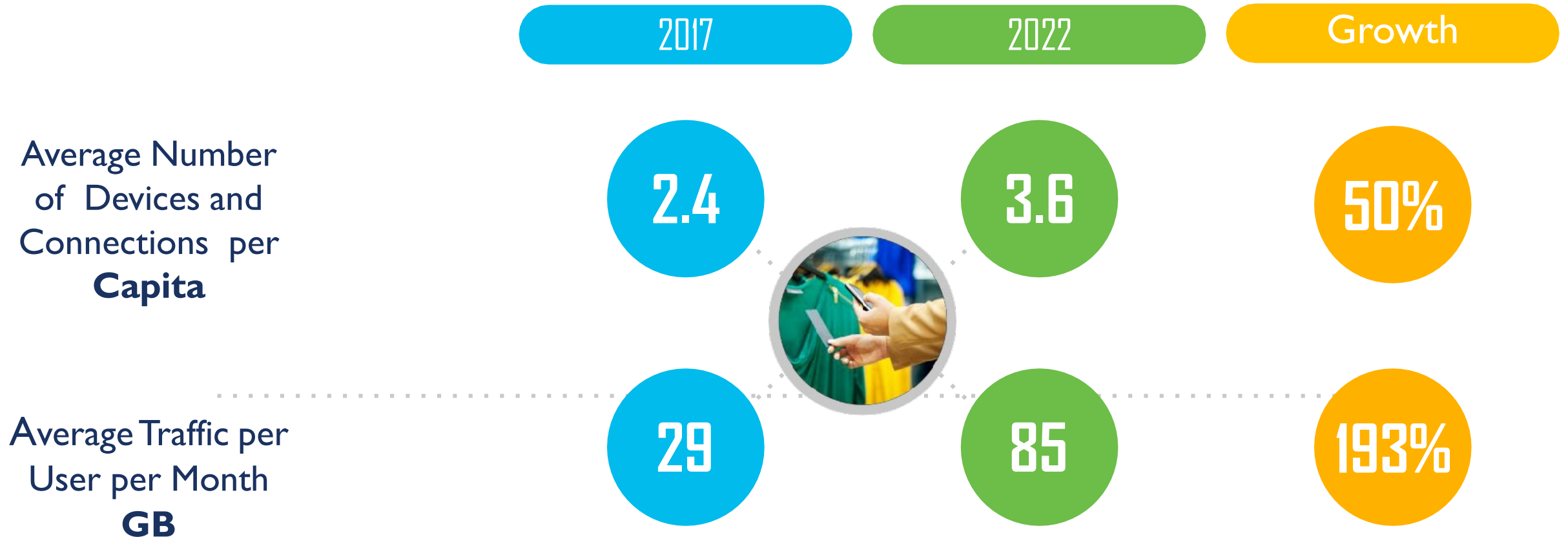
- Only 8 countries had at least 80% connectivity
- ≈2 billion people in Top 20 countries remain to be connected
- China has the largest number of internet users (829 million), but only 58% of the population was connected
- India has the second largest number of internet users (560 million), but only 41% of the population was connected

Source: Internet World Stats (as of 31 March 2019)  
<https://www.internetworldstats.com/stats.htm>

Largest opportunity for growth will be in China and India



# GLOBAL DEVICES AND CONNECTIONS AVERAGE PER CAPITA



Number of connected devices per capita is growing

The average traffic per user is growing at a much faster rate

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# SUMMARY - USERS

- Nearly 60% of world population are internet users
- China and India are the largest market opportunity for the growth in users
- The number of connected devices is roughly 2x per connected individuals
- The number of connected devices will grow to over to 3x per capita by 2022
- Bandwidth requirement per user is growing at a much faster rate

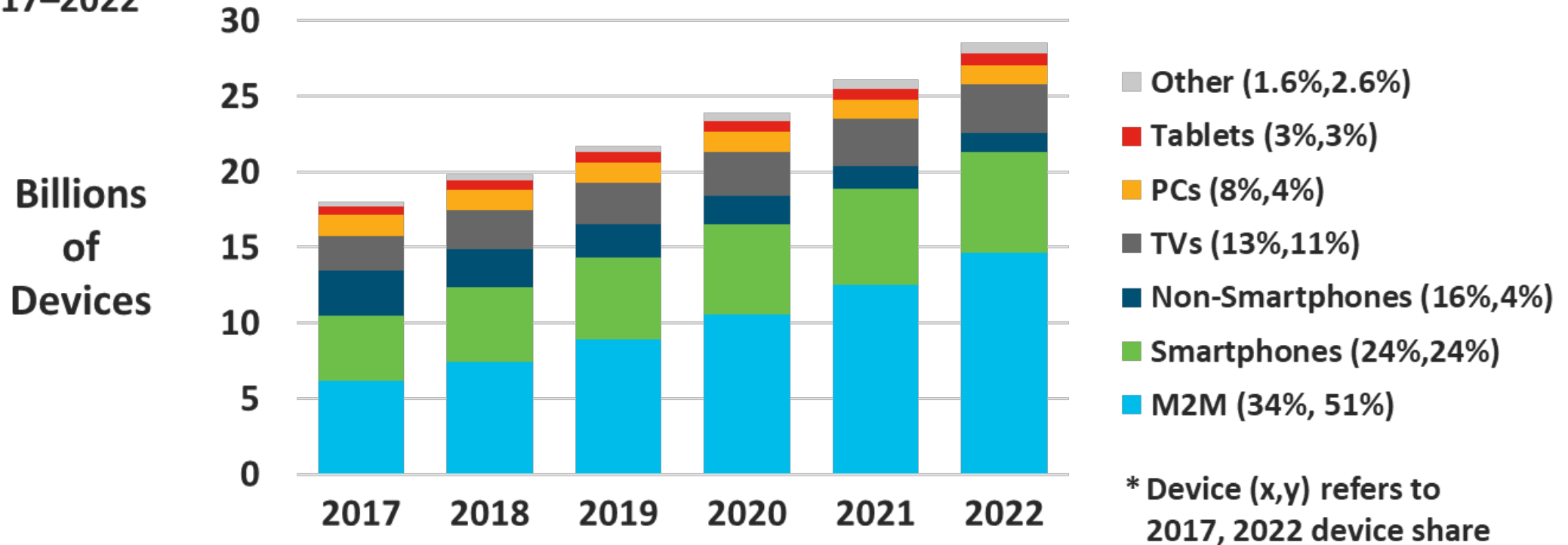
**Bottom line: Traffic will continue to grow driven by the number of users and devices**



# ACCESS RATES & METHODS

# GLOBAL DEVICE / CONNECTION GROWTH

10% CAGR  
2017–2022

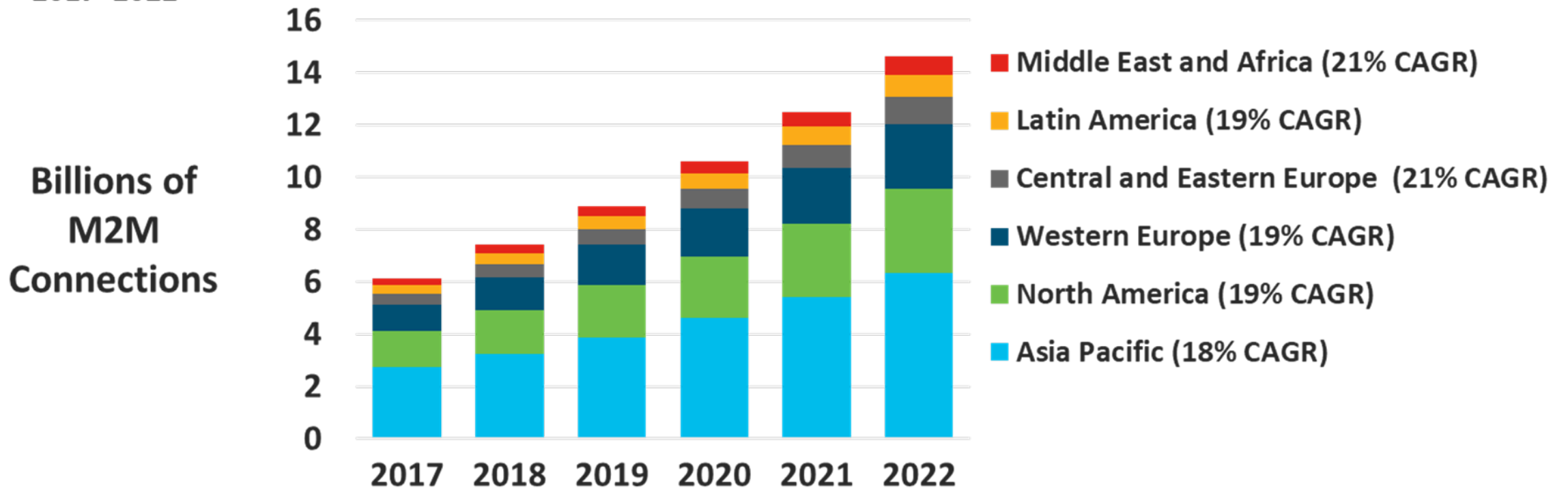


M2M connections are the largest growth area increasing to over half of the connected devices driven by IoT applications

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# GLOBAL M2M CONNECTIONS BY GLOBAL REGION

19% CAGR  
2017–2022

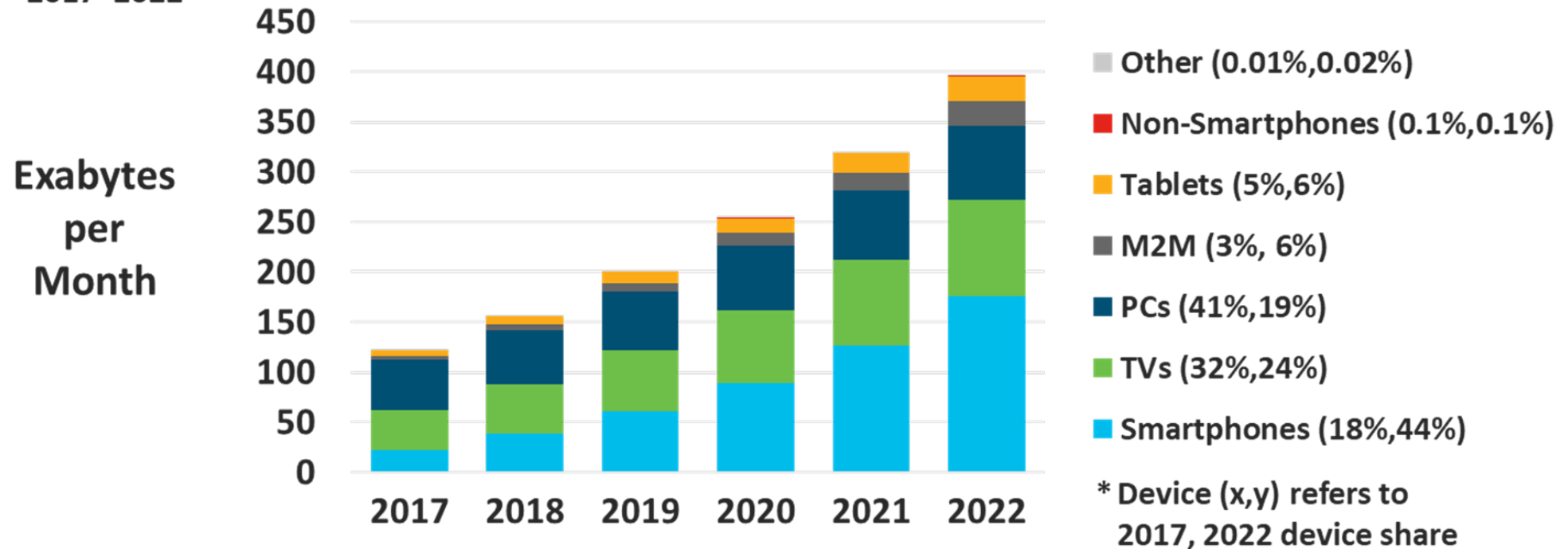


Regionally M2M connections seem to be growing uniformly across the globe

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# GLOBAL IP TRAFFIC PER DEVICE TYPE

26% CAGR  
2017–2022



In 2022, non-PC devices will drive more than 80% of global IP traffic

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# GLOBAL DEVICE CONNECTION GROWTH (AVERAGE)

North America			
(Mb/s)	2017	2022	CAGR
Fixed Broadband	43.2	94.2	16.9%
Wi-Fi	37.1	83.8	17.7%
Cellular	16.3	42.0	20.8%

Western Europe			
(Mb/s)	2017	2022	CAGR
Fixed Broadband	37.9	76.0	14.9%
Wi-Fi	25.0	49.5	14.6%
Cellular	16.0	50.5	25.8%

Central & Eastern Europe			
(Mb/s)	2017	2022	CAGR
Fixed Broadband	32.8	46.7	7.3%
Wi-Fi	19.5	32.8	11.0%
Cellular	10.1	26.2	21.0%

Latin America			
(Mb/s)	2017	2022	CAGR
Fixed Broadband	11.7	28.1	19.2%
Wi-Fi	9.0	16.8	13.3%
Cellular	4.9	17.7	29.3%

Middle East & Africa			
(Mb/s)	2017	2022	CAGR
Fixed Broadband	7.8	20.2	21.0%
Wi-Fi	6.2	11.2	12.6%
Cellular	4.4	15.3	28.3%

Asia Pacific			
(Mb/s)	2017	2022	CAGR
Fixed Broadband	46.2	98.8	16.4%
Wi-Fi	26.7	63.3	18.8%
Cellular	10.6	28.8	22.1%

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# GLOBAL DEVICE CONNECTION GROWTH (AVERAGE)

North America				Western Europe				Central & Eastern Europe			
(Mb/s)	2017	2022	CAGR	(Mb/s)	2017	2022	CAGR	(Mb/s)	2017	2022	CAGR
Fixed Broadband	43.2	94.2	16.9%	Fixed Broadband	37.9	76.0	14.9%	Fixed Broadband	32.8	46.7	7.3%
Wi-Fi	37.1	83.8	17.7%	Wi-Fi	25.0	49.5	14.6%	Wi-Fi	19.5	32.8	11.0%
Cellular	16.3	42.0	20.8%	Cellular	16.0	50.5	25.8%	Cellular	10.1	26.2	21.0%

**Globally, broadband, WiFi and mobile device bandwidths will increase**  
**By 2022 many area's mobile BW will exceed broadband BW in 2017**

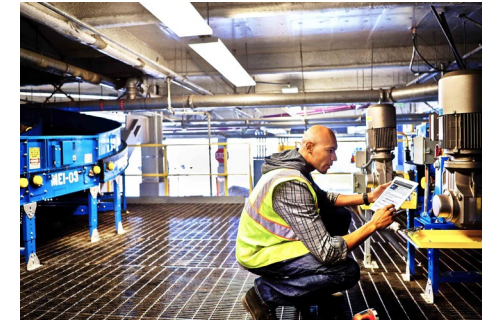
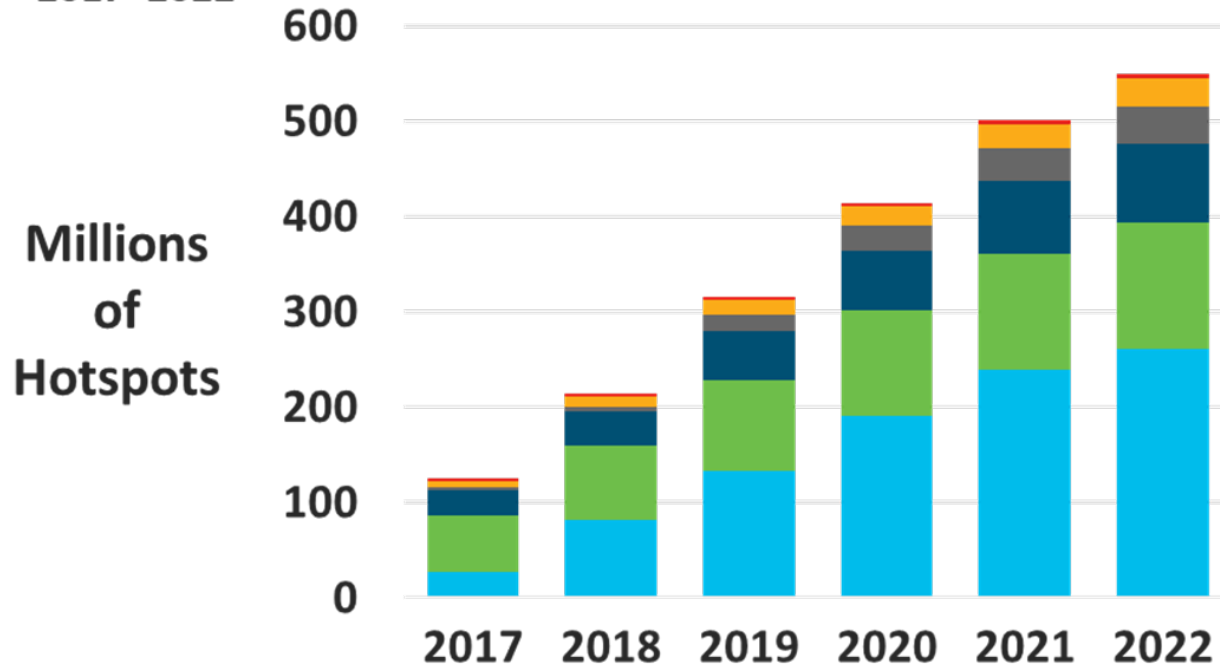
Latin America				Middle East & Africa				Asia Pacific			
(Mb/s)	2017	2022	CAGR	(Mb/s)	2017	2022	CAGR	(Mb/s)	2017	2022	CAGR
Fixed Broadband	11.7	28.1	19.2%	Fixed Broadband	7.8	20.2	21.0%	Fixed Broadband	46.2	98.8	16.4%
Wi-Fi	9.0	16.8	13.3%	Wi-Fi	6.2	11.2	12.6%	Wi-Fi	26.7	63.3	18.8%
Cellular	4.9	17.7	29.3%	Cellular	4.4	15.3	28.3%	Cellular	10.6	28.8	22.1%

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)



# GLOBAL PUBLIC WI-FI HOTSPOTS

35% CAGR  
2017–2022



- Middle East and Africa (26% CAGR)
- Central and Eastern Europe (30% CAGR)
- Latin America (75% CAGR)
- North America (26% CAGR)
- Western Europe (17% CAGR)
- Asia Pacific (57% CAGR)

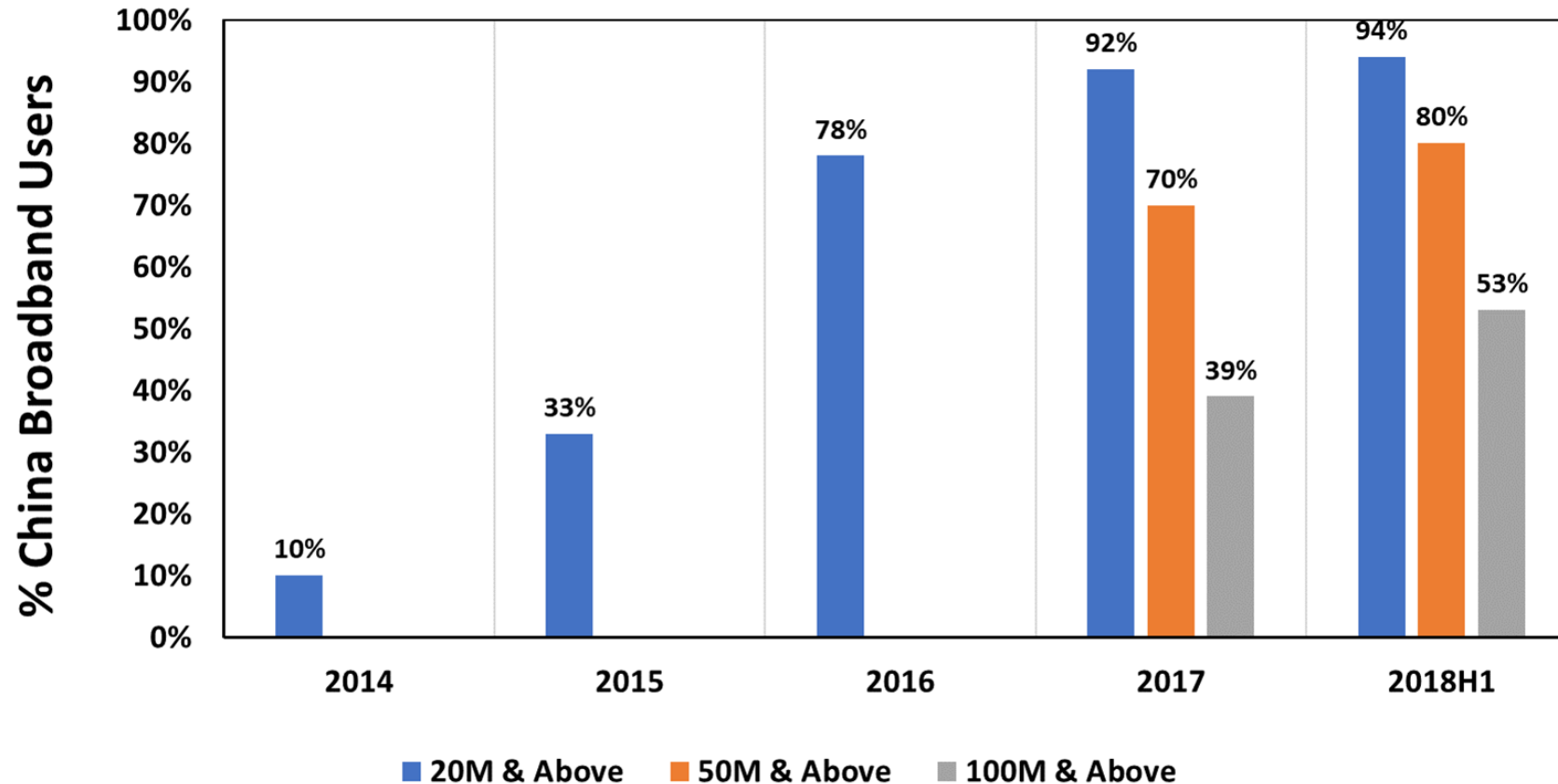
\* Middle East and Africa represents 1% of global public Wi-Fi hotspots by 2022



Regionally public WiFi infrastructure and growth rates vary

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

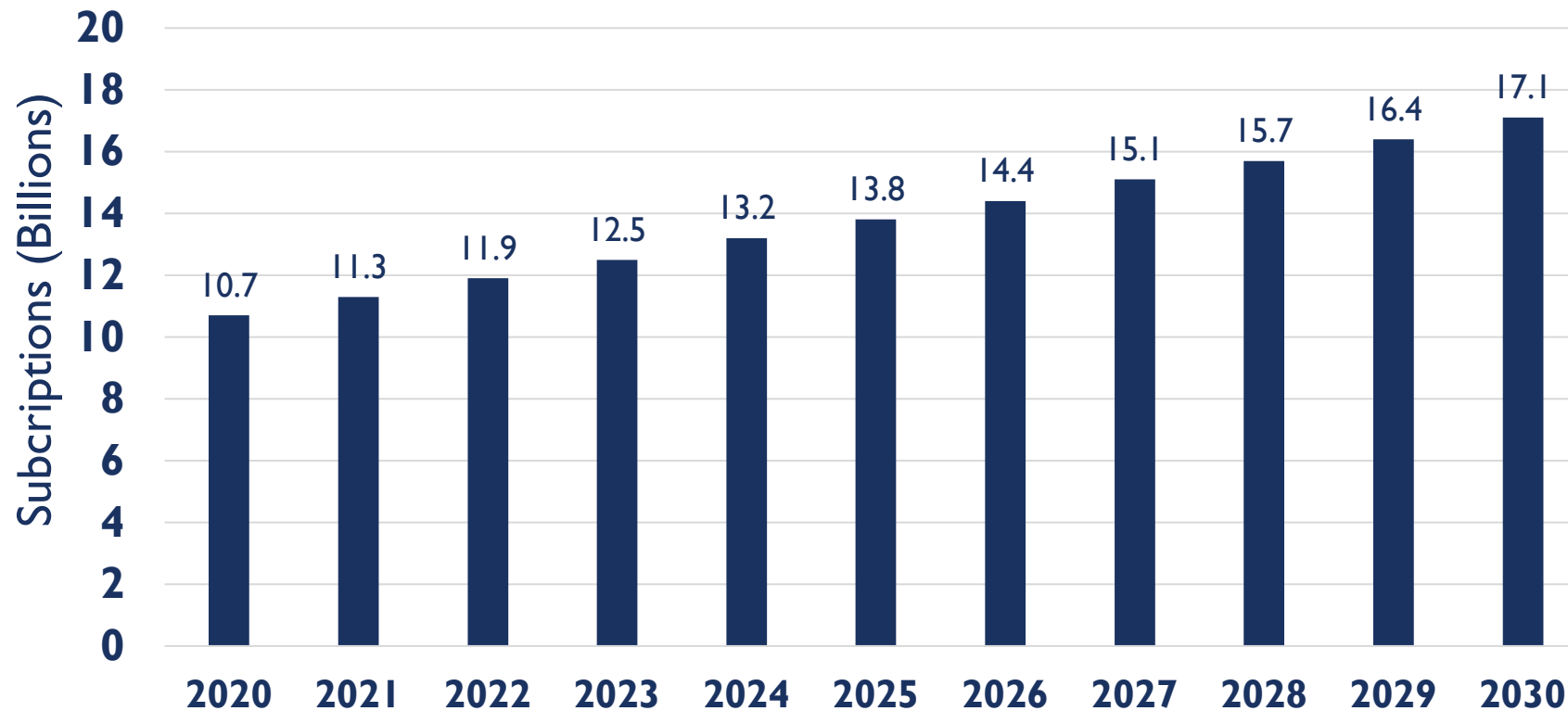
# CHINA BROADBAND ACCESS RATES



China's broadband access rates have grown rapidly over the past several years

Source: Broadband Development Status and Trend in China, [http://www.ieee802.org/3/ad\\_hoc/ngrates/public/18\\_11/zhao\\_nea\\_01\\_1118.pdf](http://www.ieee802.org/3/ad_hoc/ngrates/public/18_11/zhao_nea_01_1118.pdf)

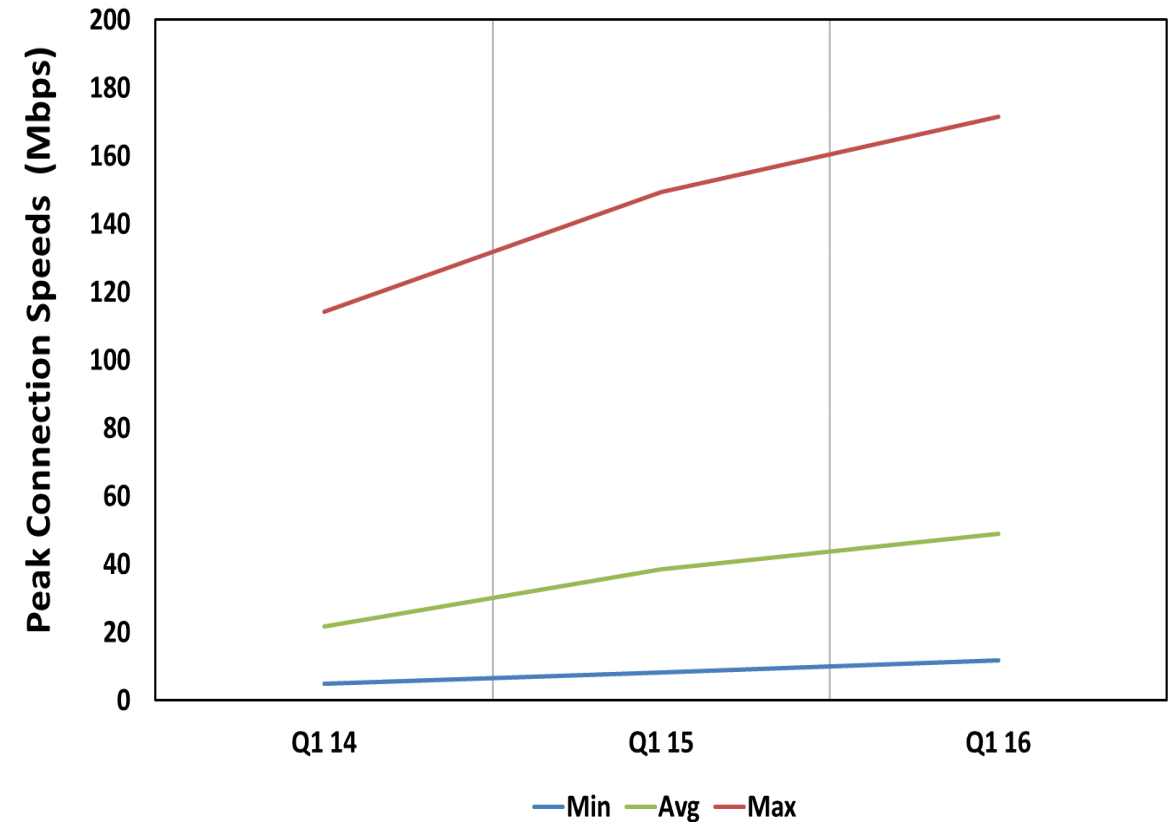
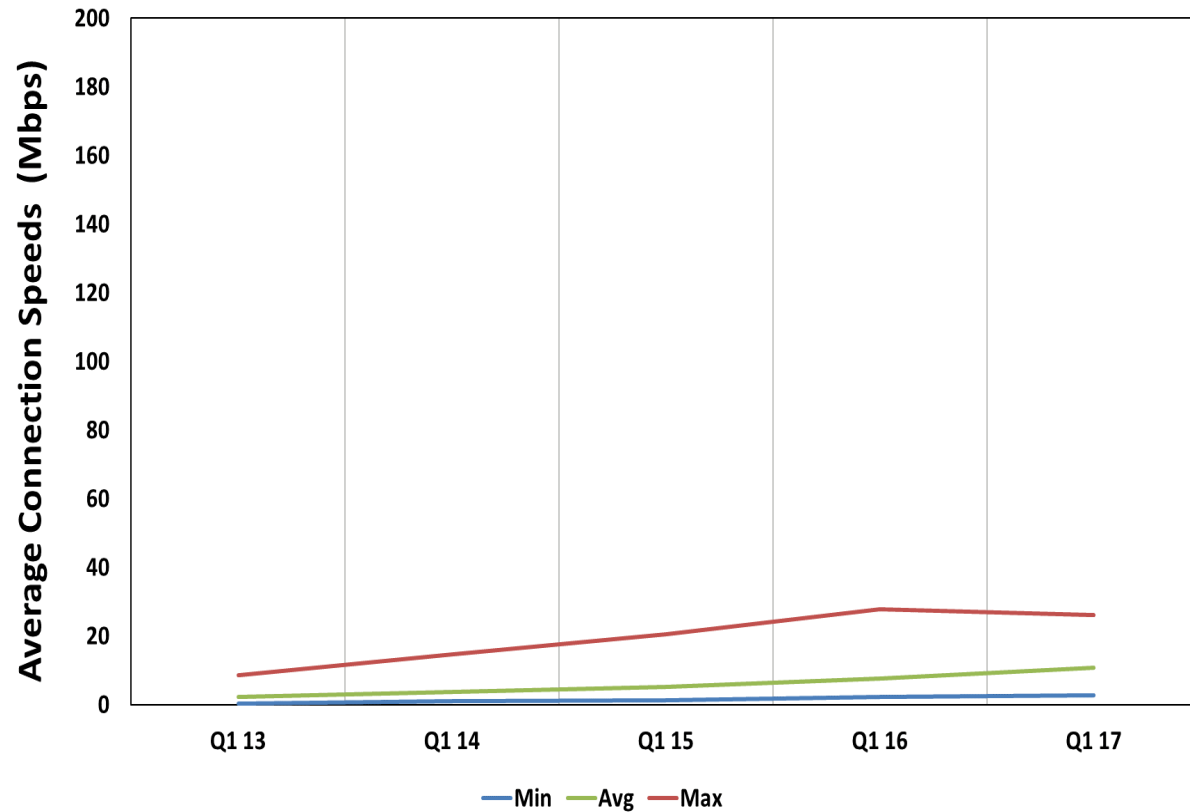
# MOBILE SUBSCRIPTIONS



Mobile subscriptions will continue to grow from individuals and IoT applications

Source: Report ITU-R M.2370-0: IMT traffic estimates for the years 2020 to 2030, <https://www.itu.int/pub/R-REP-M.2370-2015>

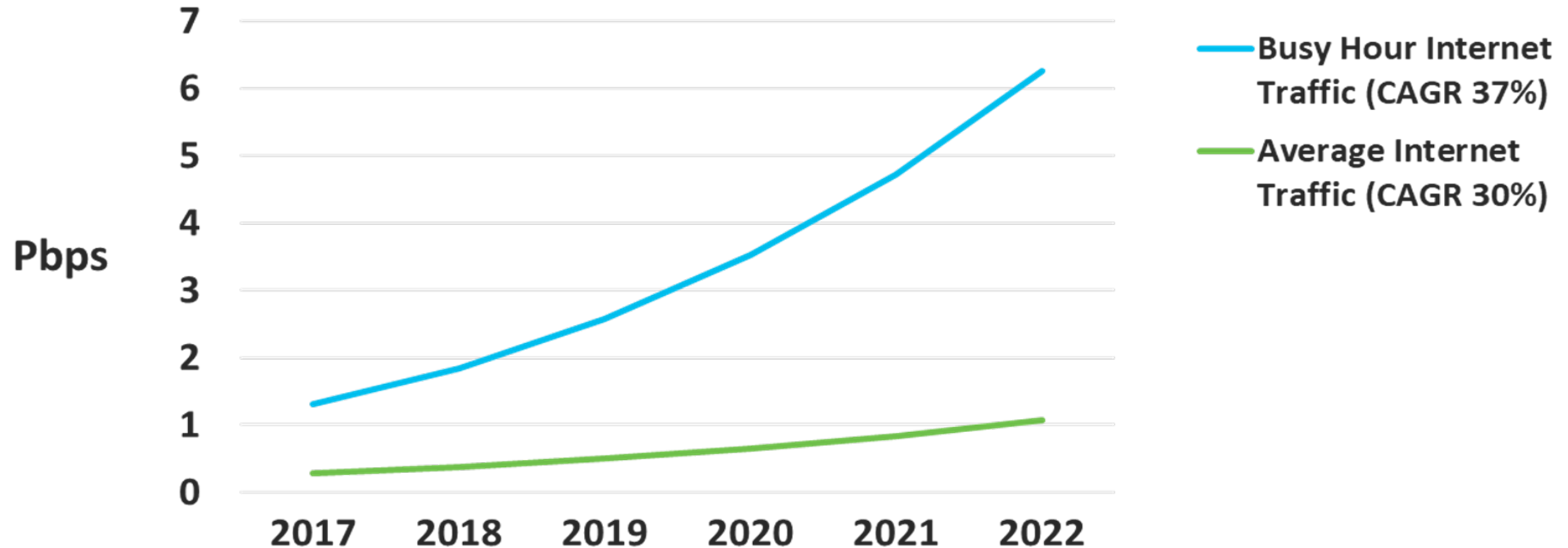
# MOBILE NETWORK CONNECTION SPEEDS (≈ 90 COUNTRIES)



Across the world, the average connection speed were growing at a CAGR of 50%  
Even the highest speed connections were growing at a CAGR of over 20%

Source: Summary of data from Akamai from “Available Industry Data”, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0611/dambrosia\\_bwa\\_01a\\_190611.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0611/dambrosia_bwa_01a_190611.pdf)

# GLOBAL BUSY-HOUR VS AVERAGE HOUR INTERNET TRAFFIC



Busy hour growth increasing faster than average growth  
What does this mean for network design?

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# FINDINGS: ACCESS RATES AND METHODS

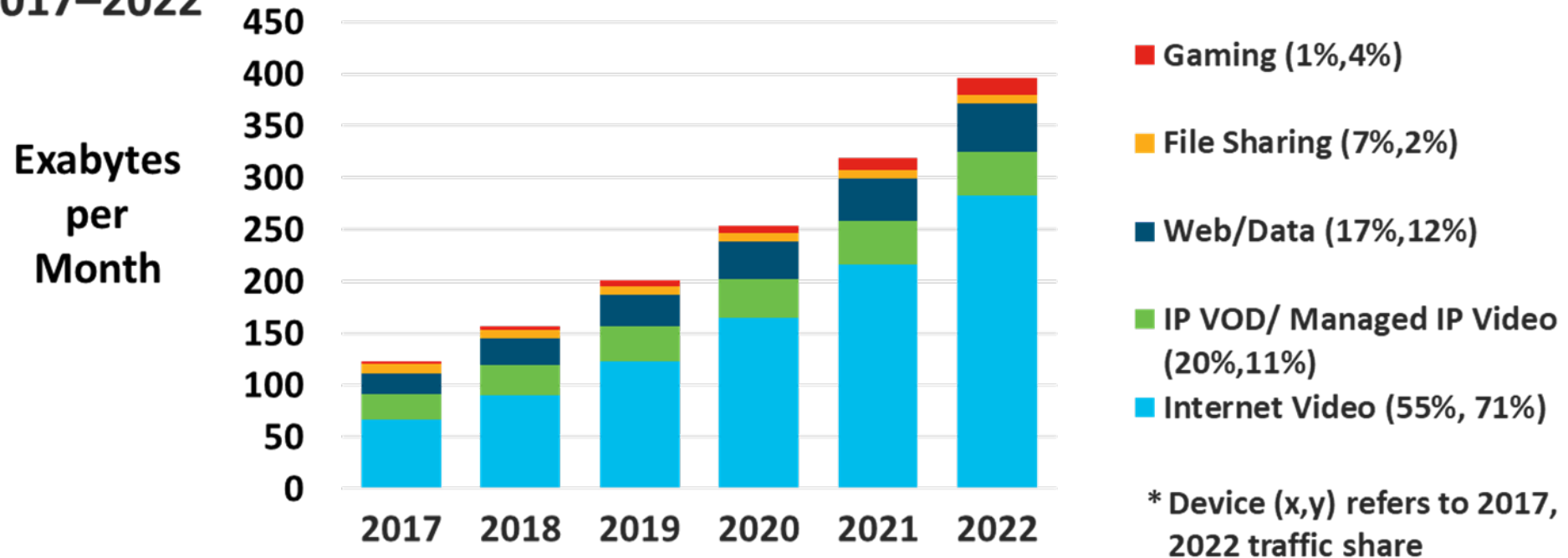
- PC's once dominated global IP traffic with over 40% share in 2017
- By 2022, Smart phones will drive more than 40% of global IP traffic follow by TV with over 20%
- M2M connections will be the dominate the number of connections by 2022
  - IoT is the primary contributor which generally is not high BW consumer
  - Traffic consumption will remain small <10%
- Fixed BB will remain the highest speed connection
- Mobile connectivity has the highest growth in access speeds globally from 2017 to 2022
  - Exceeding fixed BB speeds from 2017 in many areas
- Video will remain the dominant BW driver, but with the added complication of mobility to network design
- Peak busy hour traffic is growing at a faster rate than the average.
  - Networks will have to be designed to adapt to this changing network dynamic



# SERVICES

# GLOBAL IP TRAFFIC BY APPLICATION TYPE

26% CAGR  
2017–2022



Video will dominate IP traffic primarily driven by its accessibility and increased definition

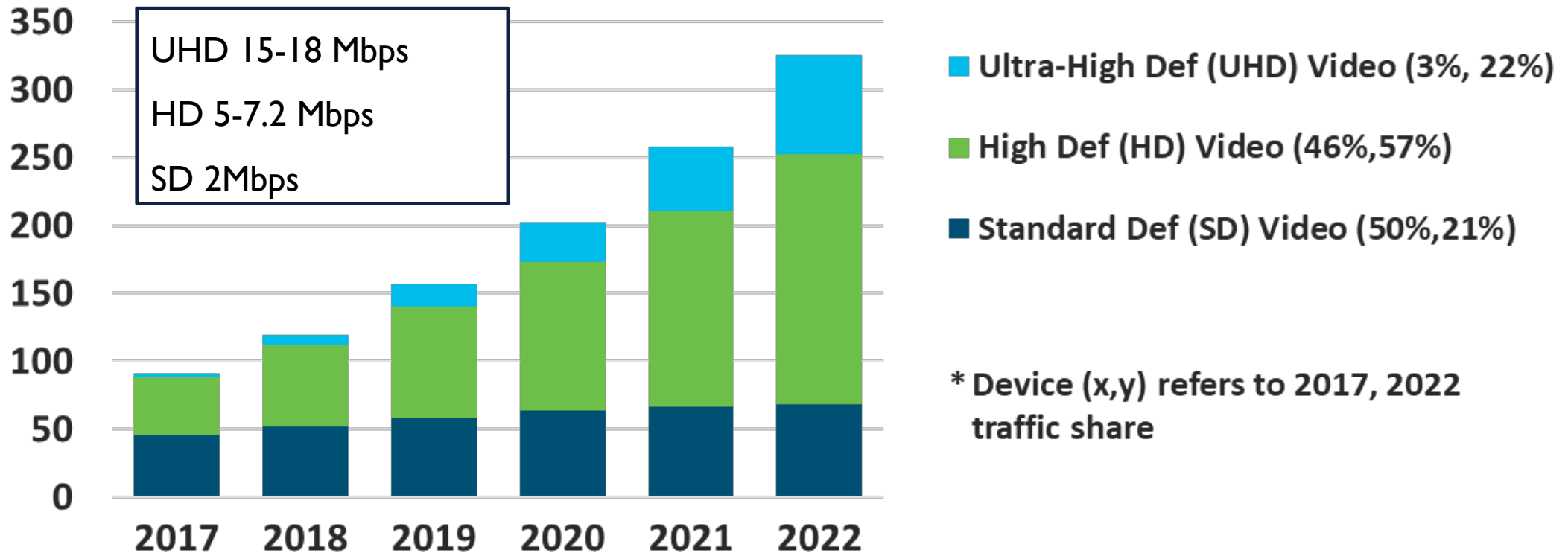
Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)



# IMPACT OF “DEFINITION” ON IP VIDEO GROWTH

**29% CAGR  
2017–2022**

**Exabytes  
per  
Month**



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

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# VIRTUAL AND AUGMENTED REALITY TRAFFIC

By 2022, VR/AR traffic will increase 12-fold

65% CAGR  
2017–2022



Source: Cisco VNI Forecast Update,  
[http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)



## Connected Home



- Home automation
- Building security
- Network equipment – printers + routers +
- Network infrastructure – routers +
- White goods
- Tracking applications
- Household information devices

## Connected Work



- Office building automation
- Building security
- Office equipment – printers + routers +
- Commercial appliances

## Connected Car



- Fleet management
- In-vehicle entertainment systems, emergency calling, Internet
- Vehicle diagnostics, navigation
- Stolen vehicle recovery
- Lease, rental, insurance management

## Connected Health



- Health monitors
- Assisted living – medicine dispensers +
- Clinical trials
- First responder connectivity
- Telemedicine

## Connected Cities



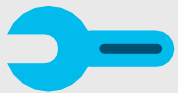
- Environment and public safety – closed-circuit TV, street lighting, waste removal, information +
- Public space advertising
- Public transport
- Road traffic management

## Retail



- Retail goods monitoring and payment
- Retail venue access and control
- Slot machines, vending machines

## Manufacturing & Supply Chain



- Mining and extraction
- Manufacturing and processing
- Supply chain
- Warehousing and storage

## Energy



- New energy sources – monitoring and power generation support apps
- Smart grid and distribution
- Micro-generation– generation of power, by residential, commercial and community users on their own property

## Other



- Agriculture – livestock, soil monitoring, water and resource conservation, temperature control for milk tanks +
- Construction: Site and equipment monitoring
- Emergency services and national security

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

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# FINDINGS:APPLICATIONS

- New applications are more BW intensive video IP BW
  - Higher video definition
  - 2017 HD & UHD accounted for 50% BW
  - 2022 HD &UHD will account for almost 80%
- Other applications emerging
  - Self driving vehicles
  - Virtual and augmented reality
    - Training / simulator, Tele-medicine, virtual real-estate, design
- What other applications not accounted for could further drive BW?
  - AI
  - Gaming

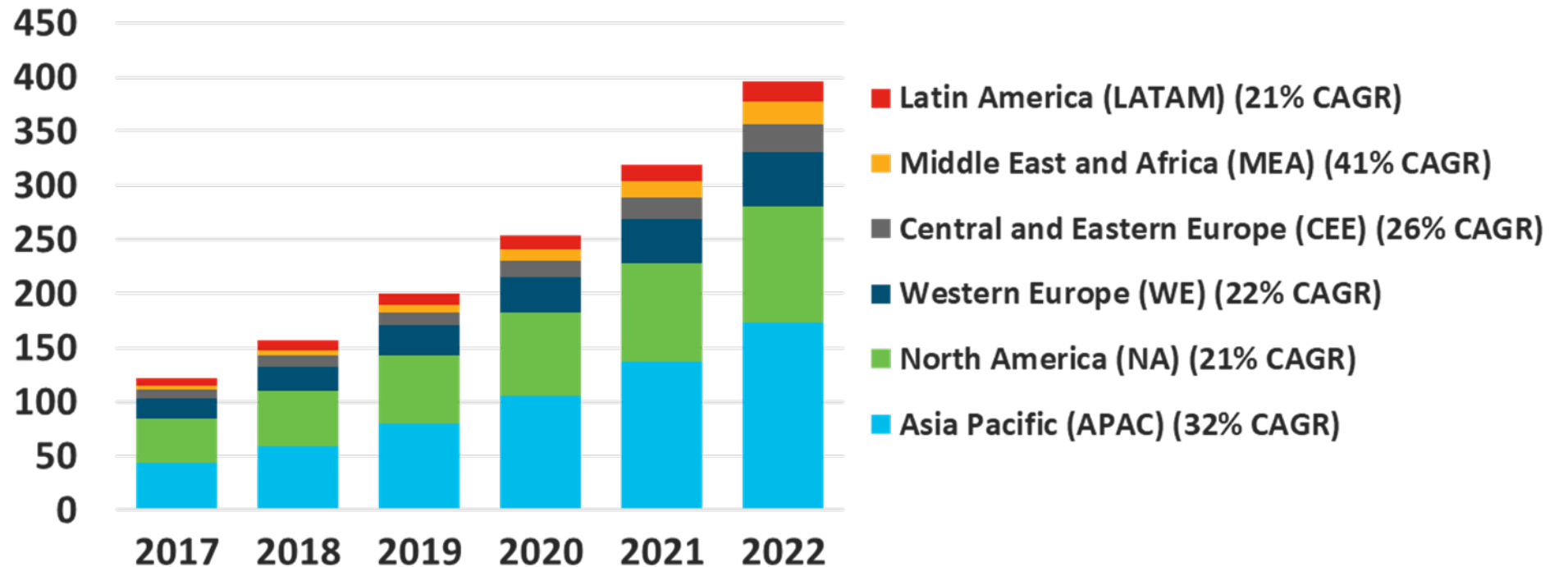


# BANDWIDTH EXPLOSION

# GLOBAL IP TRAFFIC GROWTH BY REGION

**26% CAGR  
2017–2022**

**Exabytes  
per  
Month**

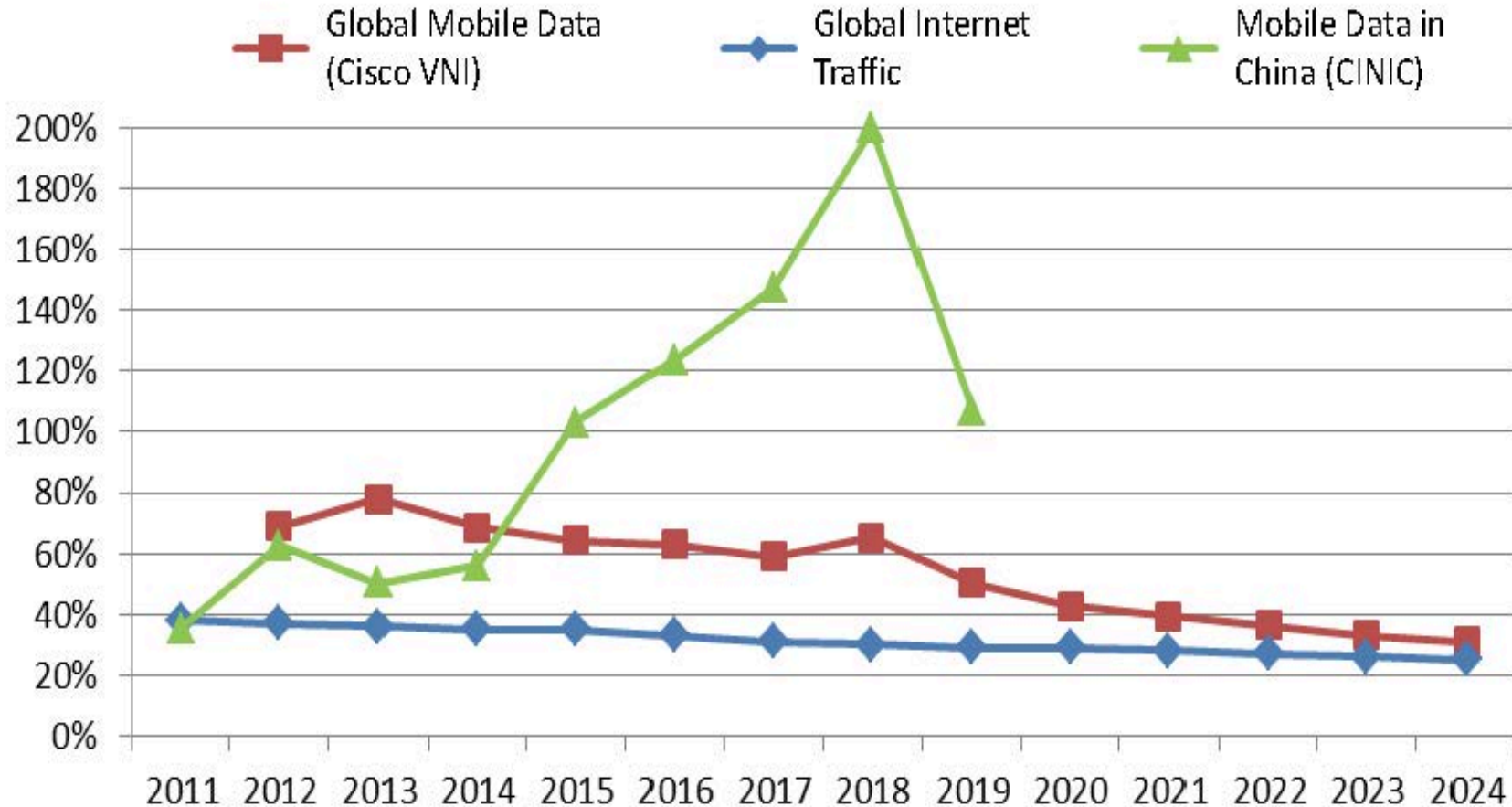


**IP traffic will grow globally, APAC will become the largest region**

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

# COMPARISON OF BANDWIDTH GROWTH RATES

## Mobile data traffic growth estimates

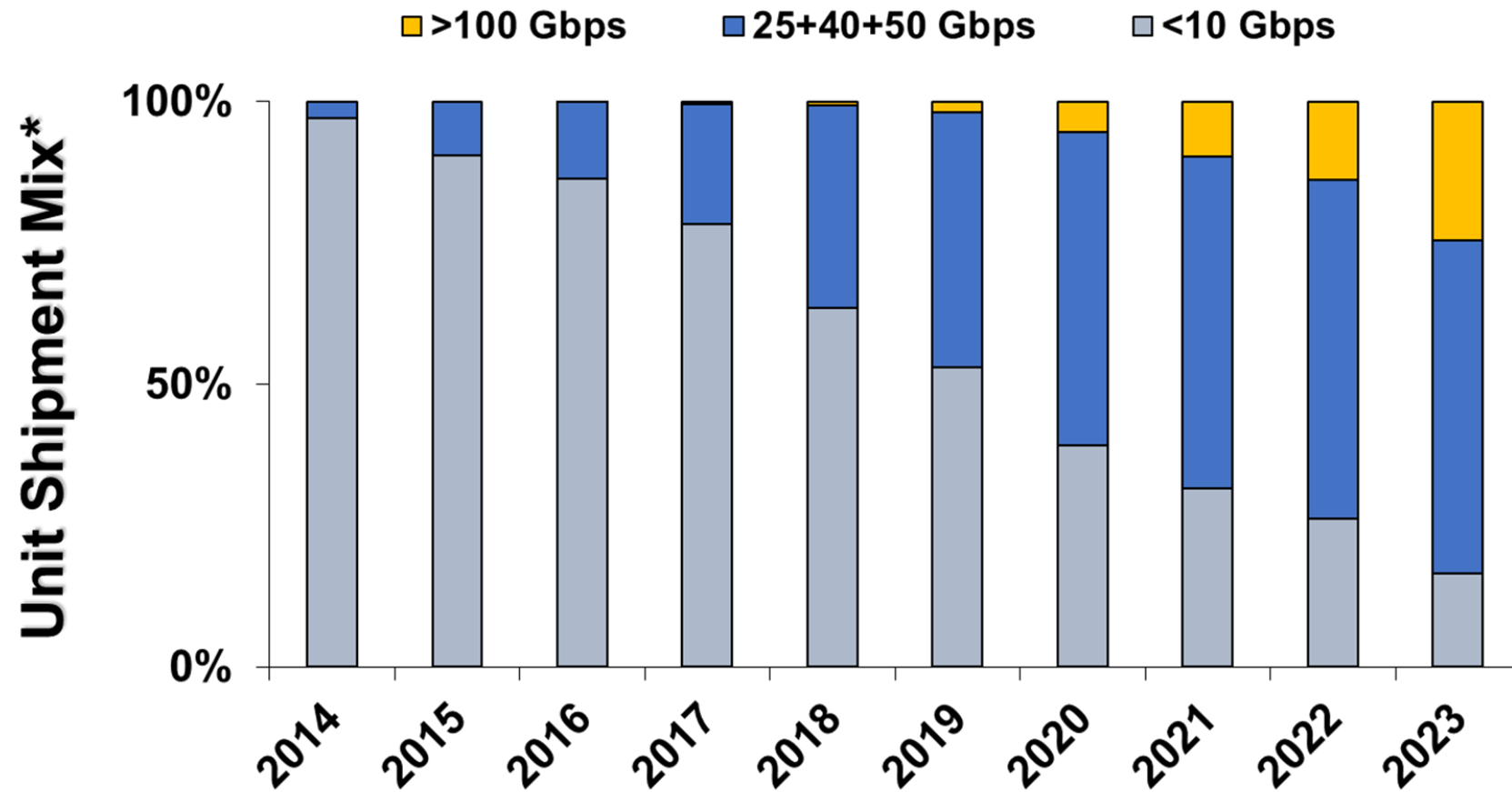


Traffic growth rates over all should decline as markets saturate

Regionally growth rates will be substantially diverse

Source: Traffic Growth in Telecom Networks and Mega Data Centers, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0409/kozlov\\_bwa\\_01\\_190409.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0409/kozlov_bwa_01_190409.pdf)

# ENTERPRISE AND CLOUD SERVER UNIT SHIPMENTS



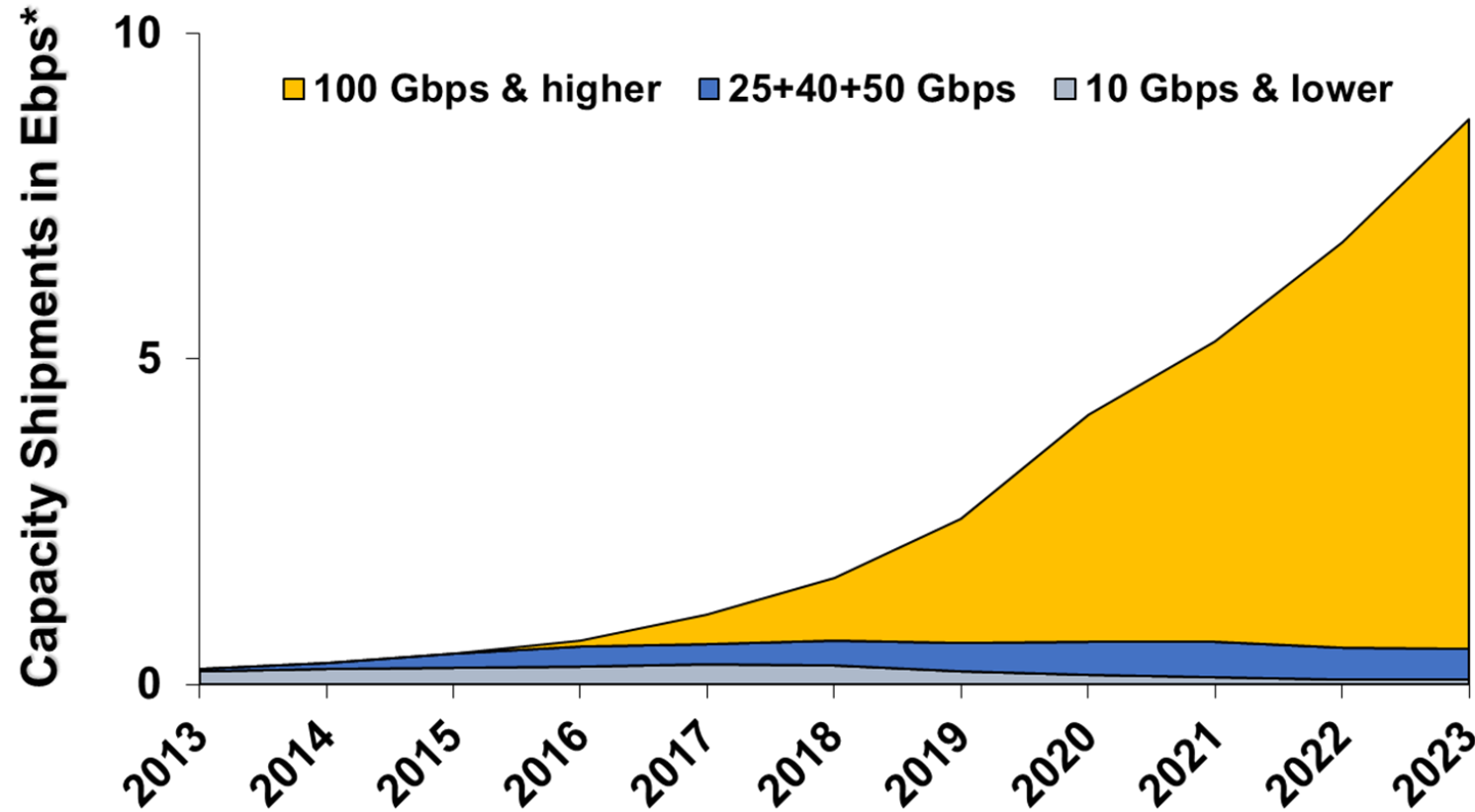
Adoption of higher speed will continue at every level of the network

\* Percent of annual server shipments categorized by speed of the attached Controllers and Adapters

Source: Data Center Ethernet Switch and Server Bandwidth Assessment for IEEE, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0927/fung\\_bwa\\_01a\\_190927.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0927/fung_bwa_01a_190927.pdf)



# DATA CENTER ETHERNET SWITCH CAPACITY SHIPMENTS



Demand for services will drive development of technologies to enable them

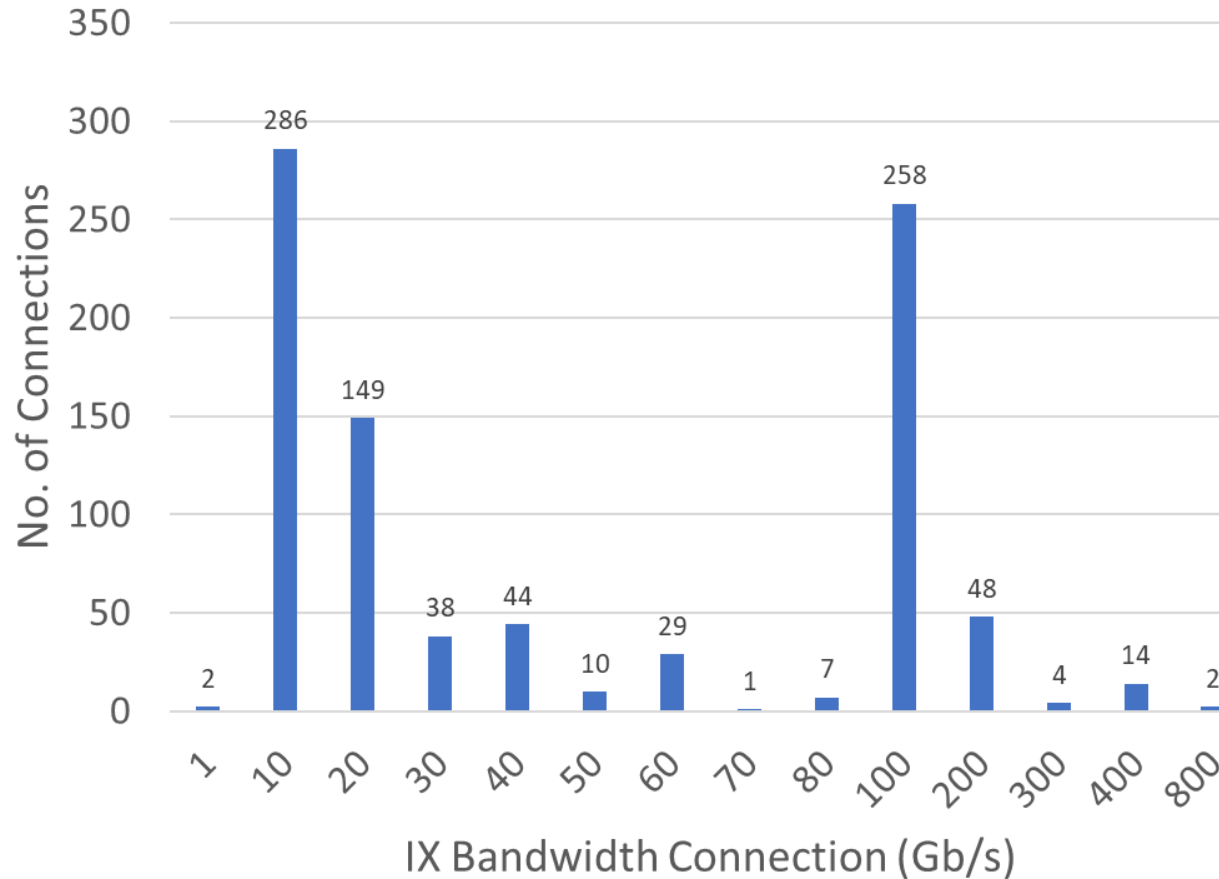
\* Annual port capacity shipped on Data Center Ethernet Switches measured in exabits per second

Source: Data Center Ethernet Switch and Server Bandwidth Assessment for IEEE, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0927/fung\\_bwa\\_01a\\_190927.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0927/fung_bwa_01a_190927.pdf)

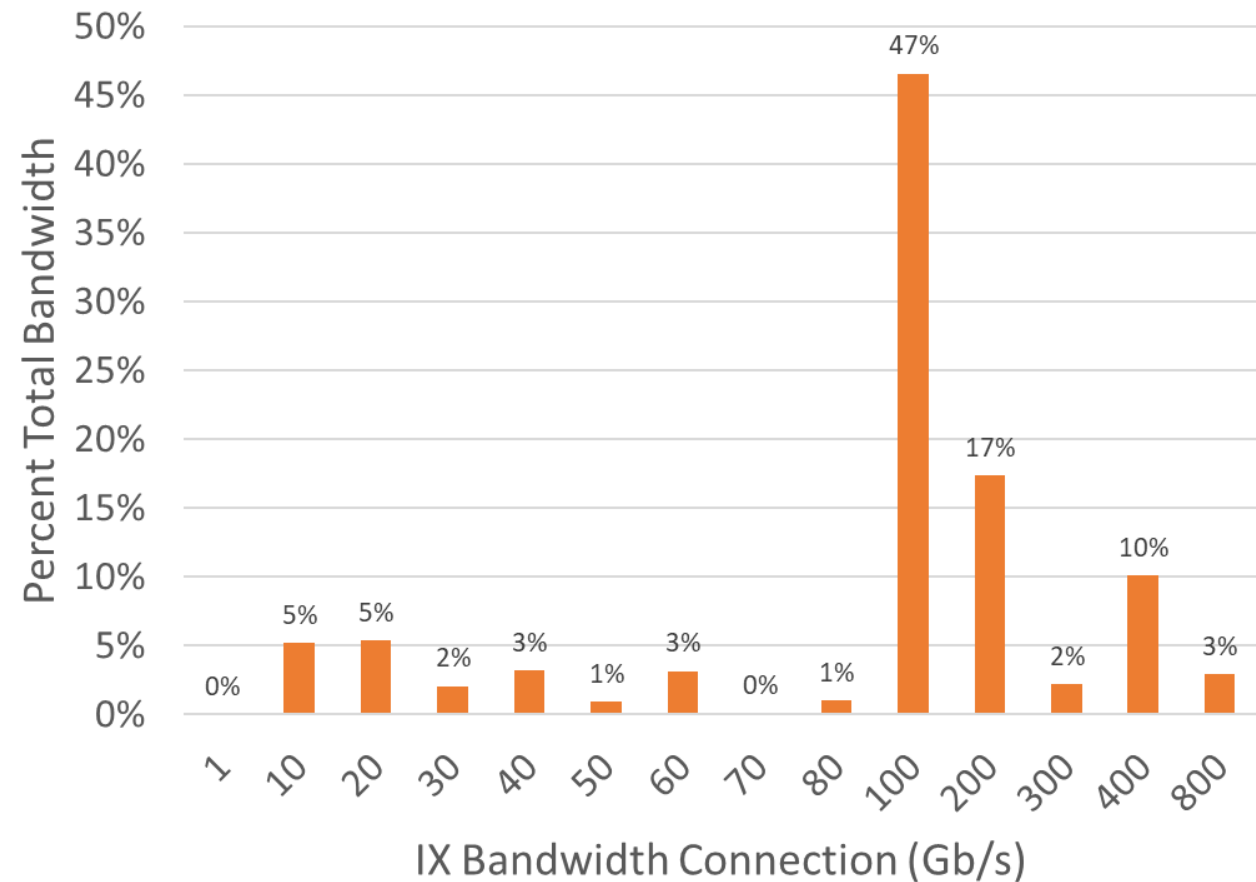
# Hyperscalers in PeeringDB

Source: Review of Networks in PeeringDB,  
[http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0827/dambrosia\\_bwa\\_01a\\_190827.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0827/dambrosia_bwa_01a_190827.pdf)

## # Network Connections



## Percent Total Bandwidth

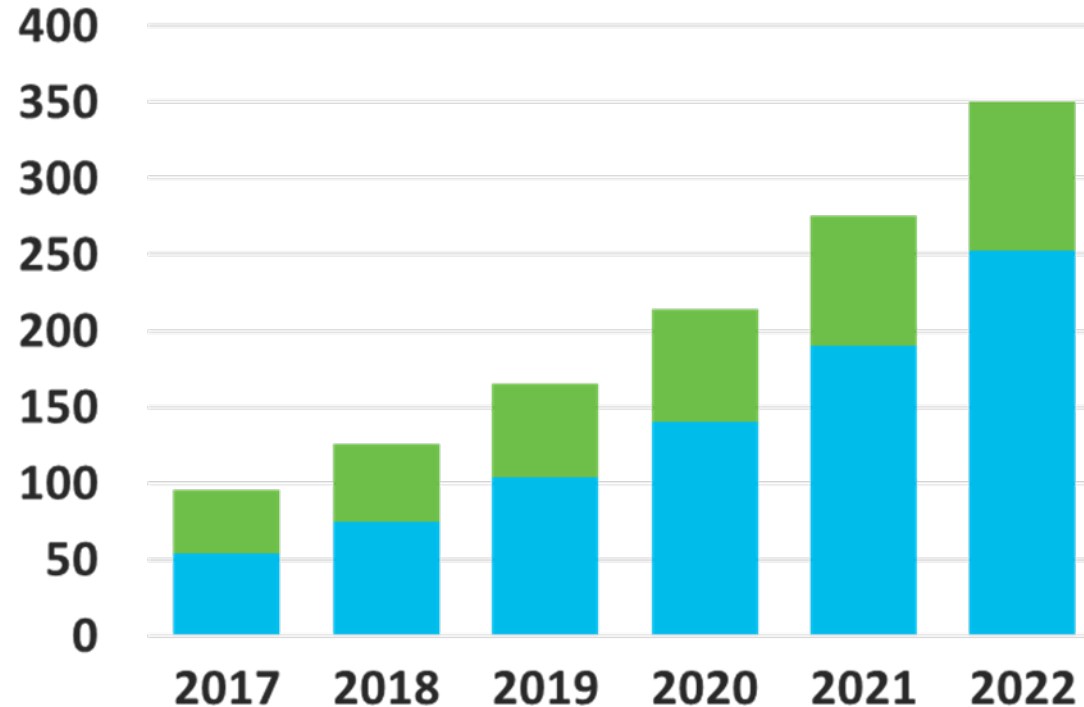


The number of high speed links drive overall BW

# GLOBAL CONTENT DELIVERY NETWORK (CDN) TRAFFIC

**30% CAGR  
2017–2022**

**Exabytes  
per  
Month**



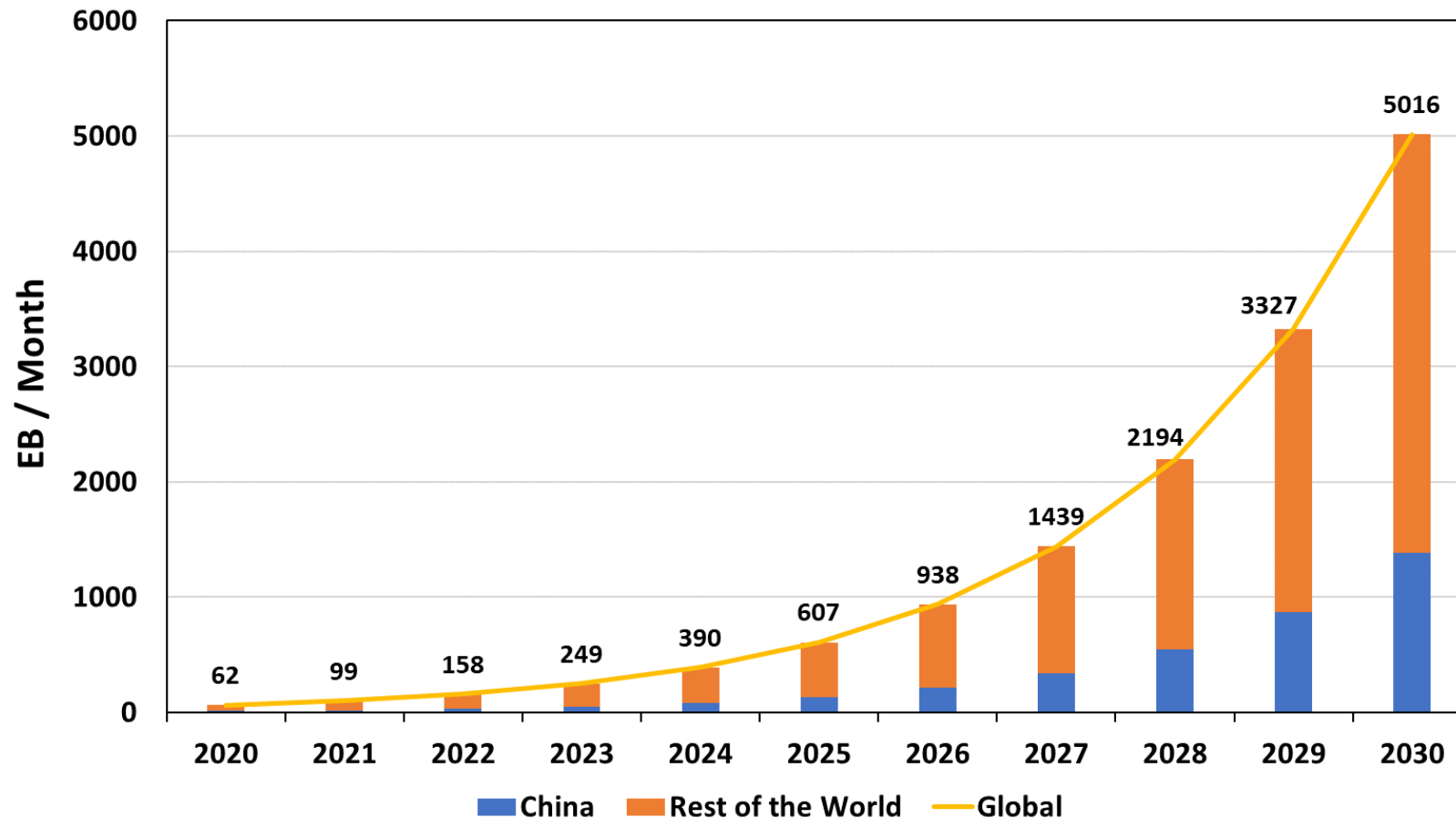
**■ Non-CDN Internet Traffic  
(44%,28%)**

**■ CDN Internet Traffic (56%, 72%)**

**\* Traffic (x,y) refers to 2017,  
2022 traffic share**

Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)

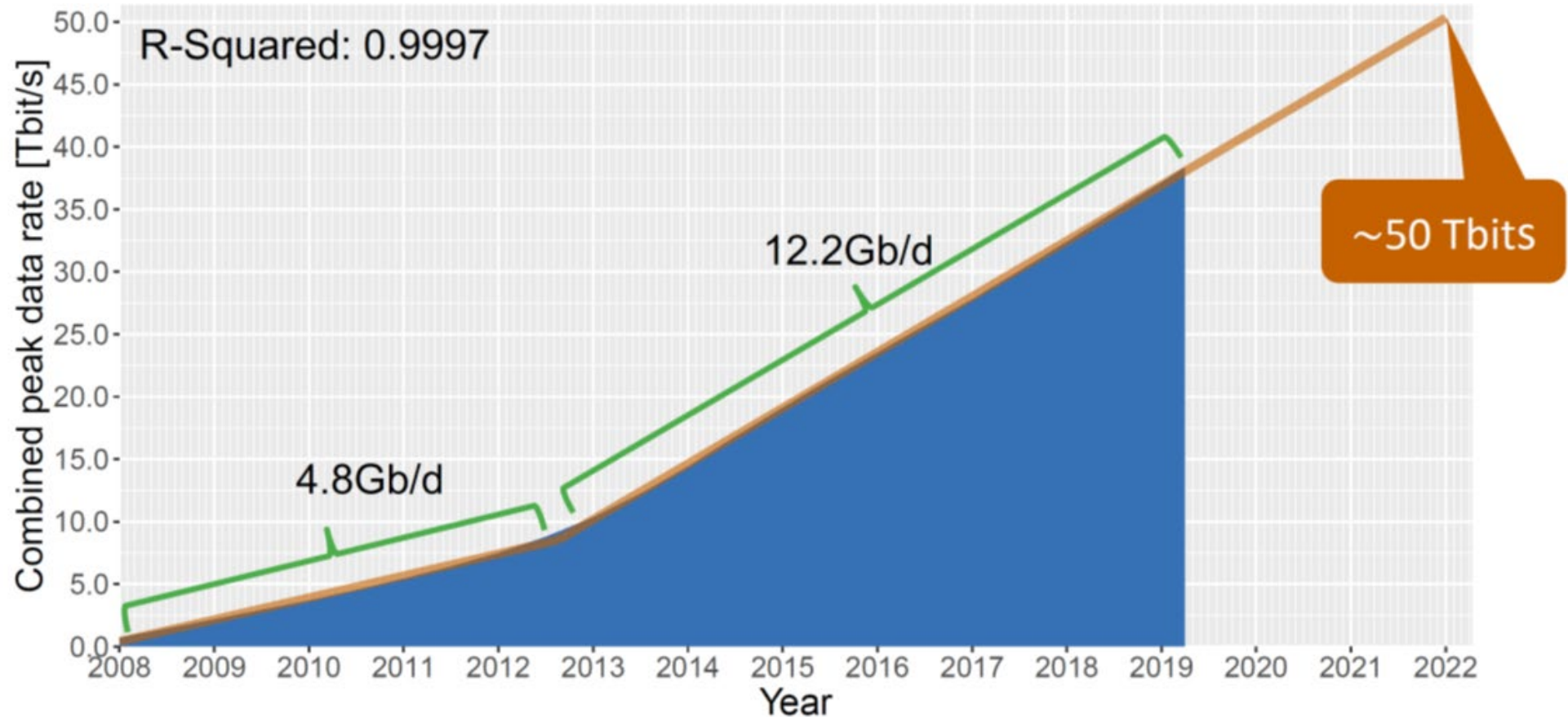
# ESTIMATION OF MOBILE TRAFFIC



Global mobile traffic is exponential and may even be underestimated

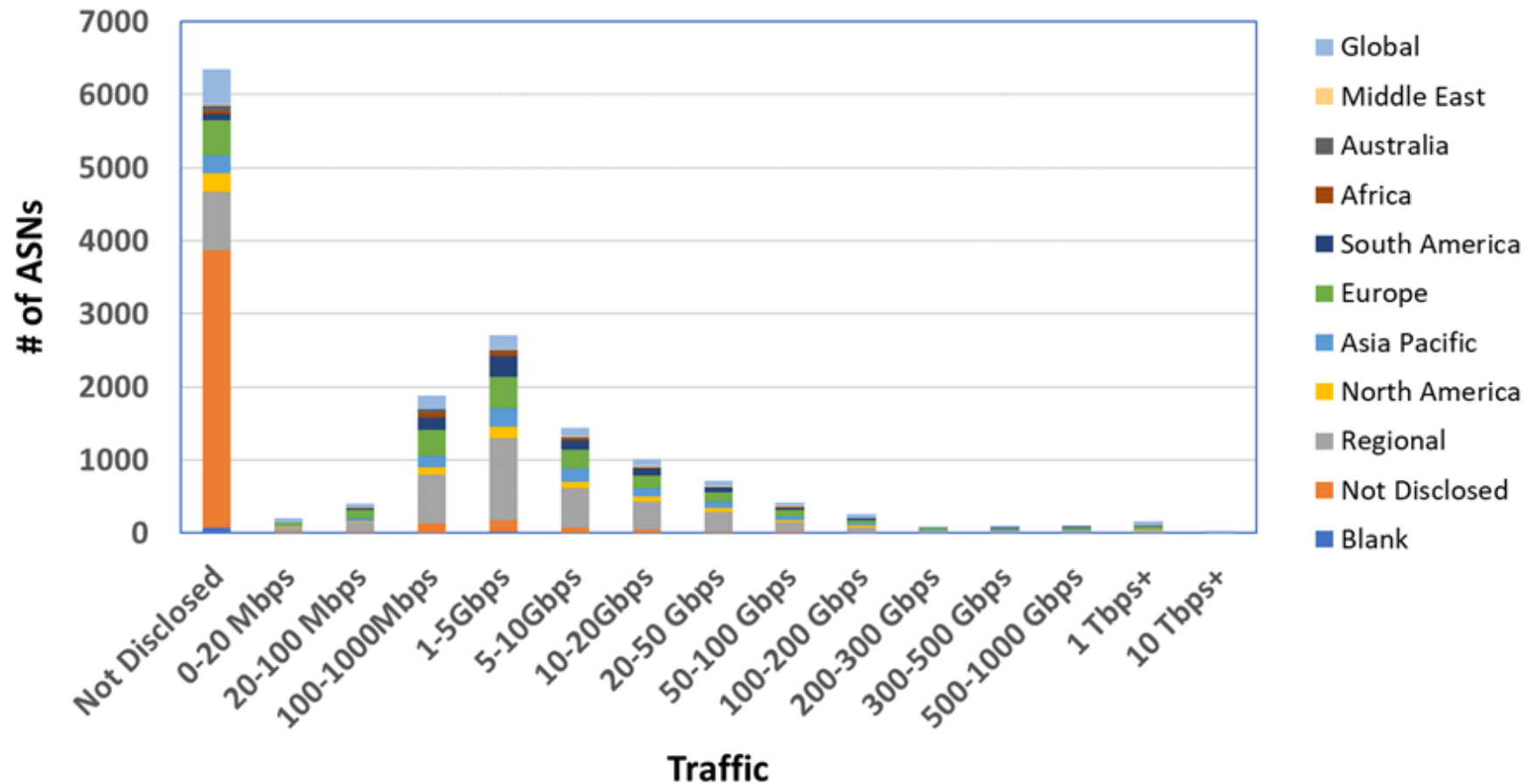
Source: Report ITU-R M.2370-0: IMT traffic estimates for the years 2020 to 2030, <https://www.itu.int/pub/R-REP-M.2370-2015>

# EURO-IX IXP PEAK DATA RATE TREND



Source: The European IXP Scene, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0709/dietzel\\_bwa\\_01b\\_190709.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0709/dietzel_bwa_01b_190709.pdf)

# PUBLIC PEERING: TRAFFIC PER NETWORK TYPE



Much of the data is undisclosed, so how accurately can we forecast?

Source: Review of Networks in PeeringDB, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/I9\\_0827/dambrosia\\_bwa\\_01a\\_I90827.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/I9_0827/dambrosia_bwa_01a_I90827.pdf)

# FINDINGS: BANDWIDTH

- Traffic growth is “Up and to the right”
- Data is validated from several angles
  - Connections to the network
  - Adoption of mobility
  - Video dominating traffic
- Regions have their own trends
  - Which technologies are convenient to adopt
  - Local issues drive the way people can adopt new services
- Still a lot of unknowns and that will not change
  - Networks are owned to be profitable and how they operate is proprietary



# SUMMARY



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

**Increased  
# of users**

x

Increased  
access  
methods  
and rates

x

Increased  
services

=

**Bandwidth  
Explosion**

- Nearly 60% of world population are internet users
- Number of connected devices: roughly 2x per connected individuals
- Number of connected devices will grow to over to 3x per capita by 2022
- Bandwidth requirement per user is growing at a much faster rate

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

- Mobile connectivity has the highest growth in access speeds globally from 2017 to 2022
- Video dominant BW driver, plus complication of mobility to network design
- M2M connections dominate number of connections by 2022, but not high BW consumer
- Peak busy hour traffic growing at faster rate than average.

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

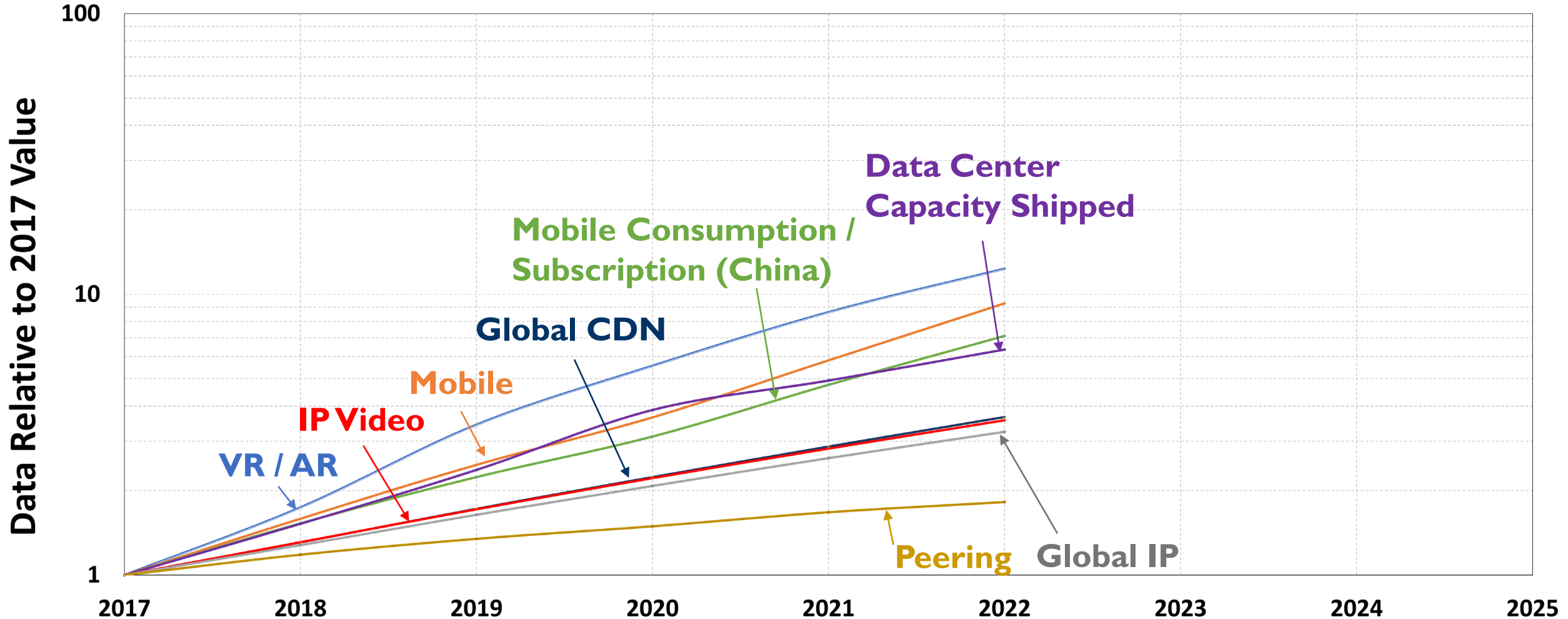
- Video remains killer app!
  - Getting worse with shift to UHD
- Other applications emerging
- What other applications not accounted for could further drive BW?

# THE FUTURE BANDWIDTH EXPLOSION

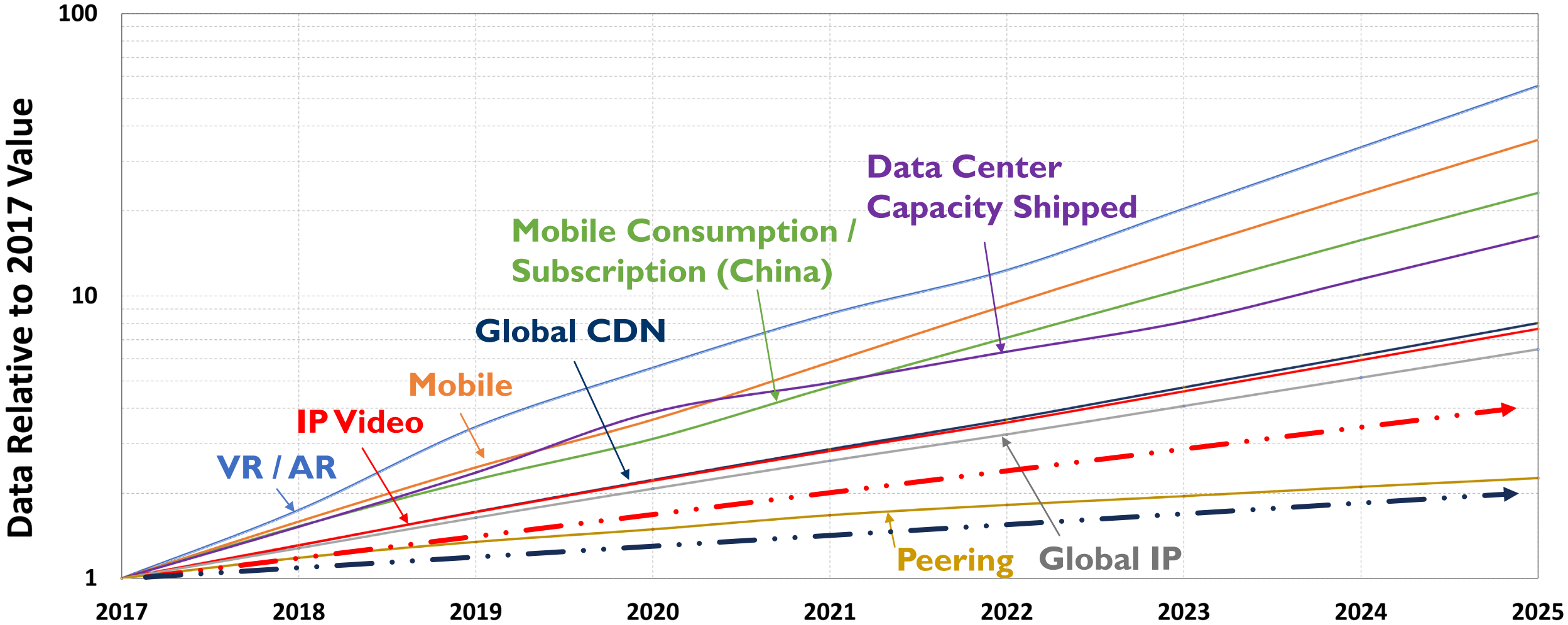
## *ANALYSIS METHODOLOGY*

- Step 1: Data Comparison for 2017 to 2022
  - Submitted bandwidth curves normalized to 2017 values
    - Data availability
    - Ratification of IEEE 802.3bs 200 GbE / 400 GbE Standard
- Step 2: Bandwidth curves extended to 2025
  - 5-year forecast
  - Estimated completion of a new higher speed Ethernet standard
  - Curves extended by either:
    - Curve fitting
    - Assume consistent CAGR for years 2022 to 2025

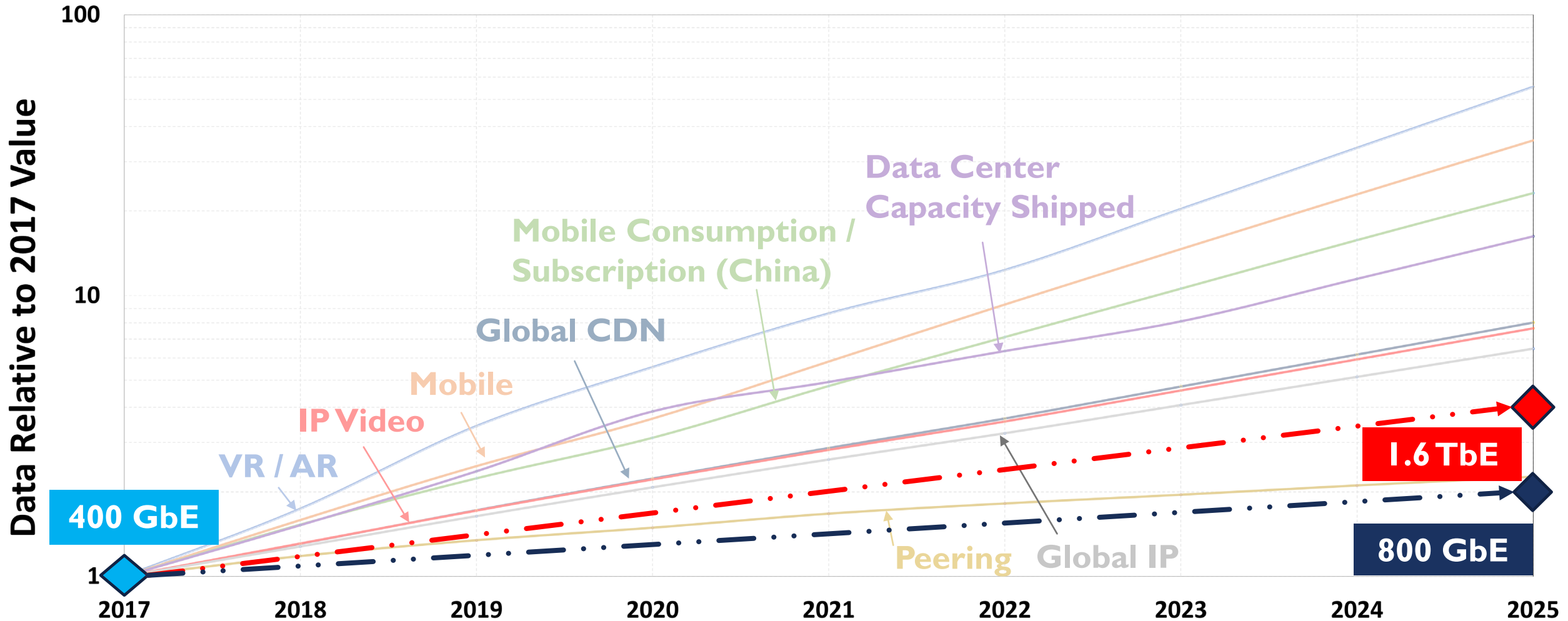
# BANDWIDTH (2017 – 2022)



# EXTENDED FORECAST: 2022 – 2025



# EXTENDED FORECAST: 2022 – 2025 (ASSUMING CONSISTENT CAGRs)





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

- Traffic growth is “Up and to the right”
- Broad diversity in growth
  - Regional basis
  - Application Basis (2.3x to 55.4x traffic levels of 2017)
- A new rate of Ethernet by 2025 will be challenged to keep up with bandwidth demands
  - This will only get worse if a new speed of Ethernet is delayed

# CONCLUSIONS

- All aspects of “The Bandwidth Explosion” equation indicate continued growth – Up & to the right!
- A 2x (800GbE) or 4x (1.6 TbE) increase in the maximum Ethernet data rate by 2025 would lag the forecasted growth rates. The impact will be exasperated by delaying the introduction of a new Ethernet rate.
- Observations
  - This assessment should be considered a snapshot, based on submitted data.
  - Continued shift to growing importance of mobile applications and [higher definition] video
  - Broad diversity & variability
    - Regional Basis
    - Application Basis
    - Average versus Peak Traffic Levels
  - Incomplete Picture
    - Some applications (artificial intelligence, 5G, etc) not addressed
    - Real network related data not submitted
  - Growing complexity to develop this forecast, due to breadth of networks and applications, as well as diversity

# STEPS GOING FORWARD

- Approval of the Ethernet Bandwidth Assessment will be accomplished via an IEEE 802.3 electronic ballot
  - Ballot Open - Monday 23<sup>rd</sup> March 2020
  - Ballot Close – Thursday 2<sup>nd</sup> April 2020 23:59 AOE
- Upon approval final report to be published:
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/BWA2\\_Report.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/BWA2_Report.pdf)



# BACKUP

# SUMMARY OF DATA SUBMISSIONS (1 OF 2)

## 1. John D'Ambrosia, Futurewei

- “Introduction – Ethernet Bandwidth Assessment, Part II”
  - [http://www.ieee802.org/3/ad\\_hoc/ngrates/public/18\\_09/dambrosia\\_bwa\\_01\\_0918.pdf](http://www.ieee802.org/3/ad_hoc/ngrates/public/18_09/dambrosia_bwa_01_0918.pdf)
- “Available Industry Data”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0611/dambrosia\\_bwa\\_01a\\_190611.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0611/dambrosia_bwa_01a_190611.pdf)
- “Review of Networks in PeeringDB”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0827/dambrosia\\_bwa\\_01a\\_190827.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0827/dambrosia_bwa_01a_190827.pdf)
- “Email Summary of Published Reports on Broadband Findings”
  - American Broadband Initiative, "Milestones Report, February 2019"  
[https://broadbandusa.ntia.doc.gov/sites/default/files/resource-files/american\\_broadband\\_initiative\\_milestones\\_report\\_feb\\_2019\\_0.pdf](https://broadbandusa.ntia.doc.gov/sites/default/files/resource-files/american_broadband_initiative_milestones_report_feb_2019_0.pdf)
  - European Commission, "Connectivity- Broadband market developments in the EU"  
[https://ec.europa.eu/newsroom/dae/document.cfm?doc\\_id=60010](https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=60010)
  - European Court of Auditors, "Broadband in the EU Member States"  
[https://www.eca.europa.eu/Lists/ECADocuments/SR18\\_12/SR\\_BROADBAND\\_EN.pdf](https://www.eca.europa.eu/Lists/ECADocuments/SR18_12/SR_BROADBAND_EN.pdf)
- Email - Inclusion of Mobile Network Data Submitted to the B10K Study Group
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/email/msg00064.html](http://www.ieee802.org/3/ad_hoc/bwa2/email/msg00064.html)

## 2. Wenyu Zhao, CAICT, “Broadband Development Status and Trend in China”

- [http://www.ieee802.org/3/ad\\_hoc/ngrates/public/18\\_11/zhao\\_nea\\_01\\_1118.pdf](http://www.ieee802.org/3/ad_hoc/ngrates/public/18_11/zhao_nea_01_1118.pdf)

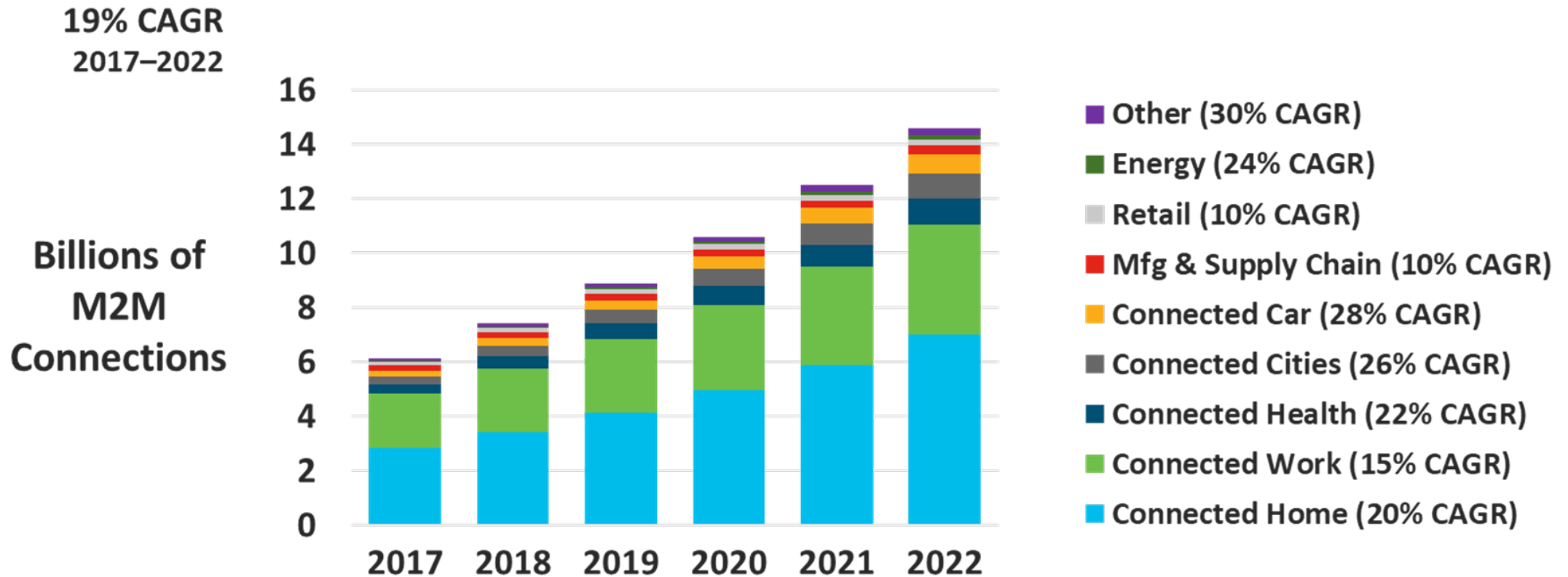
# SUMMARY OF DATA SUBMISSIONS (2 OF 2)

3. Steve Carlson, High Speed Design, Inc, “Trends in Automotive Networks”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0402/carlson\\_bwa\\_01\\_190402.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0402/carlson_bwa_01_190402.pdf)
4. Mark Laubach, Broadcom, “Future EPON Bandwidth Needs”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0402/laubach\\_bwa\\_01\\_190402.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0402/laubach_bwa_01_190402.pdf)
5. Vladimir Kozlov, LightCounting, “Traffic Growth in Telecom Networks and Mega DataCenters”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0409/kozlov\\_bwa\\_01\\_190409.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0409/kozlov_bwa_01_190409.pdf)
6. Mark Nowell, Cisco, “CISCO VNI Forecast Update”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)
7. Christoph Dietzel, “The European IXP Scene”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0709/dietzel\\_bwa\\_01b\\_190709.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0709/dietzel_bwa_01b_190709.pdf)
8. Guo, Liang, “Next Generation Data Center Connections in China”
  - [http://www.ieee802.org/3/ad\\_hoc/ngrates/public/19\\_09/guo\\_bwa\\_01\\_0919.pdf](http://www.ieee802.org/3/ad_hoc/ngrates/public/19_09/guo_bwa_01_0919.pdf)
9. Baron Fung, Sameh Boujelbene, Shin Umeda, Dell’Oro, “Data Center Ethernet Switch and Server Bandwidth Assessment for IEEE”
  - [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0927/fung\\_bwa\\_01a\\_190927.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0927/fung_bwa_01a_190927.pdf)

# ABBREVIATIONS

- 1GbE 1 Gb/s Ethernet
- 10GbE 10 Gb/s Ethernet
- 1.6TbE 1.6 Tb/s Ethernet
- 25GbE 25 Gb/s Ethernet
- 40GbE 40 Gb/s Ethernet
- 50GbE 50 Gb/s Ethernet
- 100GbE 100 Gb/s Ethernet
- 200GbE 200 Gb/s Ethernet
- 400GbE 400 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
- 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

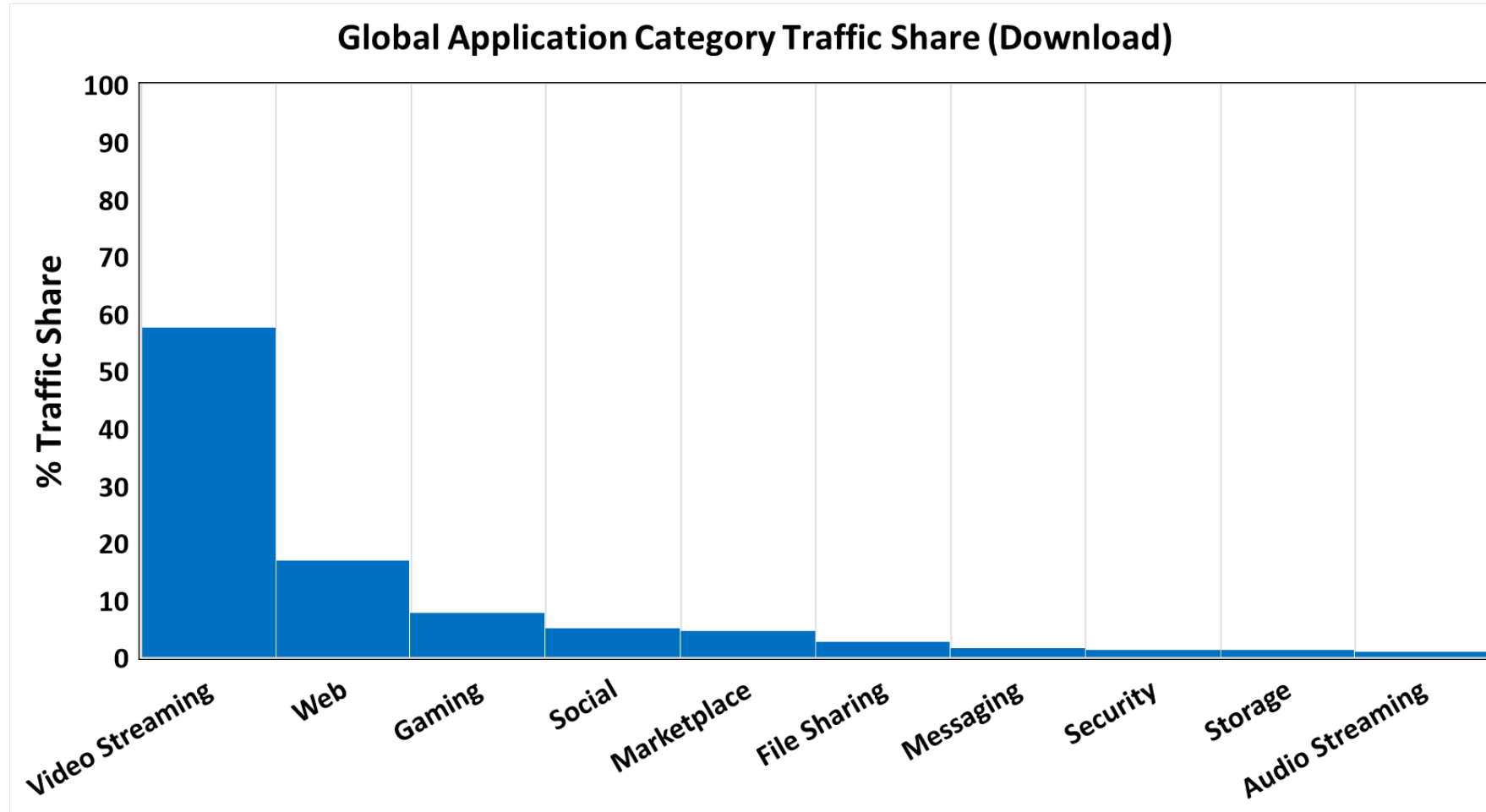
# GLOBAL M2M CONNECTIONS BY VERTICAL



Source: Cisco VNI Forecast Update, [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0624/nowell\\_bwa\\_01\\_190624.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0624/nowell_bwa_01_190624.pdf)



# GLOBAL APPLICATION CATEGORY TRAFFIC (DOWNLOAD)



Source: Summary of data from Sandvine from "Available Industry Data", [http://www.ieee802.org/3/ad\\_hoc/bwa2/public/calls/19\\_0611/dambrosia\\_bwa\\_01a\\_190611.pdf](http://www.ieee802.org/3/ad_hoc/bwa2/public/calls/19_0611/dambrosia_bwa_01a_190611.pdf)