

Storage Networking Roadmaps

Scott Kipp

Director of Engineering

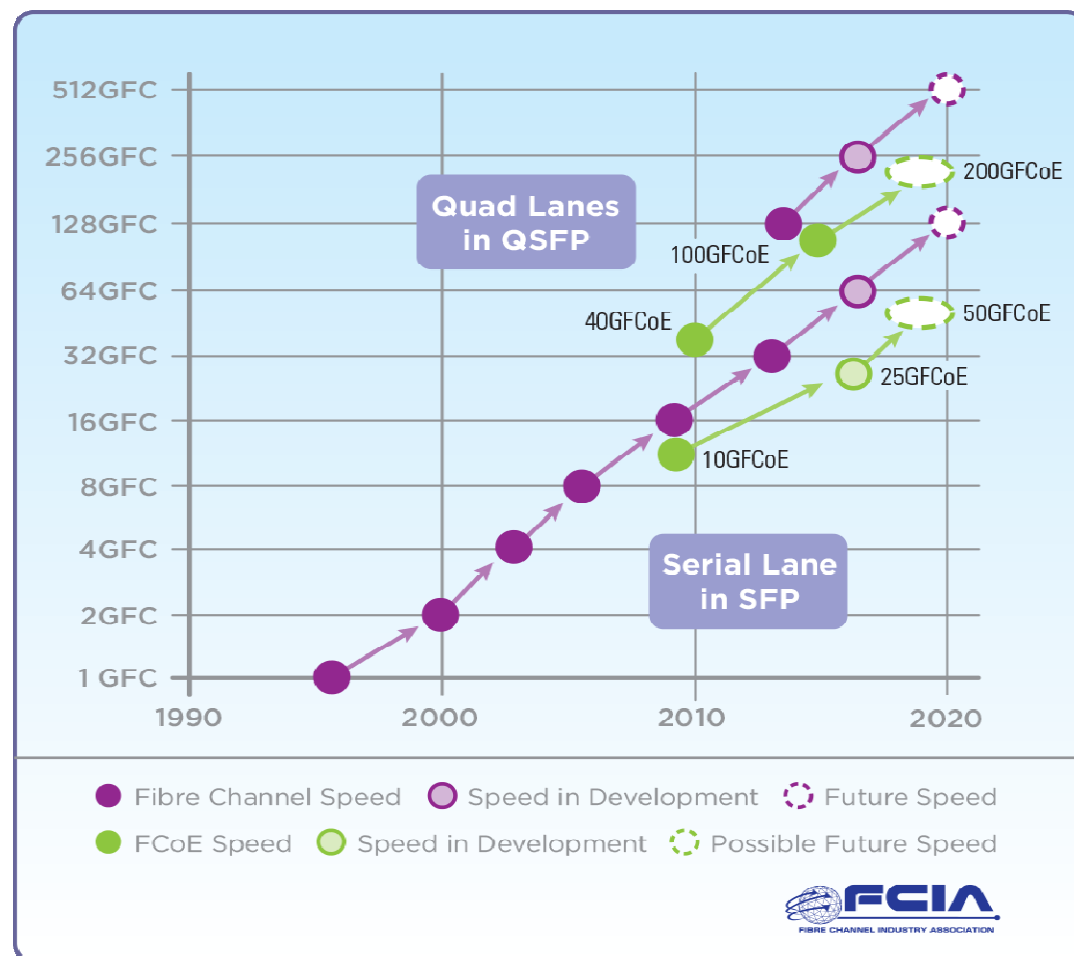
Chair of Fibre Channel and Ethernet
Roadmap Subcommittees

Disclaimer

- Opinions expressed during this presentation are the views of the presenters, and should not be considered the views or positions of the Ethernet Alliance.

Roadmaps

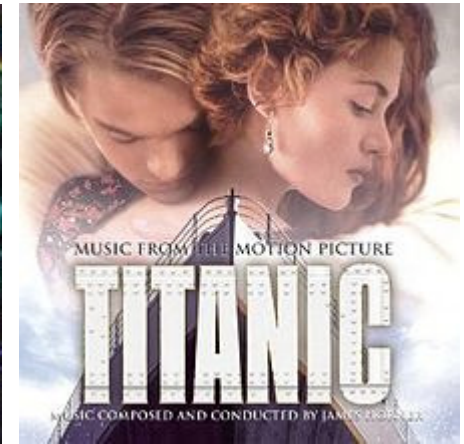
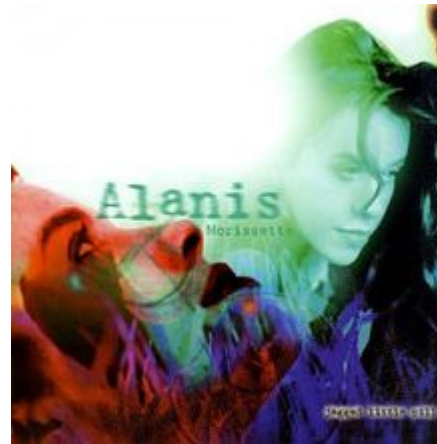
- Industry has adopted doubling down on speeds
- Innovation coming from more directions
- It's getting harder to double down each time
- www.fibrechannel.org/roadmap/
- www.ethernetalliance.org/roadmap/



Back to the 90s

- Gigabit Fibre Channel was named after the line rate with 8B/10B encoding of 100MB/s
 - $100\text{MB/s} = 800\text{Mb/s}$
 - $800\text{Mb/s} / 8 * 10 = 1\text{Gb/s}$
- Gigabit Ethernet leveraged 1GFC standards

What was the Top Selling Albums/Artist of the Year according to Billboard Magazine?



1GFC



1996

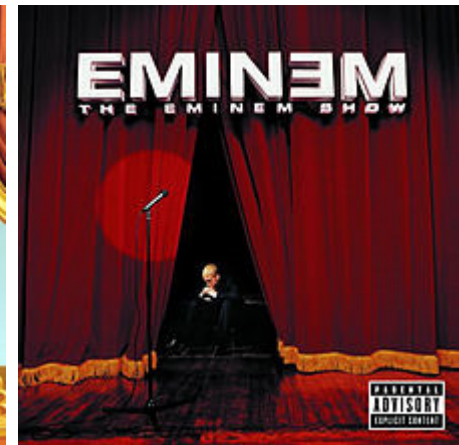
1GbE



1998

The New Millenium

- Fibre Channel doubles its speed
- Optical Speed Negotiation seems an insurmountable obstacle
- Lots of hype about 10G changing the world



2GFC



2000

10GbE



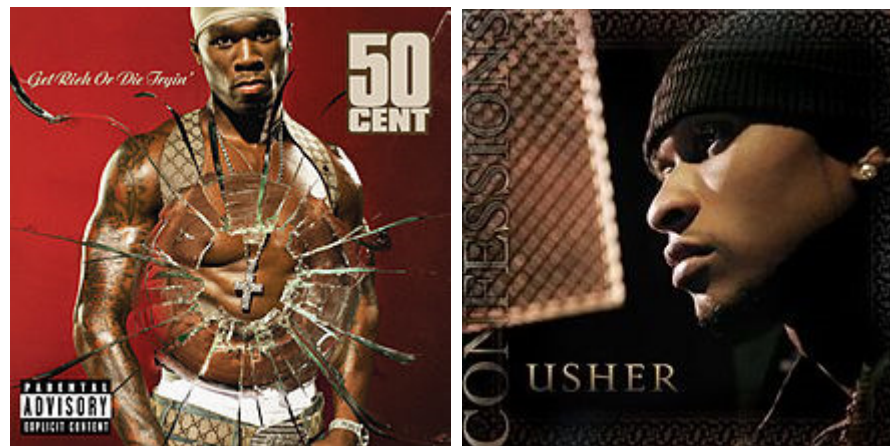
2002

The Early Naughts

- 10GFC standardized
- Fibre Channel doubles again to 4GFC
- 10GbE has 300 pin MSA, XENPAK and X2 modules



58,000 10GbE Ports Ship
2.5M 2GFC Ports Ship
-Dell'Oro - 2004



10GFC



2003

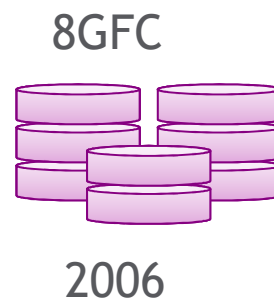
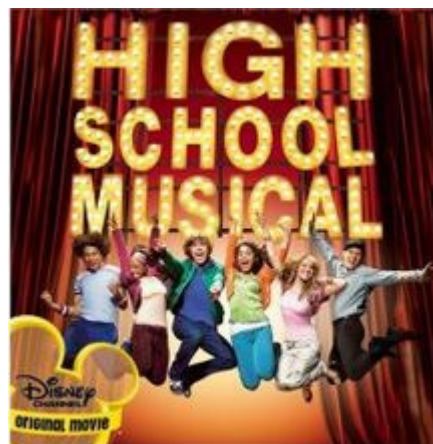
4GFC



2004

The Mid Naughts

- Fibre Channel doubles again to 8GFC
- 10GbE XFP standardized
- 10GFC released with little sales



2006
294,000 10GbE Ports Ship
5M 4GFC Ports Ship
-Dell'Oro

The Late Naughts

- Fibre Channel doubles again to 16GFC
- 10GbE SFP+ standardized

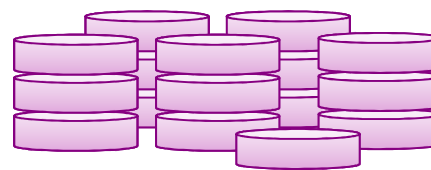
10GbE
SFP+



8GFC SFP+



16GFC



2009

2009
2.75M 10GbE
Ports Ship
2.3M 4GFC +
3.5M 8GFC Ports
Ship
-Dell'Oro

The Tens

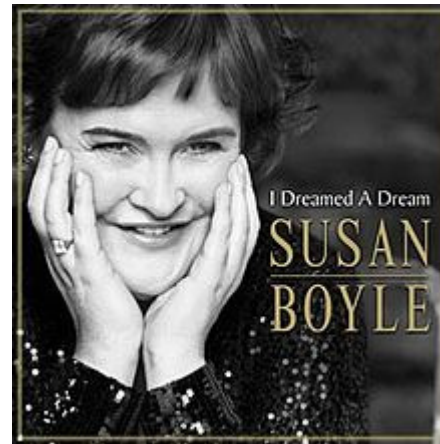
- Ethernet jumps to 40 and 100GbE
- Fibre Channel doubles again to 32GFC
- 40GbE QSFP+ standardized



40GbE
QSFP+

See next
page

100GbE Modules



40 and 100GbE



2010



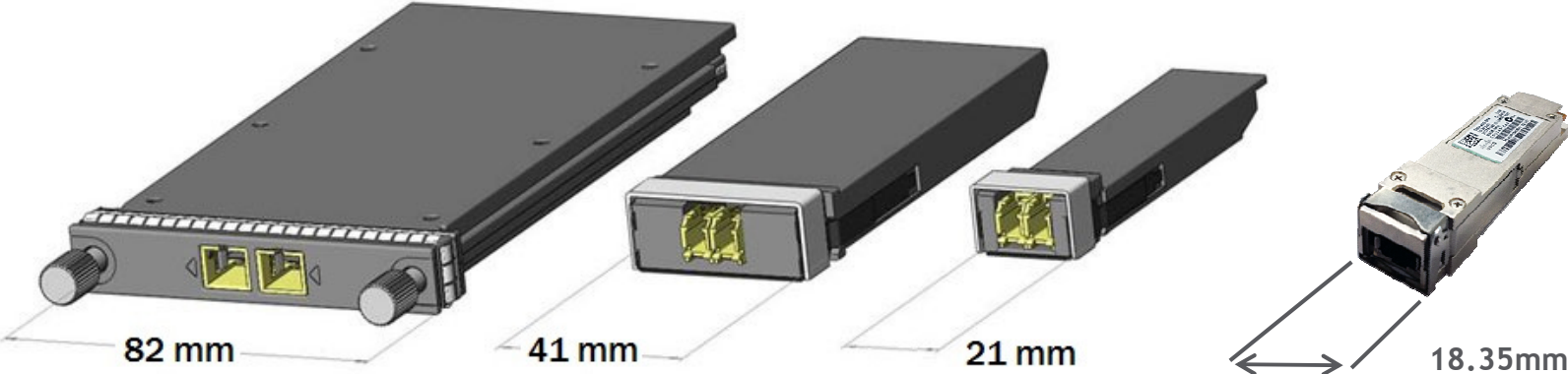
32GFC



2013

100GbE Form Factors

Router Market Requires Higher Speeds Quickly



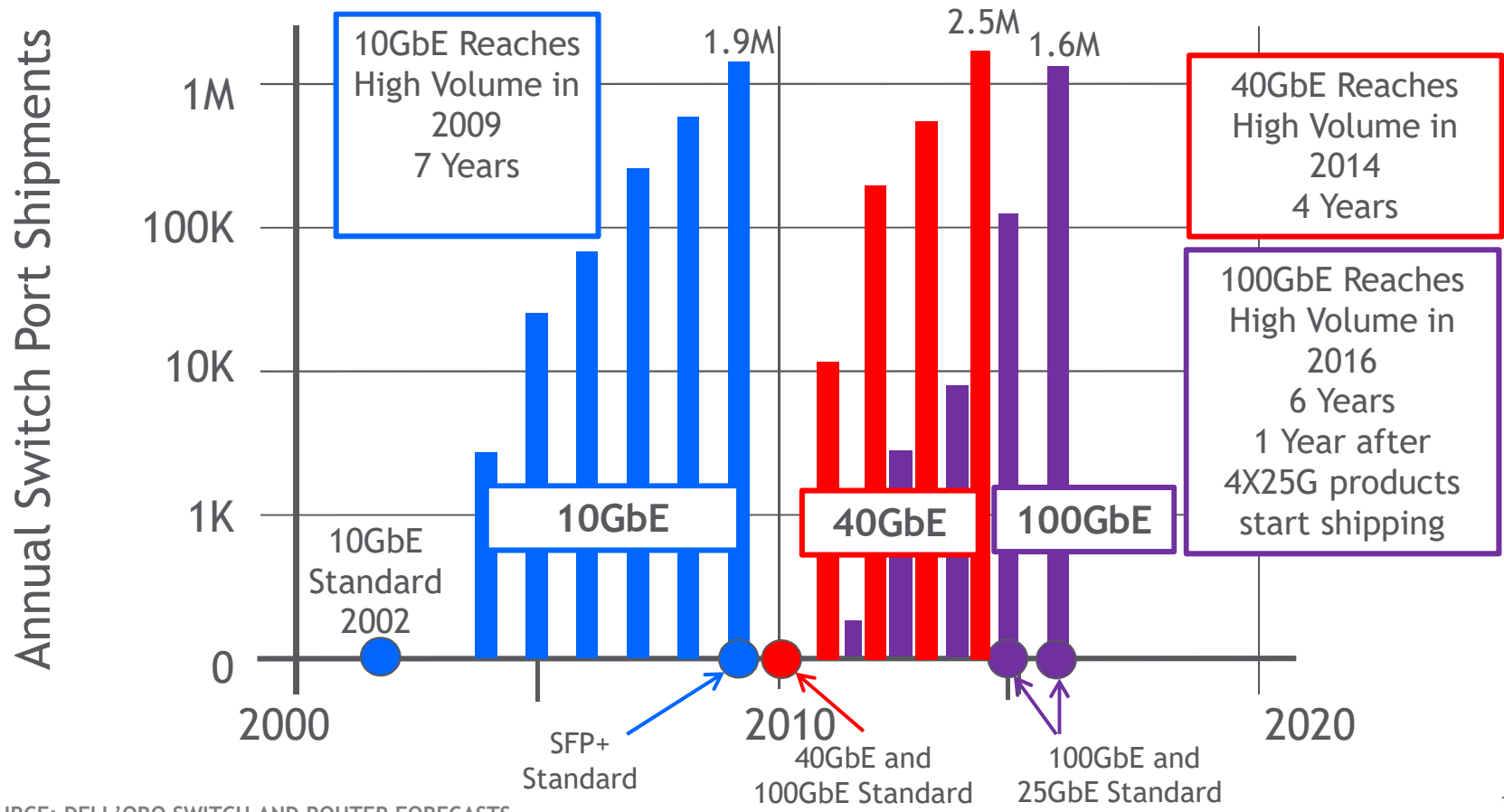
CFP

CFP2

CFP4

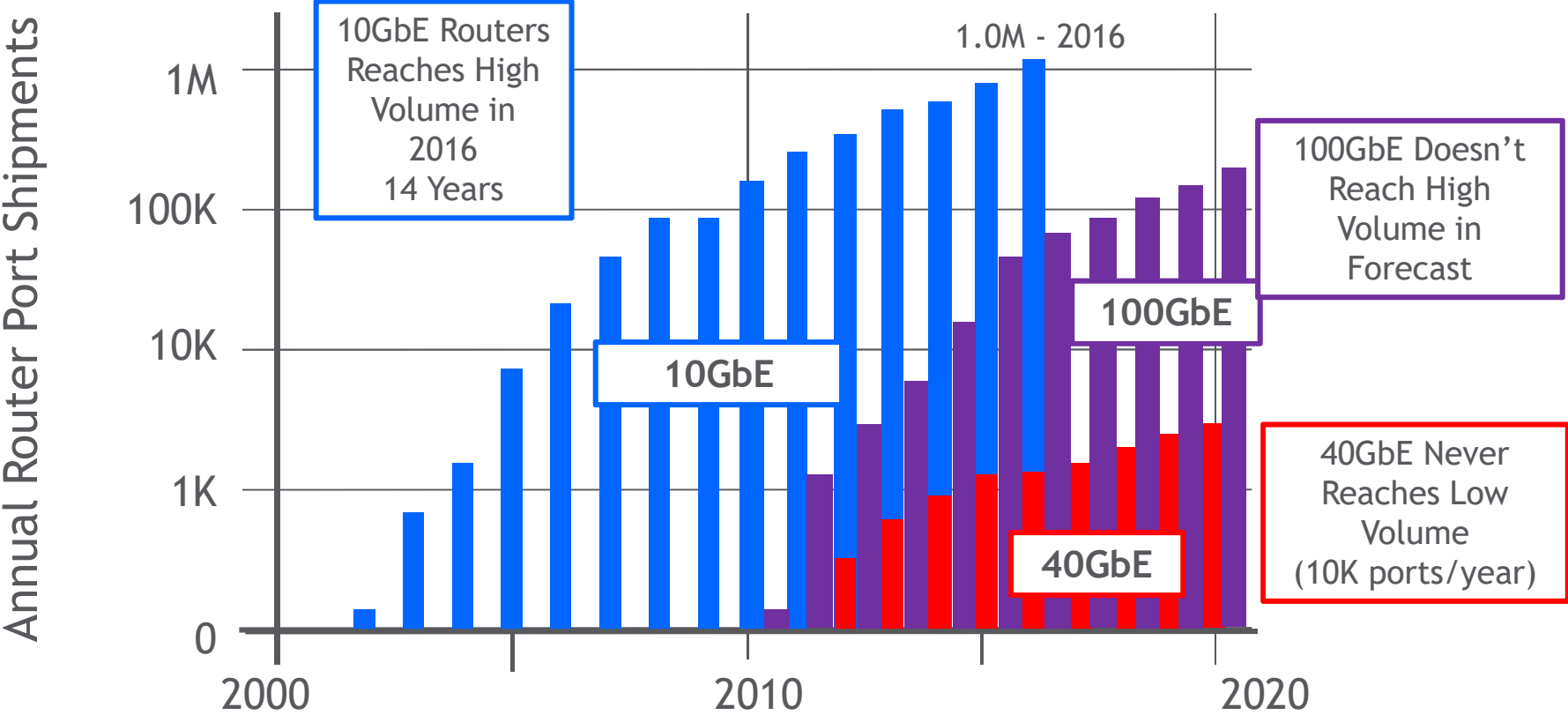
QSFP28

10G to 100G Transitions



SOURCE: DELL'ORO SWITCH AND ROUTER FORECASTS

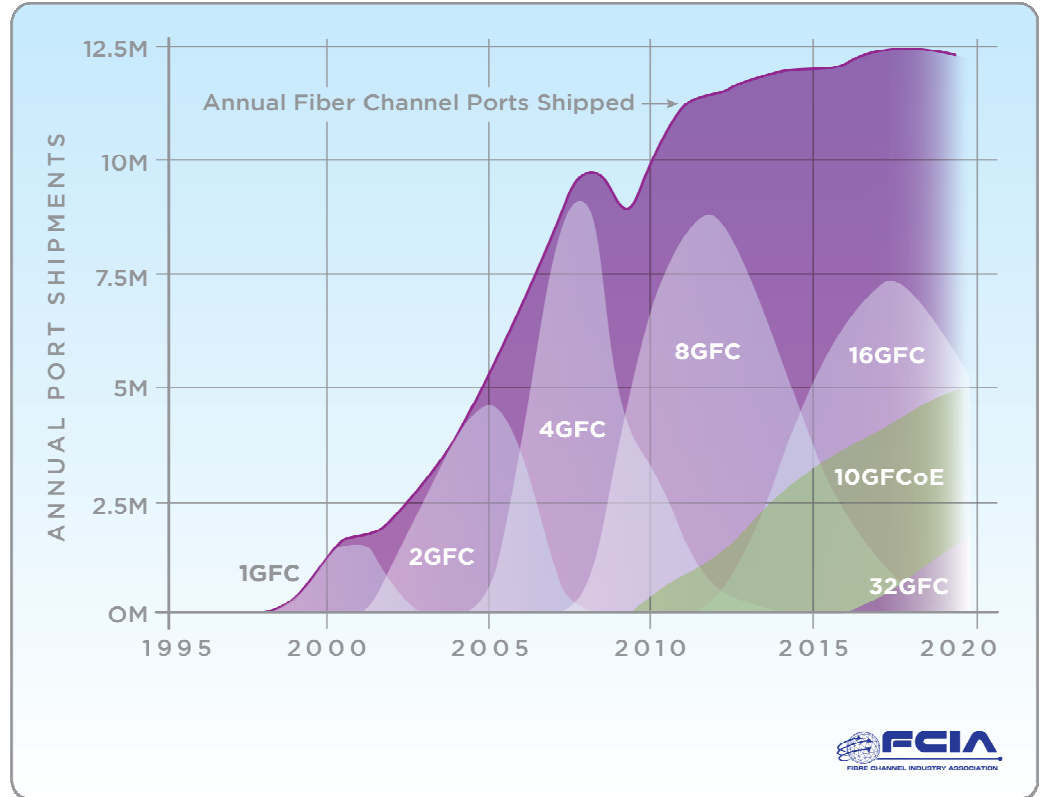
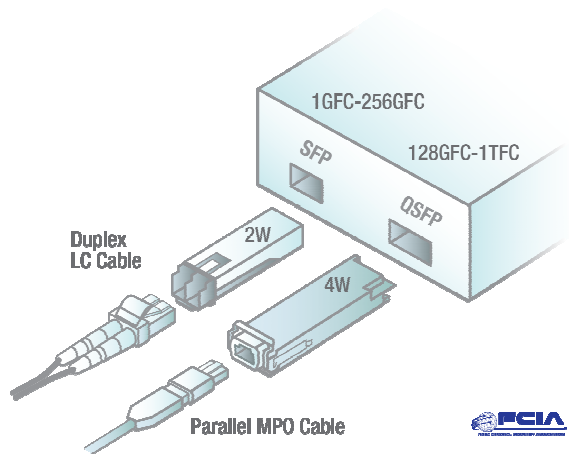
Router Port Shipments



SOURCE: DELL'ORO ROUTER FORECASTS

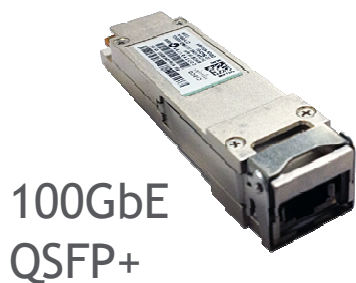
Fibre Channel Ports

- This is Fibre Channel switches and HBAs as well as FCoE
- Fibre Channel stayed focused on 2 modules



The Teens

- Fibre Channel quadruples to 128GFC
- 100GbE QSFP+ standardized



See next page

100GbE Modules

128GFC



2014

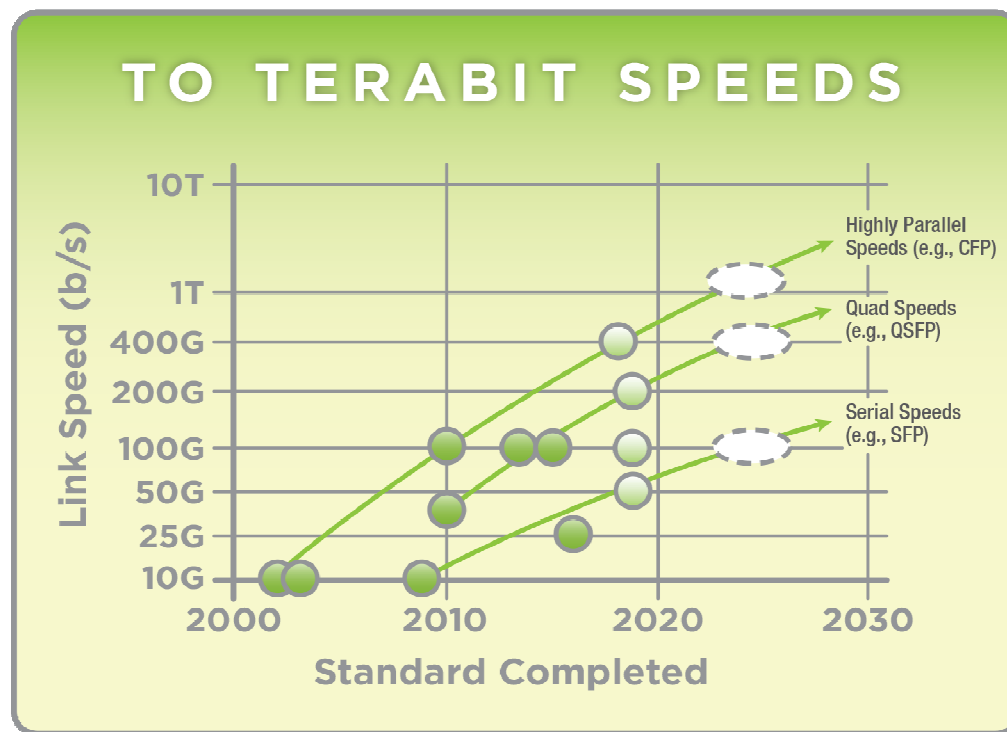
25GbE



2016

To Terabit Speeds

- Serial speeds in SFP are great for servers and switches
- Quad speeds in QSFP are good for networking
- Highly parallel speeds are needed for routers



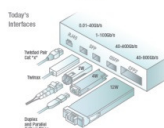
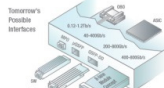
● Ethernet Speed ● Speed in Development ○ Possible Future Speed

The 2016 Ethernet Roadmap - Front

MEDIA AND MODULES

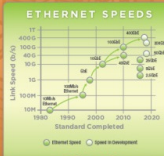
Ethernet is wired technology and supports a variety of media including backplanes, twisted pair, coax, multimode fiber and single-mode fiber. Most people know Ethernet by the twisted pair or Cat™ cabling with RJ45 connectors because close to a billion ports a year are sold.

The graphic below shows multiple types of modules that may be used for copper or optical links. The upper modules are being developed to support ultra-high density port counts. The µQSFP shrinks the QSFP down to an SFP size while the QSFP-DD doubles the lane count to 8. On Board Optics (OBO) enable the highest port counts on switches.



2016 ETHERNET ROADMAP

THE PAST, PRESENT AND FUTURE OF ETHERNET



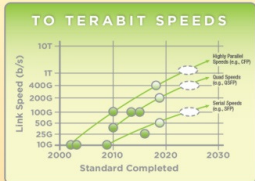
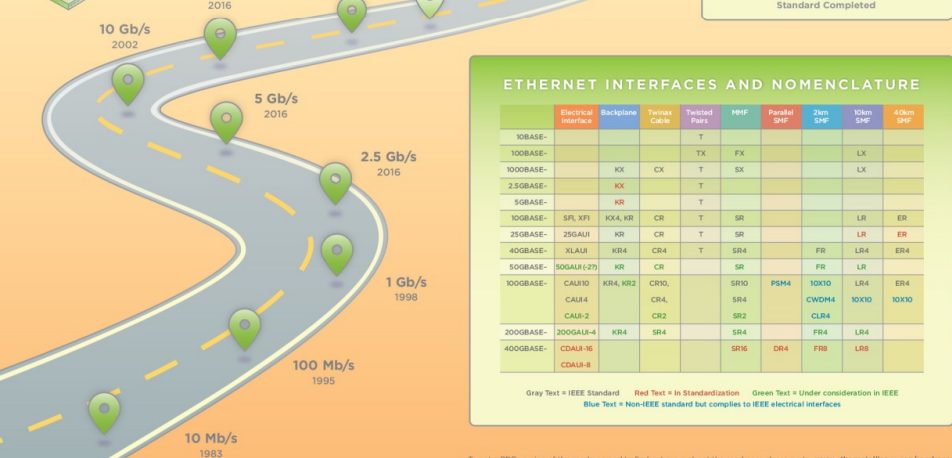
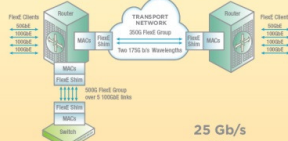
ETHERNET ALLIANCE
www.ethernetalliance.org

Designed by Scott Kipp
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\$5.00

2016 ETHERNET ROADMAP

FLEX ETHERNET (FLEXE)

Defined by the Optical Interconnecting Forum (OIF), FlexE is often called a new generation of Link Aggregation (LAG) and may provide a path to speeds higher than 400G without an IEEE standard. Proponents of FlexE claim that higher speeds like 800G/E are not necessary since these speeds just aggregate many lanes that run at lower speeds. FlexE can aggregate individual Ethernet links and creates a FlexE Mac that connects to another FlexE MAC. The illustration below shows a 500G FlexE group that bonds five 100G/E links together.



ETHERNET INTERFACES AND NOMENCLATURE

Electrical Interface	Backplane	Twisted Cable	Twisted Pair	MMF	Parallel SFP	25m SFP	10m SFP	40m SFP
10BASE-T			T					
100BASE-TX			TX	FX				LX
1000BASE-T		KX	CX	T	SX			LX
25GBASE-SR		KX		T				
50GBASE-SR		KR		T				
100BASE-SR	SFI, XFI	KX4, KR	CR	T	SR			LR, ER
25GBASE-SR	25GAUI	KR	CR	T	SR			LR, ER
40GBASE-SR	XLAI	KR4	CR4	T	SR4	FR	LR4	ER4
50GBASE-SR	50GAUI(2T)	KR	CR	SR	SR	FR	LR	
100GBASE-CAL10		KR4, KR2	CR10		SR10	PSM4	10X10	LR4, ER4
100GBASE-CAL4			CR4		SR4		CWDM4	10X10, 10X10
100GBASE-CAL2			CR2		SR2		CLR4	
200GBASE-200GAUI-4		KR4	SR4		SR4		FR4	LR4
400GBASE-400GAUI-8					SR16	DR4	FR8	LR8

Gray Text = IEEE Standard Red Text = In Standardization Green Text = Under consideration in IEEE Blue Text = Non-IEEE standard but complies to IEEE electrical interfaces

To get a PDF version of the roadmap and to find out more about the roadmap, please go to: www.ethernetalliance.org/roadmap/

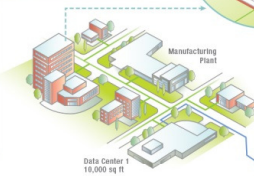
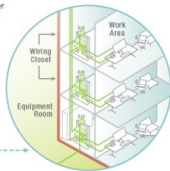
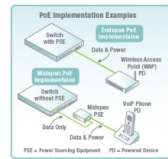
The 2016 Ethernet Roadmap - Back

ETHERNET ECOSYSTEM

ENTERPRISE AND CAMPUS

Power over Ethernet is a growing Ethernet application that delivers power and data over Category cabling that has 4 twisted pairs of wires, with Cat 5 or better cabling recommended. 4-Pair PoE is being standardized to deliver over 70W of power over all 4 twisted pairs instead of the two pairs in PoE and PoE+.

PoE Types and Classes	PoE+ - Type 2				4-Pair PoE in Standardization				
	Class 0	1	2	3	4	5	6	7	8
PSE Power (W)	15.4	4	7	15.4	30	45	60	75	90
PD Power (W)	13	3.84	6.49	13	25.5	40	51	62	71



RESIDENTIAL AND CONSUMER

Most homes have wireless access points (WAPs) with 4 or more Ethernet ports. Smart TVs, network attached storage (NAS) and other household products come with Ethernet ports that can be used to create the smart home.

Automotive Ethernet
Ethernet is being deployed to automobiles and will become the de facto standard for automobile networks by 2020. Because of requirements for lightweight autos, Ethernet was developed to deliver data and power over a single pair of wires to distances of 15 meters at 100Mbps and 10G/s.

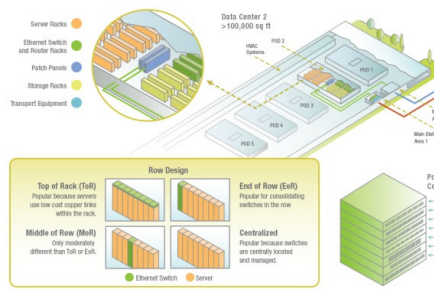
Power Over Data Lines (PoDL)
PoDL delivers data and power to cameras, lights, entertainment systems, controls and other devices throughout the car.

Wireless Connectivity
Connected cars are expected to drive increased traffic to wireless networks that result in more wireless bandwidth traffic over Ethernet.



BACKBONE TO OTHER CITIES

BACKBONE TO OTHER CITIES

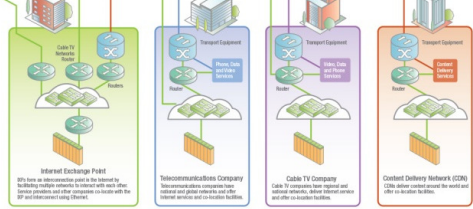


Hyperscale data centers drive amazing Ethernet volumes when hundreds of thousands of servers are connected on one site.

HYPERSCALE DATA CENTER

MANs

Metropolitan Area Networks (MANs) come in many varieties and deliver services to a variety of enterprises, organizations and consumers. Some MANs are based on Ethernet, but the largest MANs are based on Optical Transport Networks (OTN) technologies.



Service Providers deploy MANs and WANs to connect businesses and consumers. Some carriers deploy hyperscale data centers as well.

SERVICE PROVIDERS

The New Nomenclature Chart

ETHERNET INTERFACES AND NOMENCLATURE									
	Electrical Interface	Backplane	Twinax Cable	Twisted Pairs	MMF	Parallel SMF	2km SMF	10km SMF	40km SMF
10BASE-				T					
100BASE-				TX	FX			LX	
1000BASE-		KX	CX	T	SX			LX	
2.5GBASE-		KX		T					
5GBASE-		KR		T					
10GBASE-	SFI, XFI	KX4, KR	CR	T	SR			LR	ER
25GBASE-	25GAUI	KR	CR	T	SR			LR	ER
40GBASE-	XLAUI	KR4	CR4	T	SR4		FR	LR4	ER4
50GBASE-	50GAUI (-2?)	KR	CR		SR		FR	LR	
100GBASE-	CAUI10	KR4, KR2	CR10,		SR10	PSM4	10X10	LR4	ER4
	CAUI4		CR4,	SR4	CWDM4		10X10	10X10	
	CAUI-2		CR2	SR2	CLR4				
200GBASE-	200GAUI-4	KR4	SR4		SR4		FR4	LR4	
400GBASE-	CDAUI-16				SR16	DR4	FR8	LR8	
	CDAUI-8								

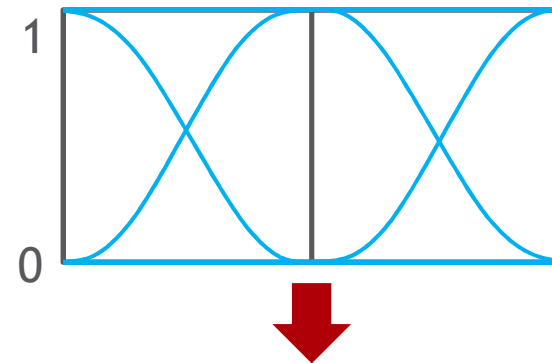
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 Blue Text = Non-IEEE standard but complies to IEEE electrical interfaces



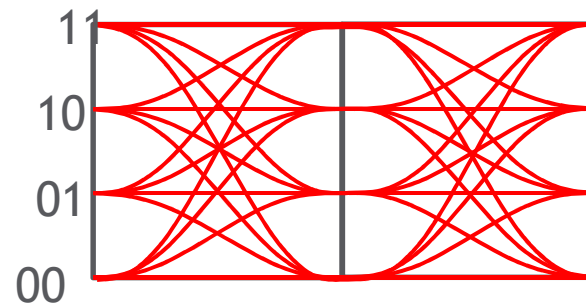
50-56G Developments

- Ethernet and Fibre Channel are basically doubling the data rate by converting from PAM-2 (1-bit NRZ with 0 or 1) to PAM-4 (2-bit - 00, 01, 10 or 11)
- OFC had many 50G PAM-4 demonstrations
- Many open technical issues as shown on next slide

25G PAM-2 Signals

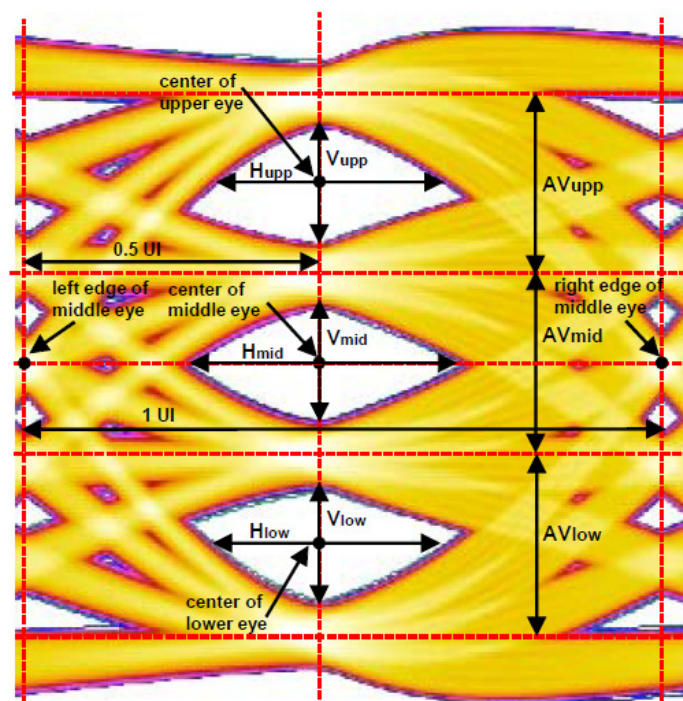


50G PAM-4 Signals



50-56G Signaling Challenges

- Which FEC to use
 - KR4 RS-FEC for compatibility with 25GbE and 32GFC
 - KP4FEC for more coding gain and compatibility with CDAUI-8
 - FEC latency
- Speed Negotiation with PAM-4
- Allocation of budgets to electrical interfaces and optical modules
- Testing methodology of PAM-4
- PAM-4 signaling in FS-5



FEC Implications

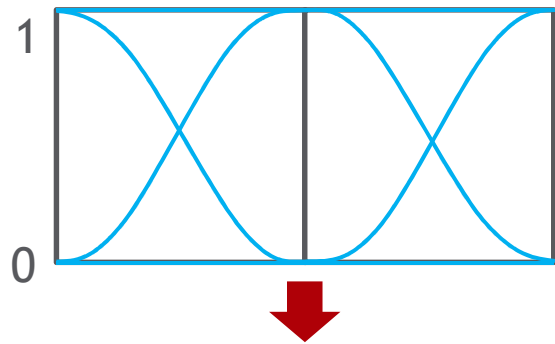
RS(544,514) FEC Makes ASICs Significantly Larger

Speed	KR-FEC	RS(528,514)	RS(544,514)	Serial Link Rate (Gbps)
16GFC	✓			14.025
32GFC		✓		28.05
400GbE (50G lanes)			✓	53.125
64GFC		✓		56.1
64GFC			✓	57.8

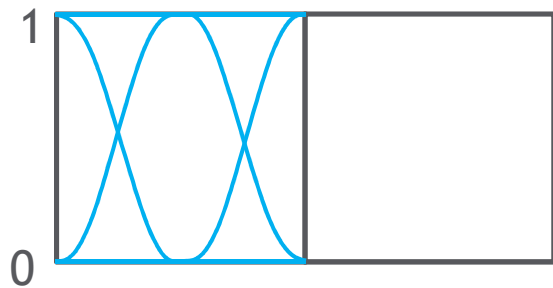


How do we get to 100G Lanes?

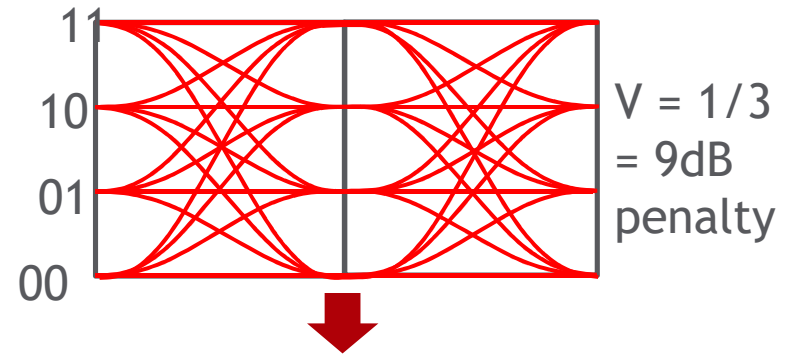
25G PAM-2 Signals



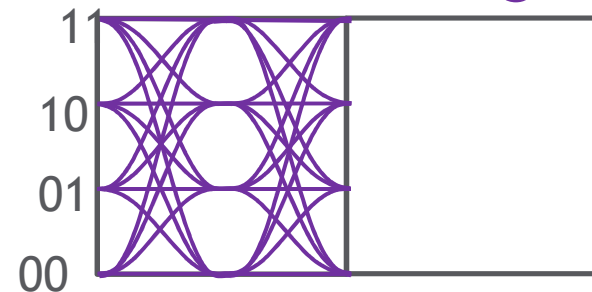
50G PAM-2 Signals



50G PAM-4 Signals



100G PAM-4 Signals



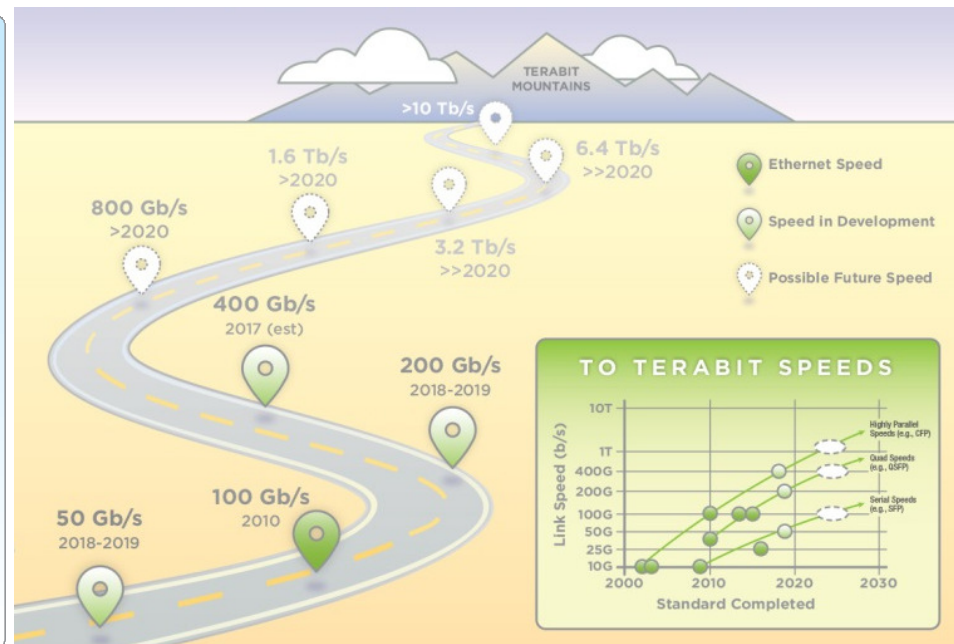
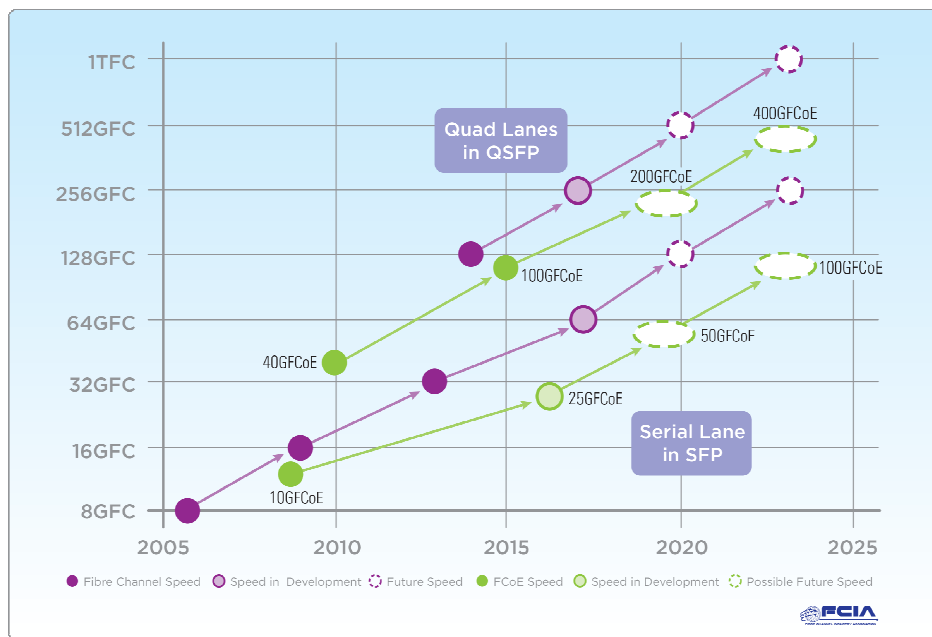
Holy Grail of the 100GbE SFP+

- The first company to publicly demonstrate a 100GbE SFP+ under 1.5W will win the Holy Grail
- Find out more information at:

<http://www.ethernetalliance.org/wp-content/uploads/2013/04/Ethernet-Alliance-100GbE-Challenges-09-16-14.pdf>



TFC and TbE



Abbreviated Fibre Channel Roadmap

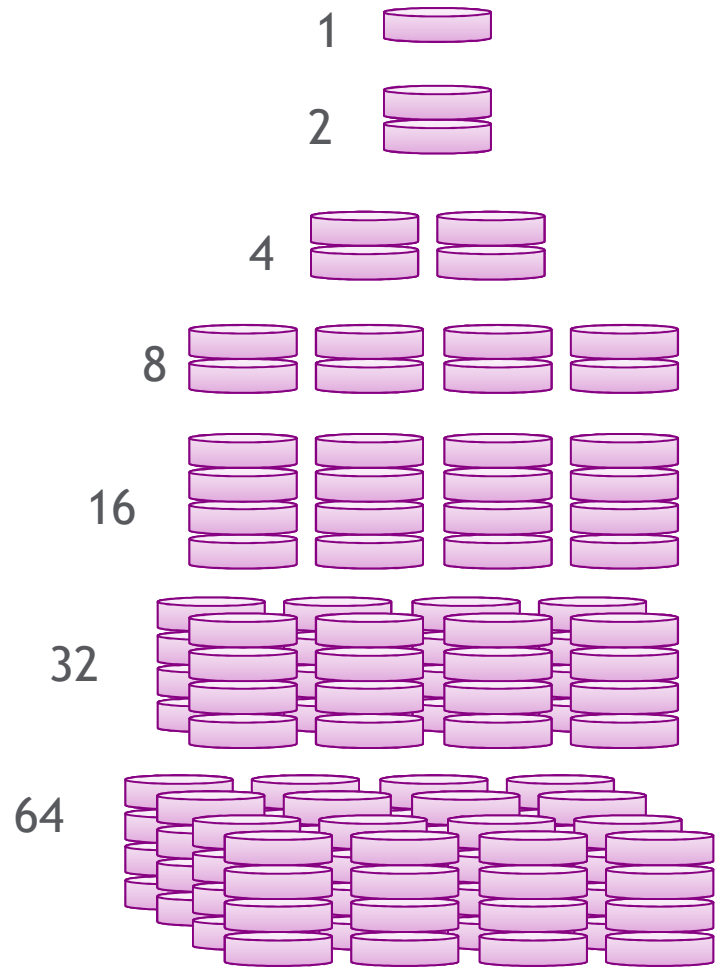
<http://fibrechannel.org/fc-roadmaps/>

Product Naming	Throughput (Mbytes/s)	Line Rate (Gbaud)	T11 Specification Technically Complete (Year)*	Market Availability (Year)*
8GFC	1,600	8.5	2006	2008
16GFC	3,200	14.025	2009	2011
32GFC	6,400	28.05	2013	2016
128GFC	25,600	4X28.05	2014	2016
64GFC	12,800	56.1	2017	2019
256GFC	51,200	4X56.1	2017	2019
128GFC	25,600	TBD	2020	Market Demand
256GFC	51,200	TBD	2023	Market Demand
512GFC	102,400	TBD	2026	Market Demand
1TFC	204,800	TBD	2029	Market Demand



Doubling Down to Infinity

- Can we keep doubling down and continue winning?
- Will we reach a physical barrier where parallel is better than serial?
 - Processors have...
- Don't bet against innovation!



Thank you!