## IEEE 802.3 NEA Ad hoc

IEEE 802.3 Call for Interest Draft Development

**"Beyond 400 GbE"** CFI Consensus Presentation

John D'Ambrosia Futurewei Technologies U.S. Subsidiary of Huawei



## **OBJECTIVE FOR THE MEETING**

- To measure the interest in starting a study group to address "Beyond 400 Gb/s Ethernet and Breakout Ethernet Rates"
- We don't need to
  - Fully explore the problem
  - Debate strengths and weaknesses of solutions
  - Choose any one solution
  - Create PAR or five criteria
  - Create a standard or specification
- Anyone in the room may speak / vote
- RESPECT... give it, get it

## Contributors

- John D'Ambrosia, Futurewei, U.S. Subsidiary of Huawei
- Matt Brown, Huawei Canada
- Joel Goergen, Cisco
- Mark Gustlin, Cisco
- **Xinyuan Wang, Huawei**

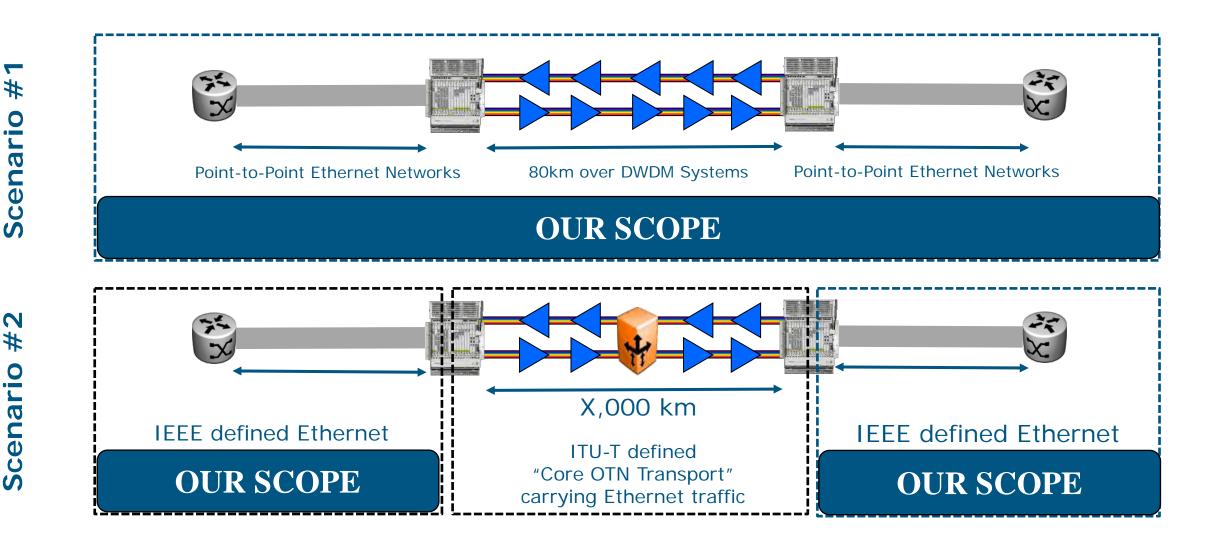
## **Today's Panel**

To be identified

## AGENDA

- Introduction
- Presentations
  - Market Pressures for Beyond 400 GbE
  - The Technical Roadmap to Beyond 400 GbE
  - Why Now?
- Straw Polls
- Future Work

## THE SCOPE OF ETHERNET TODAY



24 Aug 2020

## The Ethernet "Breakout Scenario" Ecosystem

FUTURE

**POSSIBLE** 

4

in the local division of the local divisione	1.1	The second second						To an and the second second	T. Comments of		and the second s					inin the form
1472	1444	5470	7491	UAT10	HATE	UATH	UATE I	UATE	94720	214722	STATE!	254720	274.720	2547.00	314.932	MANNE F
										Concession of the						
			(income)			è	L									

Image courtesy of David Piehler, Dell-EMC

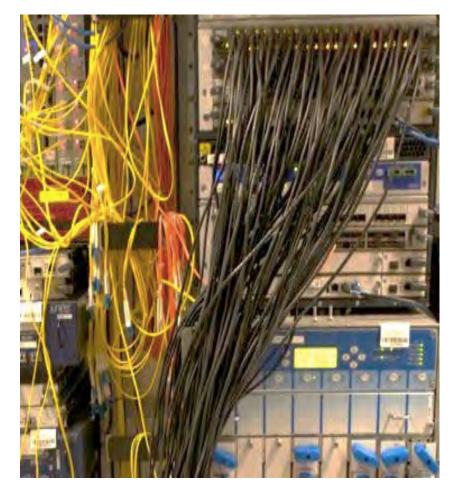
32 400GbE ports break out into 128 100GbE ports



"It has been my experience at Google that we have used optical and cu modules to support breakout applications as well as applications requiring the maximum capacity as a single port."

Cedric Lam, Google

## LINK AGGREGATION WILL NOT SUFFICE

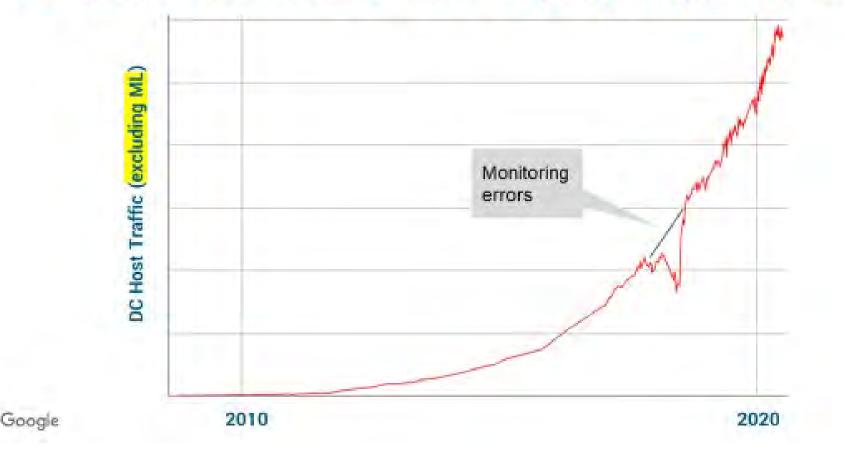


Courtesy, David Ofelt, Juniper.

- Problem: Need to scale the Network (density & cost)
- Temporary Solution: Link Aggregation
- Pros:
  - Addresses bandwidth requirements between releases of faster links
- Cons:
  - Non-deterministic performance
  - Fastest flow limited to individual link speed
  - Exponential bandwidth growth implies:
    - Exponential growth in number of links
    - Growth in operational & management issues
  - Doesn't scale forever.
- Faster links address these issues <u>and</u>
   <u>they will be LAGGed!</u>

## DATA CENTERS CONTINUE AS A PRIMARY DRIVER

### **DC Traffic Continues to Grow Rapidly (Regular Servers)**



Courtesy - Cedric Lam, Google

## **COVID-19 TRENDS, APRIL 2020**



Source - Inphi blog post 'Bandwidth in the Age of COVID-19' posted 22nd April 2020 by Ford Tamer, President and CEO, Inphi Corporation < https://www.inphi.com/blog/>

# MARKET PRESSURES FOR BEYOND 400 GbE



# THE SONG REMAINS THE SAME



# **WORLD INTERNET USAGE**

Total World	As of 3/31/19 <sup>1</sup>	As of 12/31/19 <sup>3</sup>	Increase	As of 7/20/20 <sup>2</sup>	Increase
Population	7,716,223,209	7,796,615,710	80,392,501	7,796,949,710	80,726,501
Internet Users	4,383,810,342	4,574,150,134	190,339,792	4,833,521,806	449,711,464
Internet Penetration	57%	59%	2%	62%	5%

Top 20 Countries	As of 3/31/19 <sup>1</sup>	As of 12/31/19 <sup>3</sup>	Increase
Population	5,187,499,066	5,233,377,837	45,878,771
Internet Users	3,117,533,898	3,241,273,512	123,739,614
Internet Penetration	60%	62%	2%
Rest of World	As of 3/31/19 <sup>1</sup>	As of 12/31/19 <sup>3</sup>	Increase
Population	2,565,984,143	2,563,237,873	-2,746,270
Internet Users	1,229,027,955	1,332,876,622	103,848,667
Internet Penetration	48%	52%	4%

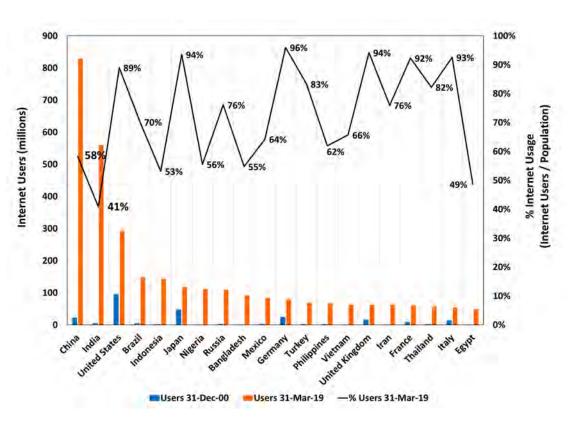
#### **Observations**

- Only 8 countries had at least 80% connectivity
- $\Rightarrow \approx 450$  million users increase
- 5% increase in Total World Internet Penetration since Mar 31 2019

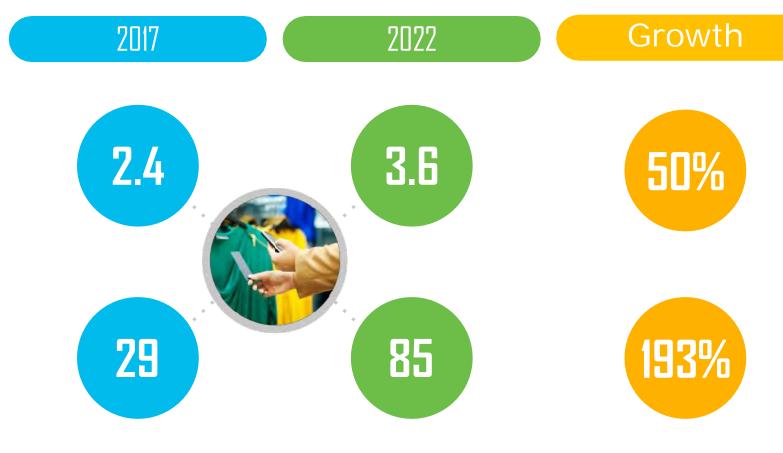


2. <u>HTTPS://WWW.INTERNETWORLDSTATS.COM/STATS.HTM</u>

3. <u>HTTPS://WWW.INTERNETWORLDSTATS.COM/TOP20.HTM</u>



## **GLOBAL DEVICES / CONNECTIONS AVERAGE PER CAPITA**



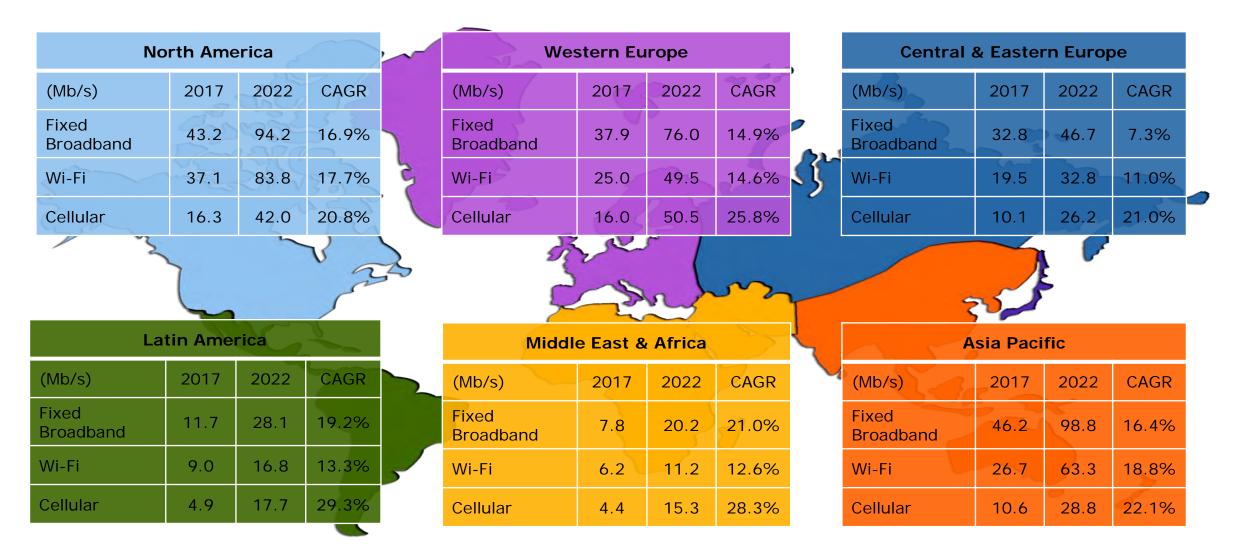
Average Number of Devices and Connections per **Capita** 

Average Traffic per User per Month **GB** 

### Number of connected devices per capita is growing The average traffic per user is growing at a much faster rate

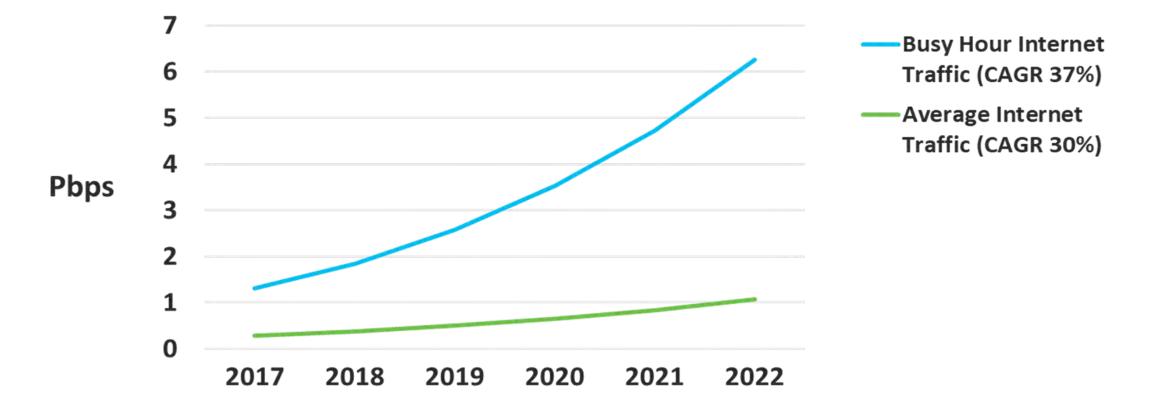
Source: Cisco VNI Forecast Update, http://www.ieee802.org/3/ad\_hoc/bwa2/public/calls/19\_0624/nowell\_bwa\_01\_190624.pdf

## **GLOBAL DEVICE CONNECTION GROWTH (AVERAGE)**



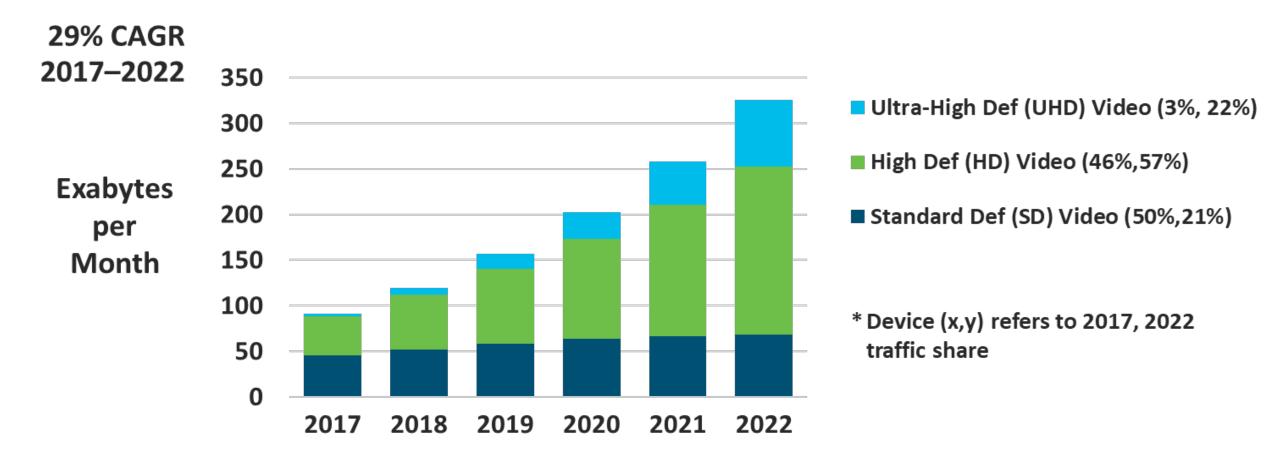
Source: Cisco VNI Forecast Update, http://www.ieee802.org/3/ad\_hoc/bwa2/public/calls/19\_0624/nowell\_bwa\_01\_190624.pdf

# GLOBAL INTERNET TRAFFIC BUSY-HOUR VS AVERAGE HOUR



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

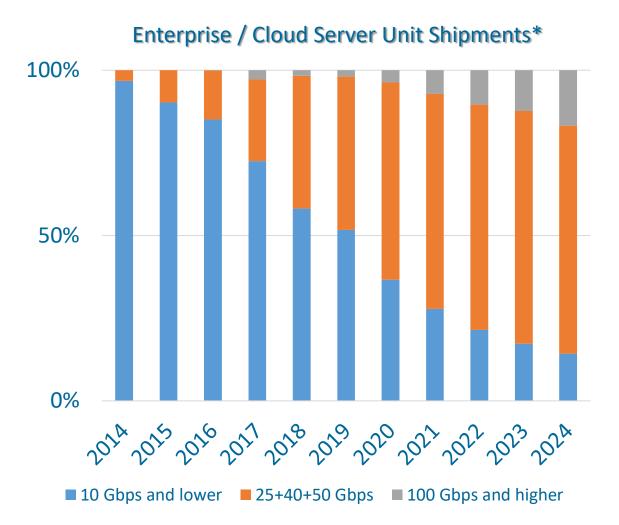
## IMPACT OF "DEFINITION' ON IP VIDEO GROWTH



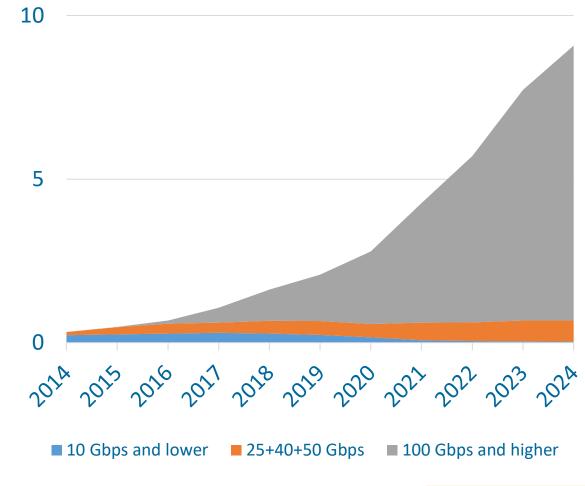
### Growth in the adoption of HD and UHD dominate IP video traffic

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

## DATA CENTER CAPACITY CONTINUES TO GROW



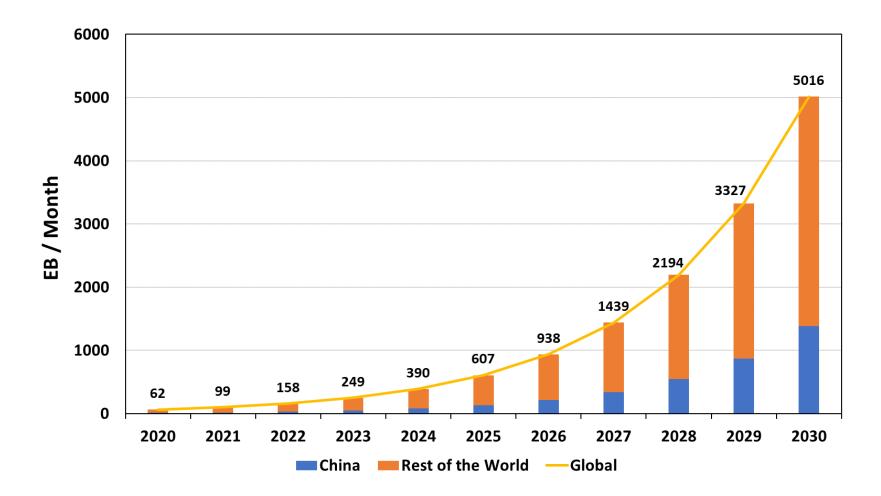
### Switch Capacity Shipments in Eb/s\*\*



\* Percent of annual server shipments categorized by speed of the attached controllers and adapters
 \*\* Annual port capacity shipped on Data Center Ethernet Switches measured in exabits per second



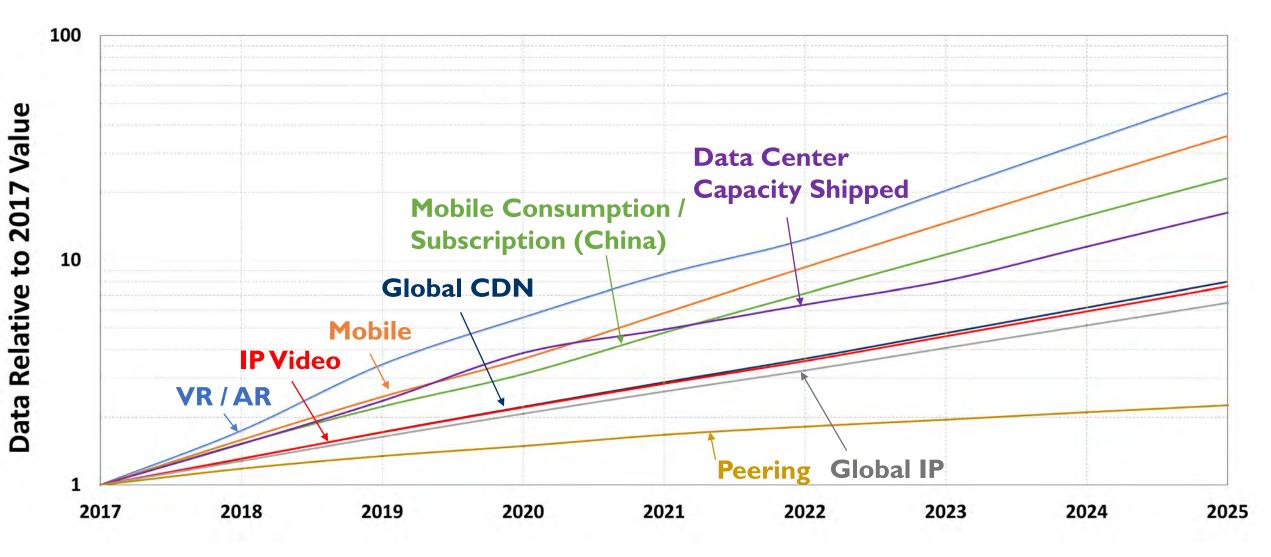
## **ESTIMATION OF MOBILE TRAFFIC**



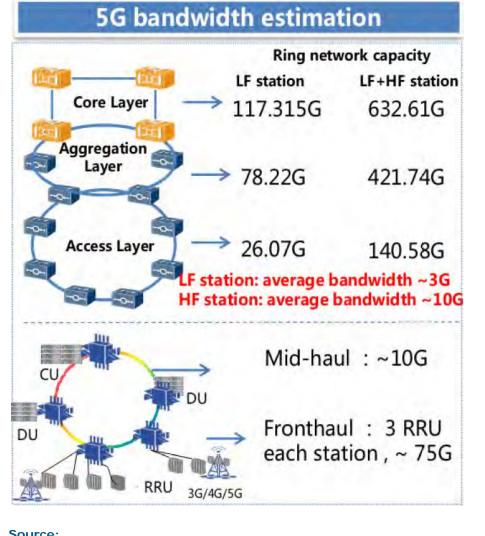
Global mobile traffic is expediential and may even be underestimated

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

## The 2020 Ethernet Bandwidth Assessment



## **EXAMPLE EMERGING APPLICATION – 5G BACKHAUL**

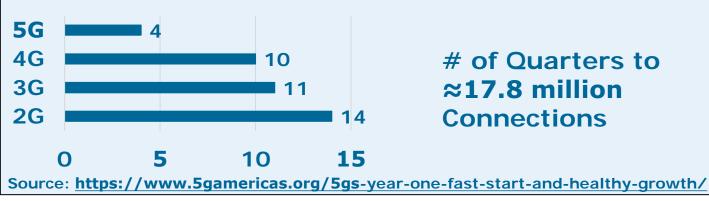


Source.	
http://www.ieee802.org/3/B10K/public/18_	01/wang_b10k
_01b_0118.pdf	

LTE	LTE Advanced	5G
145	42	4
162	74	29
93	59	14
127	50	8
44	29	12
20	11	7
88	70	31
683	335	105
	145 162 93 127 44 20 88	145       42         162       74         93       59         127       50         44       29         20       11         88       70

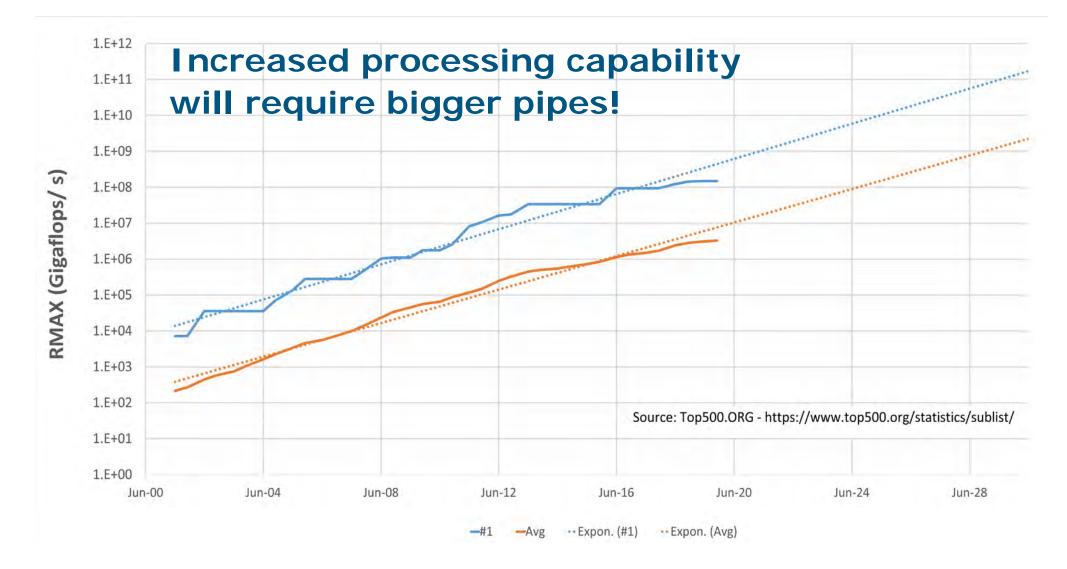
Source: as of 8/14/2020, https://www.5gamericas.org/resources/deployments/

#### Omdia projects 91 million global 5G connections by end of 2020



24 Aug 2020

# **HIGH PERFORMANCE COMPUTING**

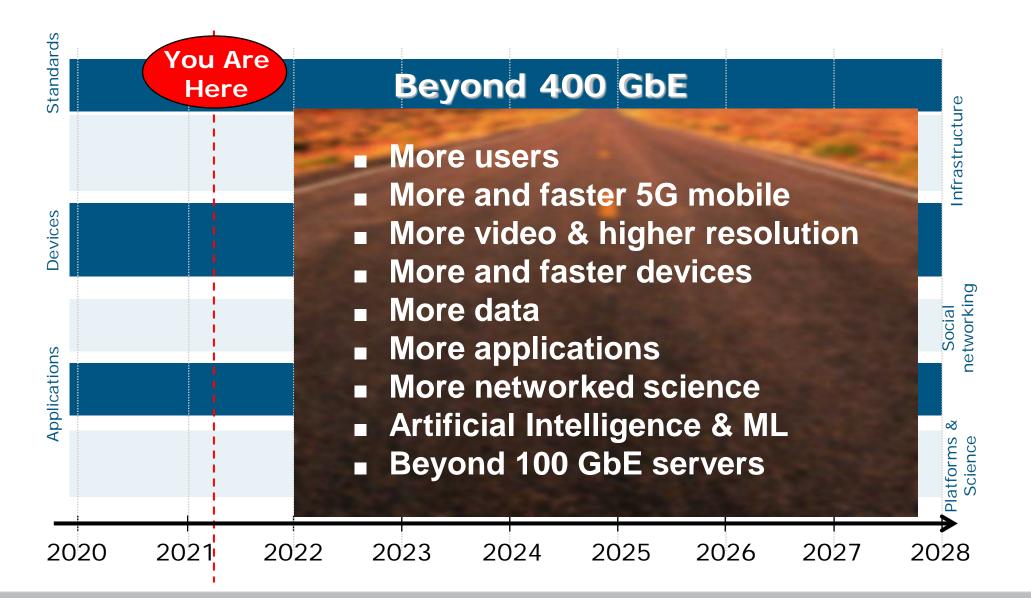


## **ARTIFICAL INTELLIGENCE & COMPUTE**

### Two Distinct Eras

- First Era (Before 2012)
  - Moore's Law 2-year doubling for compute
  - Uncommon to use GPUs for machine learning
- Modern Era (2012 and later)
  - 2012 2014: most results used 1-8 GPUs rated at 1-2 TFLOPS
  - 2014 2016: large-scale results used 10-100 GPUs rated at 5-10 TFLOPS
  - 2016 2017: greater algorithmic parallism (huge batch sizes, architecture search, expert iteration), specialized hardware (TPUs), faster interconnects
- Source: <u>https://openai.com/blog/ai-and-compute/</u>

## MORE OF THE SAME.....



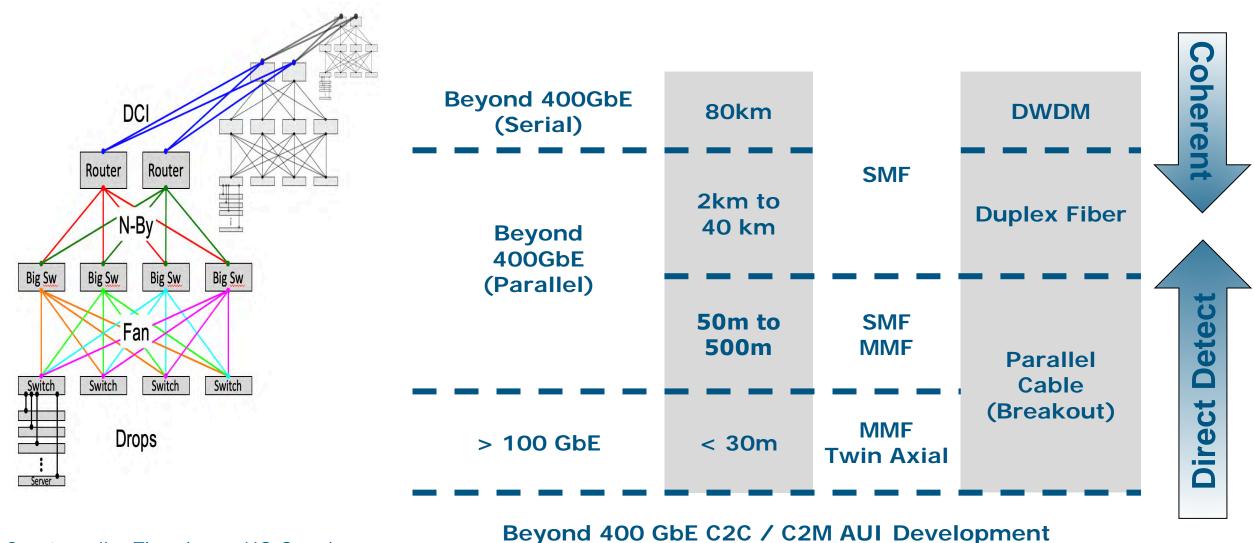
## **SUMMARY**

- Bandwidth growth continues and underlying factors indicate further bandwidth growth
  - Video and mobile!
  - Increasing delta between "peak" and "average"
- New applications fueling bandwidth growth
- In today's COVID world
  - Connectivity has been critical!
  - "Instantaneous" growth in multiple application spaces
- "Up and to the right" continues

# THE TECHNICAL ROADMAP TO BEYOND 400 GbE

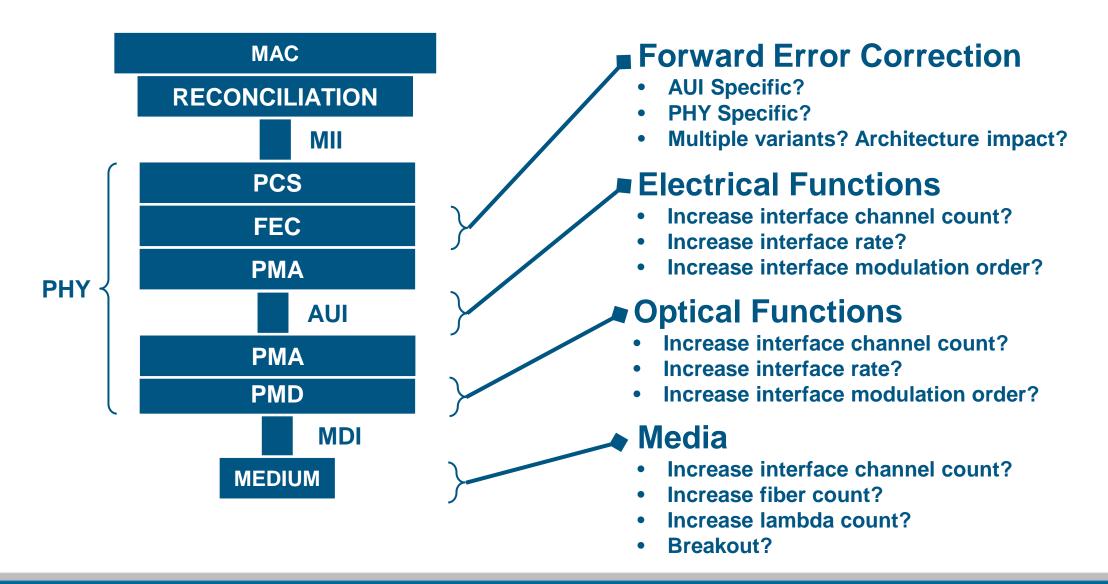


## **Understanding the Physical Challenges**



Courtesy Jim Theodoras, HG Genuine

## THE CHALLENGES TO BEYOND 400 GBE



## **MAC/PCS Technical Feasibility**



The options below are very feasible in near term technology (as an example, actual rate(s) are TBD)

MAC Rate	Technology Node	Device Type	Bus Width	Clock Rate
800 Gb/s	5nm	ASIC	1024b	800 MHz
	5nm	ASIC	512b	1.6 GHz
	7nm	FPGA	1536b	533MHz
1.6 Tb/s	5nm	ASIC	2048b	800 MHz
	5nm	ASIC	1024b	1.6 GHz
	5nm (or equiv)	FPGA	3072b	533MHz

Source – Mark Gustlin, Cisco

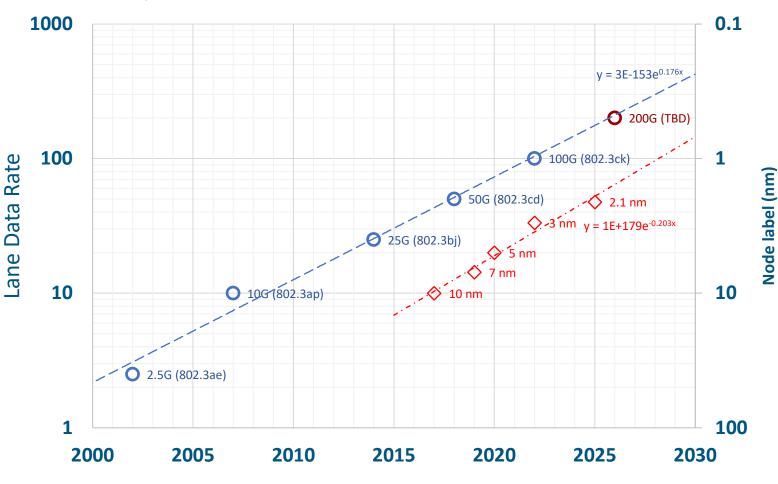
## PCS/FEC

- Previous PCS concepts could be re-used
  - 64b/66b, transcoding, scrambling, AMs
- Will likely want a new stronger FEC for 200G lanes (if the project chooses to define 200G lanes)
  - Multiple FEC options for direct detect, coherent light and longer reach coherent?
  - Still support end to end FEC for some options?
  - Optimize gain, latency, power and implementation burden for chosen FECs
    - While minimizing the overall # of FEC options

Source – Mark Gustlin, Cisco

## **CMOS Roadmap**

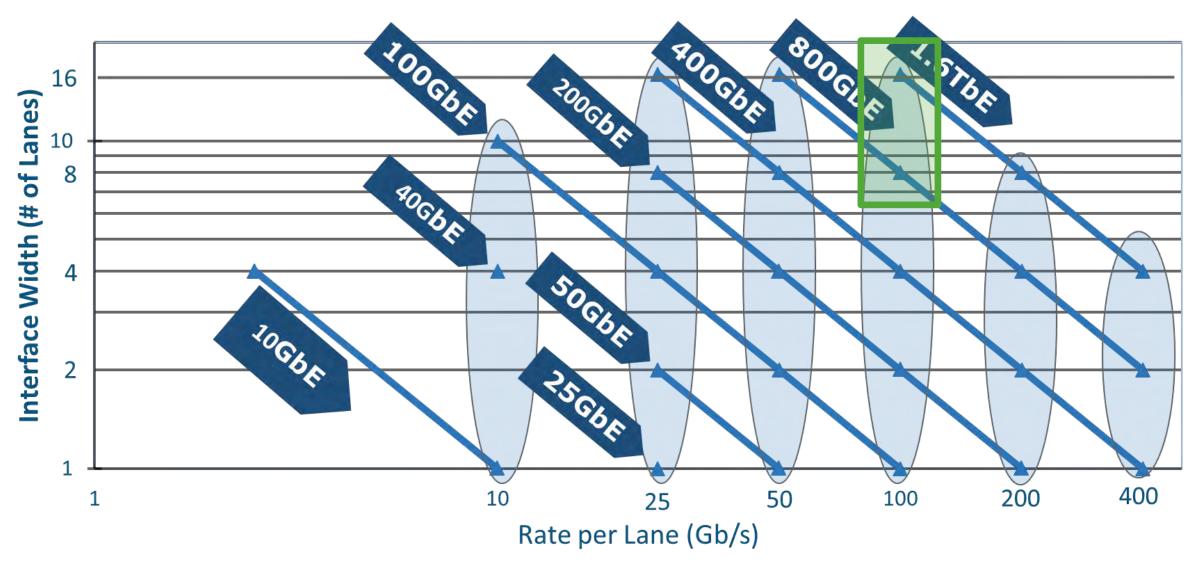
### **Comparison of Lane Data Rate and Node Label Timelines**



- The upper data (blue) shows evolution of electrical lane data rate over time.
- The lower data (red) shows the evolution of node label over time.
- Current designs for 100 Gb/s per lane are in 7 nm and are moving to 5 nm.
- 3 nm and 2.1 nm will be available when
   200 Gb/s per lane is standardized.
- The node label (halving every 3.4 years) is progressing faster than the electrical lane rate (doubling every 3.9 years).

#### Source – Matt Brown, Huawei Canada

## Beyond 400 GbE - Leveraging 100 Gb/s



Page 32

## Industry Efforts - 100 Gb/s Signaling

## IEEE 802.3

- Standard IEEE P802.3bs 400GBASE-DR4 (4x100G)
- In Development
  - IEEE P802.3ck 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Task Force
  - IEEE P802.3cu 100 Gb/s and 400 Gb/s over SMF at 100 Gb/s per Wavelength Task Force
  - IEEE P802.3db 100 Gb/s, 200 Gb/s, and 400 Gb/s Short Reach Fiber Task Force
- Other Industry Efforts
  - OIF Common Electrical Interface 112G Efforts
  - 100G Lambda MSA (100Gb/s optical interfaces specifications)

## 800 Gb/s Industry Activities

## Ethernet Technology Consortium

- <u>https://ethernettechnologyconsortium.org/</u>
- "The 800 GbE specification introduces a new media access control (MAC) and Physical Coding Sublayer (PCS)"

## QSFP-DD800 MSA

- http://www.qsfp-dd800.net/
- Rev 1.0 released Mar 6 2020

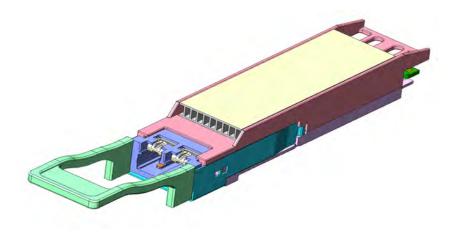
## OSFP





#### Source- Nathan Tracy, TE Connectivity

## Example: 800 Gb/s OSFP Capacity Module

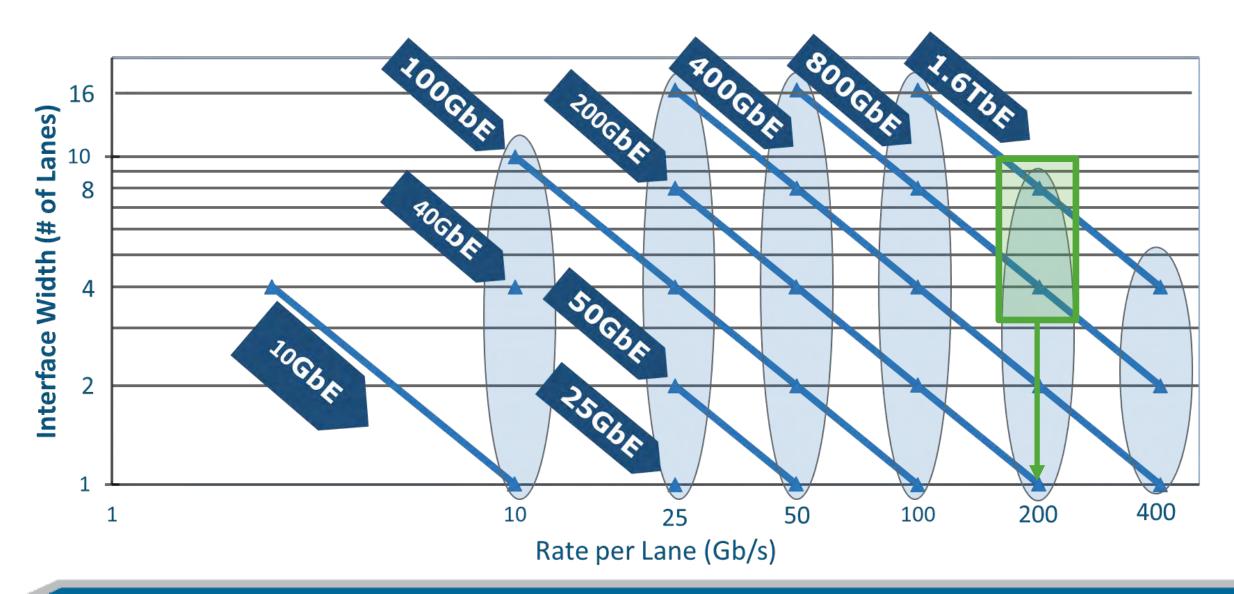


- OSFP Form Factor
- 8x100G DR8+ 2km with MPO-16 and 2x400G FR4 with CS connector
- OIF CEI-112G-VSR interface
- PMD spec follows 400G DR4+ and FR4. interoperable with 400G
- \* 0~70degC 18W, 10~60C 17W
- \* 7nm DSP inside

Source – Tedros Tsegaye, Innolight

ope		0						7		Scope Result				
Setup	Measure	Amplitude O/E	Time CRU	Control Ch All	Ch A	Ch B	Ch C	<u>Ch D</u>	Sampling Hold	Screen Copy				
					TIOId	THOMO	T HONG	145304 200 Juny 204006		Amplitude/Time				
and a state of the		Constant in the		1000	No.		- ANIA COLORA	Tuetre		CHA PAM4 CHB PAM4 CHC PAM4 CHD PAM4	Ch	Current	Average	1
	Sources of	and the state	Contraction of the local division of the loc		Concernances			1. Mar 1.	Auto Scale	Average Power (dBm)	A	0.83		dBm
			Section of the sectio	119.2494		-		Contra Co		Average Power (dBm)	B	0.13		dBm
					6 - LUN (8)					Average Power (dBm)	C	1.20	1.21	dBm
	10 11 10		No.	19. Veran				1.1		Average Power (dBm)	D	0.78	0.78	dBm
	Contraction of the local division of	and the second second	and Manager		-	ALCONO.		-		TDECQ	A	2.38	2.43	dB
	- State	1210 . 120 - 11		-		-			Clear Display	TDECQ	В	2.33	2.36	
	and the second second		No. of Lot.	a loss of the same	TO THOM	and the second second		The second second		TDECQ	С	2.36	2.48	
				Party and	Sull Ma		all shales			TDECQ	D	2.33	2.37	
Systematic		In I FILL BOOMERS	-	AND LODGER	NY T		1. I COMPANY	-		Outer OMA(dBm)	A	3.00		dBm
North Contraction of the local distance of the local distance of the local distance of the local distance of the	and the second	Station of the second second		a little state	Section Provide		A CONTRACTOR OF THE			Outer OMA(dBm)	B	2.07		dBm
ICH I			53 125 000 Hoave	d 3.8 ps/Div				53125000 keaud	Quick Menu	Outer OMA(dBm) A Outer OMA(dBm)	D	2.85		dBm dBm
624) MY			Wat 2.00 U	A MILEORLE		_		Mar 3 10 U			A	10.52	10.50	
INT INT										Outer ExR	B	9.78	9.80	
	State of the second			Contraction of the	Solid La	and the second	a saidestan	Shine Protection		Outer ExR A	C	10.73	10.75	
	C. C		2	C. Internation	Star Ing	1000		T WAR		Outer ExR A	D	10.61	10.63	
	A STREET	and and and		a logical second	A Dane	and the second		Contraction of the local division of the loc		Linearity(A_120D)	A	0.946	0.943	
	1.0		10000		and the second	States of the local division of the local di		- No and		Linearity(A_120D)	В	0.973	0.968	
			-	1000	1. 31.	115		ST.	<u> </u>	Linearity(A_120D)	С	0.955	0.951	
								Sec.	Overlap 🔀	Linearity(A_120D)	D	0.977	0.970	
	Cardina a		( Section of the sect	A STATE	The Local Division	and the			Single 1					
	A DECEMBER OF	All all	THE OWNER	10 C	STR. SALES			11.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1	Single	The La		Te		
	and the second second	the second second		and a second										
The lights		antifrancia.		and to the second	Antilen Market	100	STREET.		Tile III	<b>IX</b> 1-4 LC	W	le	<b>M</b>	
r ingelss and in a second second a				Control Ch					Tile 🔛	Tx1-4 LC	W	le	mp	
Setup	Measure	Amplitude O/E	Time CRU	Control Ch All	Ch A Hord	Ch B Hold	Ch C Hold	Ch D Hold	Tile	Screen Copy	W	le	mp	
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Hold	Ch D Hold	Sampling	Screen Copy	W	le	mp	
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Hold	Ch D Hold	Sampling Hold	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4				1
Setup	Measure				Ch A. Hold	Ch B Hold	Ch C Hold	Ch D Held Protect	Sampling	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHD PAM4	Ch	Current -0.63	Average	dBm
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Held	Ch D Hold Hold Hold Hold Hold Hold	Sampling Hold	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4		Current	Average -0.62	
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Head	Ch D Hold Hold Hold Hold	Sampling Hold	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHD PAM4 Average Power (dBm)	Ch	Current -0.63	Average -0.62 -0.14 0.07	dBm dBm
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Hold	Ch D Hold Hold Hold Hold	Sampling Hold	Screen Copy Amplitude/Time CHAPAM4 CHBPAM4 CHC PAM4 CHBPAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm)	Ch A B C D	Current -0.63 -0.16 0.13 0.67	Average -0.62 -0.14 0.07 0.66	dBm dBm dBm
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Held	Ch D Hord Hord Hord Hord Hord Hord	Sampling Hold	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ	Ch A B C D A	Current -0.63 -0.16 0.13 0.67 2.71	Average -0.62 -0.14 0.07 0.66 2.68	dBm dBm dBm dB
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Hota	Ch D Ch D Hord Ch Ch D Ch C	Sampling Hold	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ	Ch A B C D A B	Current -0.63 -0.16 0.13 0.67 2.71 2.41	Average -0.62 -0.14 -0.17 -0.66 2.68 2.36	dBm dBm dBm dB dB
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Head	Ch D Ch D Hore Harris	Sampling Hold	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ	Ch A B C D A B C	Current -0.63 -0.16 0.67 2.71 2.41 2.70	Average -0.62 -0.14 0.07 0.66 2.68 2.36 2.36	dBm dBm dB dB dB dB
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Meld	Ch D Hois Hois	Sampling Hold	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ TDECQ	Ch A B C D A B C D D D	Current -0.63 -0.16 0.13 0.67 2.71 2.70 2.24	Average -0.62 -0.14 0.07 0.66 2.68 2.36 2.64 2.21	dBm dBm dB dB dB dB dB dB
Setup	Measure				Ch A Hold	Ch B Heid	Ch C Hold		Sampling Hold	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm)	Ch A B C D A B C D A A	Current -0.63 -0.16 0.13 0.67 2.71 2.70 2.24 2.70 2.24 1.67	Average -0.62 -0.14 -0.07 -0.66 -2.68 -2.36 -2.64 -2.21 -1.65	dBm dBm dB dB dB dB dB dB dBm
Setup	Measure				Ch A Hold	Ch B Hold	Ch C Head		Auto Scale	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) (A Outer OMA(dBm) (A)	Ch B C D A B C D A B C D A B	Current -0.63 -0.16 0.67 2.71 2.41 2.70 2.24 1.67 2.04	Average 0.62 0.14 0.07 0.66 2.68 2.36 2.64 2.21 1.65 2.04	dBm dBm dB dB dB dB dBm dBm
Setup	Measure				Ch A Here	Ch B Hold	Ch C Pold		Sampling Hold	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) Auter OMA(dBm) Cuter OMA(	Ch A B C D A B C D A B C C	Current -0.63 -0.16 0.13 -0.77 2.71 2.41 2.70 2.24 1.67 2.04 2.37	Average -0.62 -0.14 -0.07 -0.66 -2.68 -2.64 -2.21 -1.65 -2.04 -2.36	dBm dBm dB dB dB dB dBm dBm dBm
Setup	Measure		CRU		Ch A Tota	Ch B Hold	Ch C Hold		Auto Scale	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) Ch Out	Ch A B C D A B C D A B C D D C D D	Current -0.63 -0.16 0.13 0.67 2.71 2.70 2.24 1.67 2.04 2.37 2.77	Average -0.62 -0.14 0.07 0.66 2.68 2.36 2.64 2.21 1.65 2.04 2.36 2.76 2.36 2.76 2.64 2.24 2.54 2.54 2.54 2.54 2.54 2.54 2.54 2.54 2.54 2.55 2.64 2.55 2.64 2.55 2.65 2.75 2.65 2.65 2.75 2.65 2.75 2.65 2.75 2.65 2.75 2	dBm dBm dB dB dB dB dBm dBm dBm dBm
Setup	Measure		CRU		Ch A Hod	Ch B Hold	Ch C Heid		Auto Scale	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CH2 PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer OMA(dBm) A Outer OMA(dBm) A Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA	Ch A B C D A B C D A B C C	Current -0.63 -0.16 0.13 -0.77 2.71 2.41 2.70 2.24 1.67 2.04 2.37	Average -0.62 -0.14 -0.07 -0.66 -2.68 -2.64 -2.21 -1.65 -2.04 -2.36	dBm dBm dB dB dB dB dBm dBm dBm dBm dBm
Setup	Measure		CRU		Ch A Hoad	Ch B Hold	Ch C Hold		Auto Scale	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A	Ch A B C D A B C D A B C D A A	Current -0.63 -0.16 0.13 0.67 2.71 2.41 2.70 2.24 1.67 2.04 2.37 2.07 10.85	Average -0.62 -0.14 -0.07 -0.66 2.68 2.36 2.64 2.21 1.65 2.04 2.36 2.04 2.36 2.77 10.72	dBm dBm dB dB dB dB dBm dBm dBm dBm dBm
Setup	Measure		CRU		Ch A Hoad		Ch C Head		Auto Scale	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) Ch Outer OMA(dBm) Ch Outer CMA(dBm) Ch OUter CMA	Ch A B C D A B C C D A B C C D A B B C C D C A B C C D A B C C D A B C C D C A B C C D C C D C C D D C C D D C C D D C C D D C C D D C C D D C C D D C C D D C C D D C C D D C C D D C C D D C C C D D C C D D C C C D D C C C D D C C C D D C C C D D C C C D D C C C D D C C C D C C C D C	Current -0.63 -0.16 0.13 2.71 2.71 2.70 2.24 1.67 2.04 2.37 2.07 10.05 10.47	Average -0.62 -0.14 -0.07 -0.66 -2.68 -2.68 -2.64 -2.21 -1.65 -2.04 -2.36 -2.77 -10.72 -	dBm dBm dB dB dB dBm dBm dBm dBm dBm dBm
Setup	Measure		CRU		Ch A Had		Ch C Hold		Auto Scale	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer OMA(dBm) A Outer OMA(dBm) A Outer CMA(dBm) A Outer ExR Outer ExR Outer ExR A Outer ExR A	Ch A B C D A A B C C D A A B C C D A A A B C C D A A A B C C D A A B C C D A A B C D A A B C D D A A B C D D A A B C D D A A B C D D A A B C D D A A A B C D D A A A B C D D A A A C D D A A A C D D A A A C D D A A A C D D A A A C D D A A A C D D A A A C D D A A A C D D A A A C D D A A A A	Current -0.63 -0.16 0.13 0.67 2.71 2.70 2.24 1.67 2.24 1.67 2.04 2.37 2.77 10.85 10.47 10.06	Average 0.62 0.14 0.07 0.66 2.68 2.36 2.64 2.21 1.65 2.04 2.36 2.77 10.72 10.48 10.10	dBm dBm dB dB dB dBm dBm dBm dBm dBm dBm
Setup	Measure 1		CRU		Ch A Hoad				Auto Scale	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer ExR Outer ExR Outer ExR Ch Outer ExR	Ch B C C D A B C C D A B C C D A B C C D A B B C C D A B B C D A B B C C D A B B C C D A B B C C D D A B C D D A B C D D D D C D D D D D C D D D D D C D	Current .0.63 .0.16 0.13 0.67 2.71 2.71 2.70 2.24 1.67 2.77 2.04 2.37 2.77 10.85 10.47 10.06 10.16 0.976 0.959	Average -0.62 -0.14 0.07 0.66 2.68 2.36 2.21 1.65 2.04 2.36 2.77 10.72 10.48 10.10 10.21 0.979 0.953	dBm dBm dB dB dB dBm dBm dBm dBm dBm dBm
Setup	Measure		CRU		Ch A	Ch B Total			Auto Scale	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 CHC PAM4 CHD PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer ExR A Outer ExR A Linearity(A 120D) Linearity(A 120D) Linearity(A 120D)	Ch A B C D A A B C C D A A B C C D A A B C C D A C C D C A C D C A C D C A C D C D	Current -0.63 -0.16 0.13 0.67 2.71 2.04 2.24 1.67 2.04 2.27 7.04 2.37 2.04 0.25 10.47 10.85 10.47 10.66 0.976 0.959 0.959	Average 0.62 0.14 0.07 0.66 2.68 2.64 2.21 1.65 2.04 2.36 2.77 10.72 10.48 10.10 10.21 10.979 0.953 0.954	dBm dBm dB dB dB dBm dBm dBm dBm dBm dBm
Setup	Measure		CRU			Ch B Hot			Auto Scale	Screen Copy Amplitude/Time CHAPAM4 CHB PAM4 CHC PAM4 CHB PAM4 Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer ExR Outer ExR Outer ExR Ch Outer ExR	Ch B C C D A B C C D A B C C D A B C C D A B B C C D A B B C D A B B C C D A B B C C D A B B C C D D A B C D D A B C D D D D C D D D D D C D D D D D C D	Current .0.63 .0.16 0.13 0.67 2.71 2.71 2.70 2.24 1.67 2.77 2.04 2.37 2.77 10.85 10.47 10.06 10.16 0.976 0.959	Average -0.62 -0.14 0.07 0.66 2.68 2.36 2.21 1.65 2.04 2.36 2.77 10.72 10.48 10.10 10.21 0.979 0.953	dB dB dBm dBm dBm dBm dB dB dB dB dB
Setup	Measure		CRU			Ch B Poor	Ch C Hold		Auto Scale Clear Display Quick Menu Overlap	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 CHC PAM4 CHD PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer ExR A Outer ExR A Linearity(A 120D) Linearity(A 120D) Linearity(A 120D)	Ch A B C D A A B C C D A A B C C D A A B C C D A C C D C A C D C A C D C A C D C D	Current -0.63 -0.16 0.13 0.67 2.71 2.04 2.24 1.67 2.04 2.27 7.04 2.37 2.04 0.25 10.47 10.85 10.47 10.66 0.976 0.959 0.959	Average 0.62 0.14 0.07 0.66 2.68 2.64 2.21 1.65 2.04 2.36 2.77 10.72 10.48 10.10 10.21 10.979 0.953 0.954	dBm dBm dB dB dB dBm dBm dBm dBm dBm dB dB dB dB dB
Setup	Measure		CRU		Ch A Haad		Ch C Bold		Auto Scale Clear Display Quick Menu	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 CHC PAM4 CHD PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer EXR A O	Ch A B C D D A A B B C D D A A B B C D D A A B C D D D D D D D D D D D D D D D D D D	Current -0.63 -0.16 0.13 2.71 2.70 2.24 1.67 2.04 2.37 10.85 10.47 10.06 10.16 0.976 0.950 0.962	Average 0.62 0.14 0.07 0.66 2.68 2.36 2.24 1.65 2.04 2.21 1.65 2.04 1.65 2.04 1.65 2.04 0.979 0.963 0.979 0.954 0.957	dBm dBm dB dB dB dB dB dB dB dB dB dB dB dB dB
Setup	Measure 1		CRU						Auto Scale Clear Display Quick Menu Overlap	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 CHC PAM4 CHD PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer EXR A O	Ch A B C D D A A B B C D D A A B B C D D A A B C D D D D D D D D D D D D D D D D D D	Current -0.63 -0.16 0.13 2.71 2.70 2.24 1.67 2.04 2.37 10.85 10.47 10.06 10.16 0.976 0.950 0.962	Average 0.62 0.14 0.07 0.66 2.68 2.36 2.24 1.65 2.04 2.21 1.65 2.04 1.65 2.04 1.65 2.04 0.979 0.963 0.979 0.954 0.957	dBm dBm dB dB dB dB dB dB dB dB dB dB dB dB dB
Setup	Measure		CRU						Auto Scale Clear Display Quick Menu Overlap	Screen Copy Amplitude/Time CHA PAM4 CHB PAM4 CHC PAM4 CHB PAM4 CHC PAM4 CHD PAM4 Average Power (dBm) Average Power (dBm) Average Power (dBm) TDECQ TDECQ TDECQ Outer OMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer CMA(dBm) A Outer ExR A Outer ExR A Linearity(A 120D) Linearity(A 120D) Linearity(A 120D)	Ch A B C D D A A B B C D D A A B B C D D A A B C D D D D D D D D D D D D D D D D D D	Current -0.63 -0.16 0.13 2.71 2.70 2.24 1.67 2.04 2.37 10.85 10.47 10.06 10.16 0.976 0.950 0.962	Average 0.62 0.14 0.07 0.66 2.68 2.36 2.24 1.65 2.04 2.21 1.65 2.04 1.65 2.04 1.65 2.04 0.979 0.963 0.979 0.954 0.957	dBm dBm dB dB dB dB dB dB dB dB dB dB dB

## Beyond 400 GbE - Leveraging 100 Gb/s



### Examples of Beyond 100 Gb/s Research

- S. Yamaoka et al., "239.3-Gbit/s net rate PAM-4 transmission using directly modulated membrane lasers on high-thermal-conductivity SiC" in Proceedings of European Conference on Optical Communication (ECOC), 2019/9.
- X. Pang et al., 200 Gbps/lane IM/DD Technologies for Short Reach Optical Interconnects, <u>https://core.ac.uk/download/pdf/289286726.pdf</u>, 2019/04/24.
- W. Heni et al., Ultra-High-Speed 2:1 Digital Selector and Plasmonic Modulator IM/DD Transmitter Operating at 222 GBaud for Intra-Datacenter Applications, <u>https://www.osapublishing.org/jlt/abstract.cfm?URI=jlt-38-9-2734</u>, 2020/9.
- S Lange et al., 100 GBd Intensity Modulation and Direct Detection with an InP-based Monolithic DFB Laser Mach-Zehnder Modulator, Journal of Lightwave Technology, <u>https://www.researchgate.net/publication/319259046\_100\_GBd\_Intensity\_Modulation\_and\_Direct\_D</u> <u>etection\_with\_an\_InP-based\_Monolithic\_DFB\_Laser\_Mach-Zehnder\_Modulator, 2017/8.</u>
- E. Sentieri et al., "12.2 A 4-Channel 200Gb/s PAM-4 BiCMOS Transceiver with Silicon Photonics Front-Ends for Gigabit Ethernet Applications," 2020 IEEE International Solid- State Circuits Conference -(ISSCC), San Francisco, CA, USA, 2020, pp. 210-212, doi: 10.1109/ISSCC19947.2020.9062992.
- T. Wettlin et al., "Beyond 200 Gb/s PAM4 transmission using Tomlinson-Harashima precoding," 45th European Conference on Optical Communication (ECOC 2019), Dublin, Ireland, 2019, pp. 1-4, doi: 10.1049/cp.2019.0834.

### 200 Gb/s Signaling – The Next Generation?

#### **OIF CEI 224G**

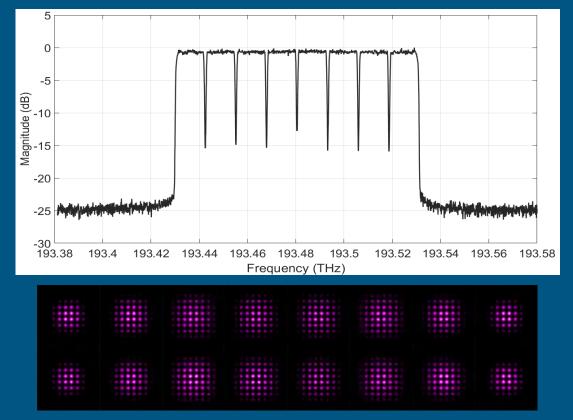
 Use of 200 Gb/s enables a new generation of 200 GbE / 400 GbE solutions related to the breakout of the physical media for "Beyond 400 GbE" physical layer specifications

## 800 Gb/s Single Wavelength Transmission

#### The Future of Coherent is emerging ....

- Successful trial of 800 Gb/s single-wave transmission over
   950 km - <u>https://bit.ly/2Wdkh8e</u>
- Platform supporting 200 Gb/s to 800 Gb/s single-carrier -<u>https://bit.ly/2KLpW05</u>
- "Industry's first 800G tunable ultra-high-speed optical module" <u>https://bit.ly/2yTYNFK</u>
- "Verizon says it has successfully transmitted an 800-Gb/s wavelength on its live network" -<u>https://bit.ly/3d2GX1M</u>

800 Gb/s single wavelength transmission over 730km in real world long-haul network



#### 8 subcarrier constellation

https://www.lightreading.com/optical-ip/infinera-windstreamtout-optical-networking-milestone/d/d-id/761738

Source – Ted Sprague, Infinera

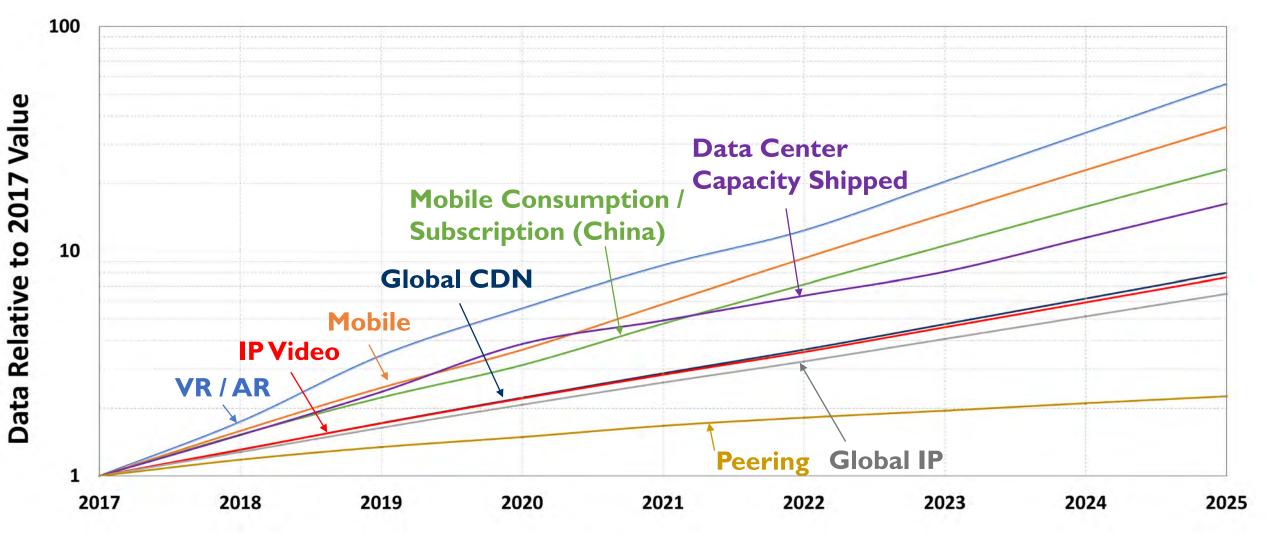
#### **SUMMARY**

- A path to Beyond 400 GbE exists
- Leverage 100 Gb/s building blocks
- 800 GbE building blocks and example available now
- Plausible implementations for today and next generation
- 800 Gb/s over a single wavelength for DWDM systems is emerging now

# BEYOND 400 GbE WHY NOW?

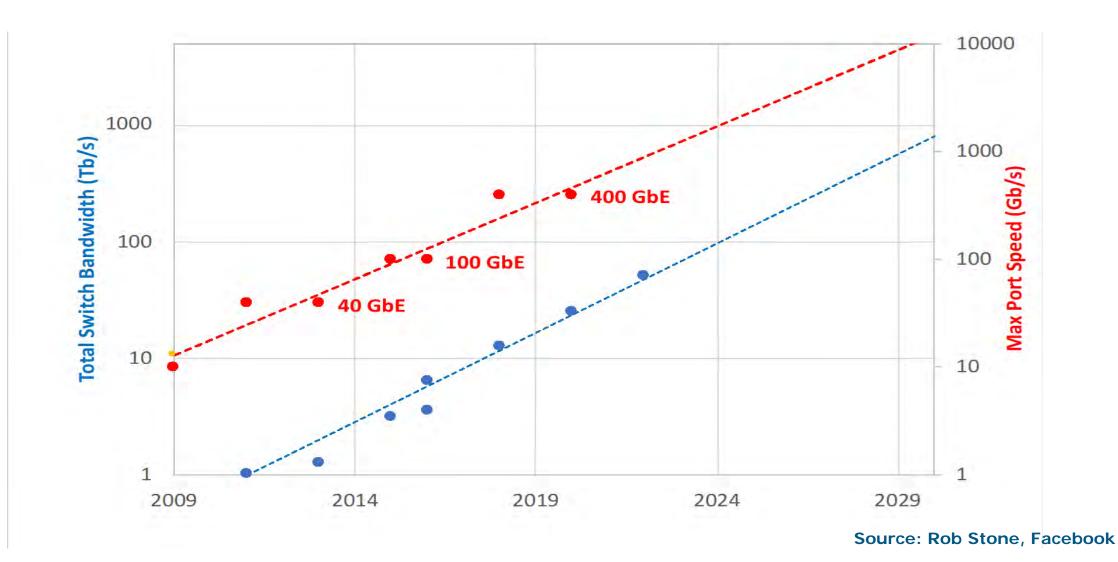


#### The 2020 Ethernet Bandwidth Assessment



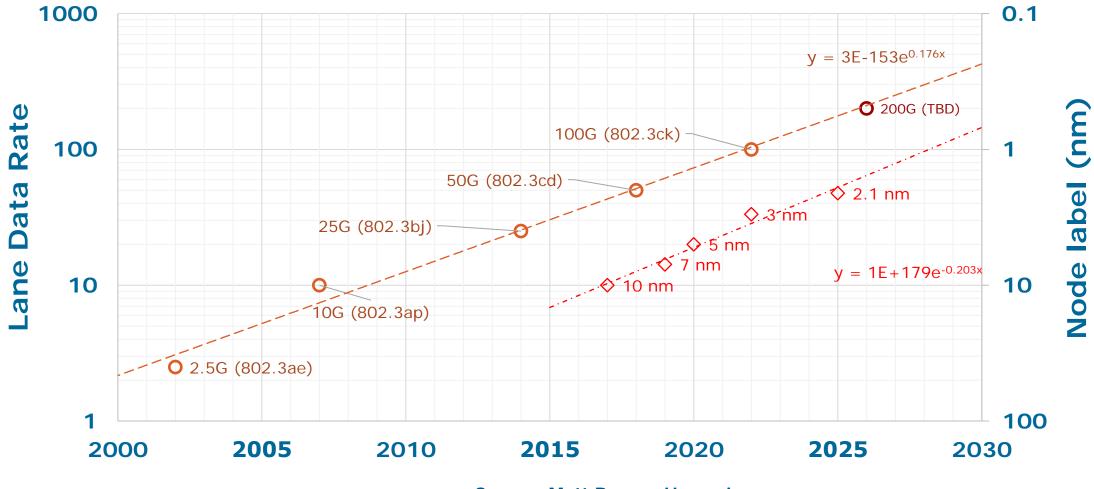
Source: https://bit.ly/802d3bwa2

#### **TRENDLINE – SWITCH CAPACITY**



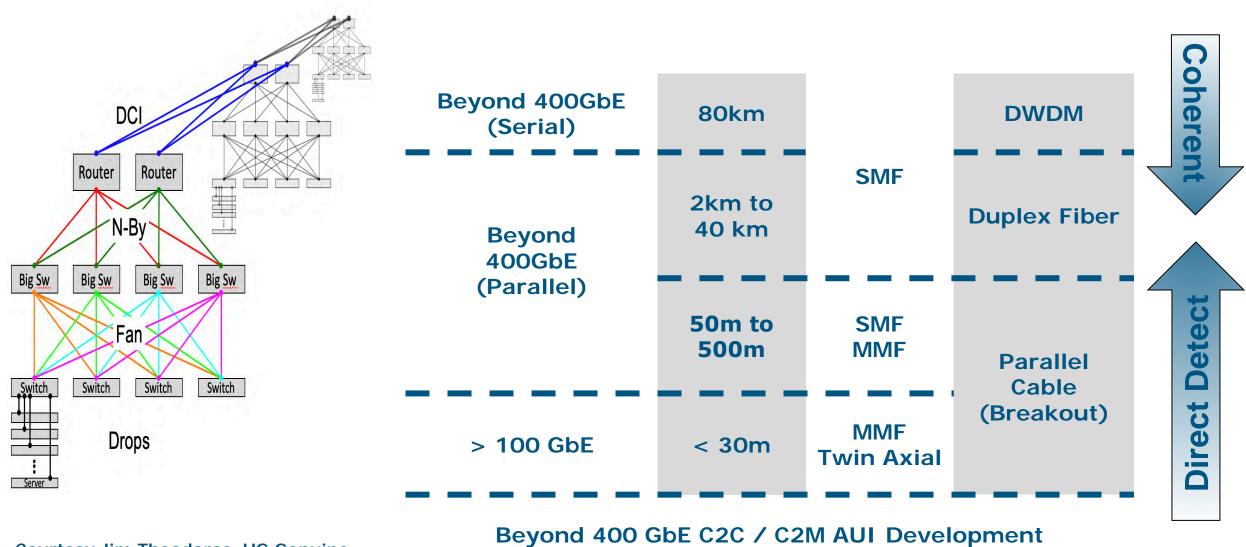
#### **TRENDLINE – SERDES DEVELOPMENT**

**Comparison of Lane Data Rate and Node Label Timelines** 



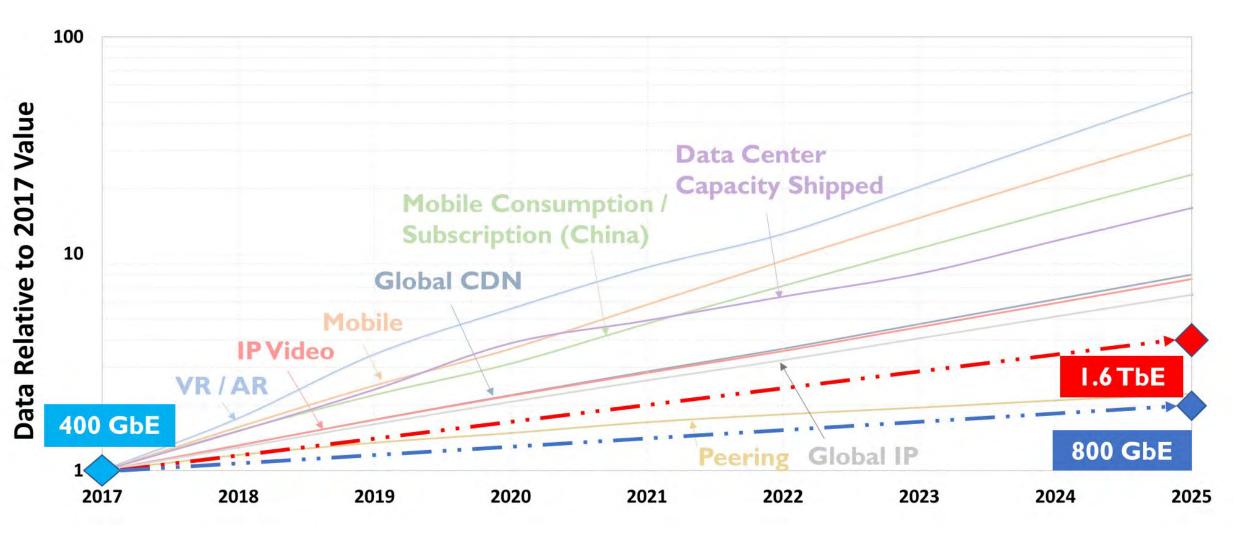
Source: Matt Brown, Huawei

#### What is needed?



Courtesy Jim Theodoras, HG Genuine

#### **CONSIDERING THE NEXT ETHERNET RATE STANDARD**



Source: https://bit.ly/802d3bwa2

#### **SUMMARY**

- Bandwidth
  - Underlying factors all indicate continued growth
  - Exponential growth continues!
- New bandwidth generating applications constantly being introduced
  - Mobile (5G) / Video
  - Artificial Intelligence
  - Virtual / Augmented Reality
- Today's world stressing the need for connectivity and bandwidth
- Last two "Higher Speed" efforts (from CFI to standard ratification)
  - 40 / 100 GbE 3 years, 11 months
  - 200 / 400 GbE 4 years, 9 months
- There is some time between standard ratification and product introduction
  - The bandwidth problem will only continue to grow
- We need to begin the process to study the problem! Big questions to consider
  - Next speed or speeds?
  - What physical layer specifications?

## Supporters (as of 8/24/20)

Vipul	Bhatt	II-VI Incorporated
Leon	Bruckman	Huawei
John	<b>D'Ambrosia</b>	Futurewei, U.S. Subsidiary of Huawei
Bob	Grow	RMG Consulting
Mark	Gustlin	Cisco
Cedric	Lam	Google
Earl	Parsons	CommScope
Rob	Stone	Facebook
Tomoo	Takahara	Fujitsu
Jim	Theodoras	HG Geuine USA
Yangling	Wen	Futurewei
Xiang	Zhou	Google

## **STRAW POLLS**



#### **Call-for-interest**

# Should a Study Group be formed for ..... - TBD (Study Group Scope in definition at this time)

- YES
- No
- Abstain

#### Room Count

#### participation

I would participate in the "TBD" Study Group in IEEE 802.3

Tally:

I believe my company would support participation in the "TBD" Study Group in IEEE 802.3 Tally:

#### **Future work**

- Ask 802.3 WG for approval
- If approved, request formation of "TBD" Study Group by 802 EC
- If approved,
  - Creation of Study Group page
  - First "TBD" Study Group anticipated for Jan 21 Interim

# THANK YOU!

