2024 ETHERNET ROADMAP

The Past, Present and Future of Ethernet

ethernet alliance

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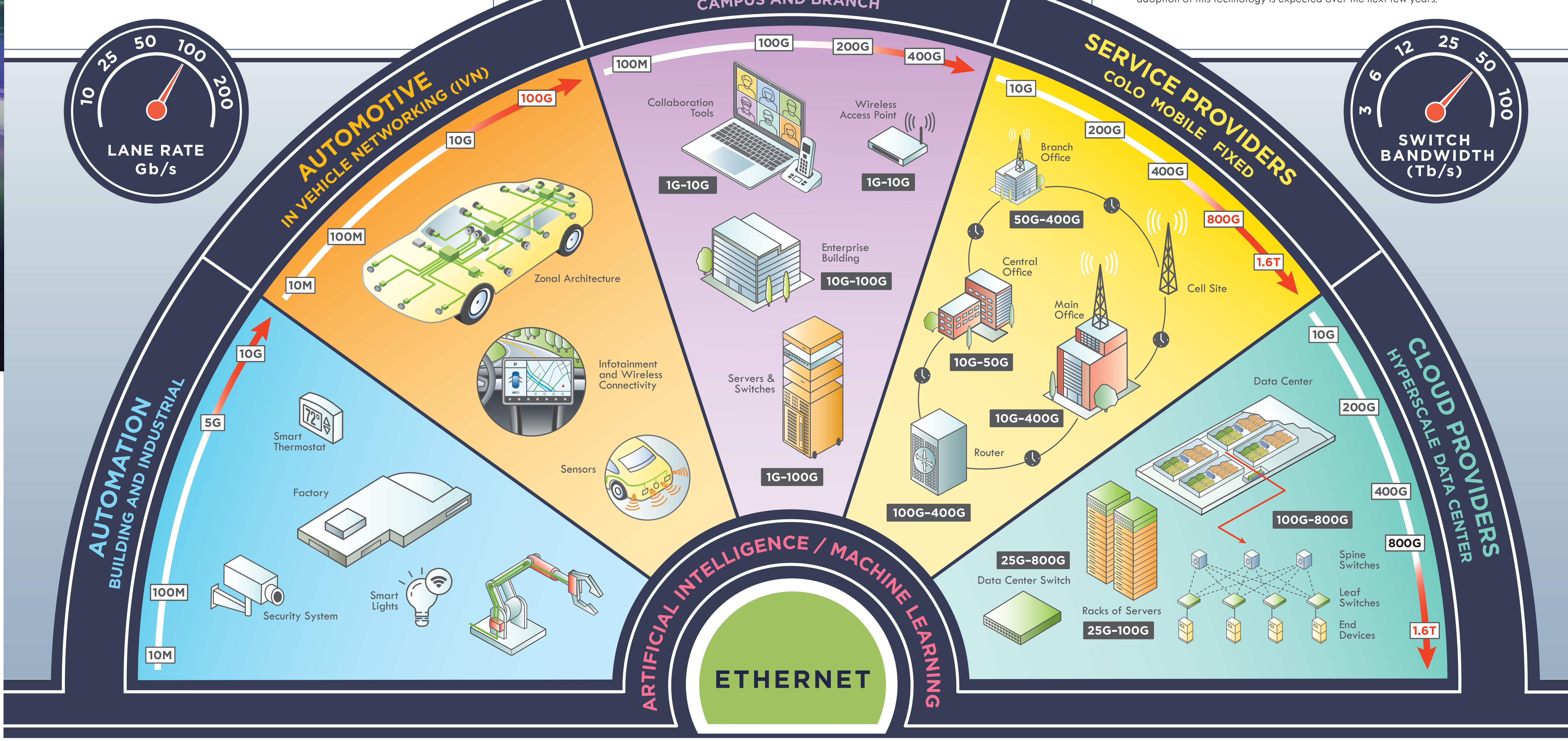
ETHERNET APPLICATIONS

AUTOMOTIVE is one of Ethernet's latest success stories. Ethernet links within cars provide data using Single-Pair Ethernet (SPE) to reduce the cost while providing economies of scale and interoperability. Richer multimedia experience, autonomous driver assistance systems (ADAS), roll-out of autonomous vehicles and convergence of legacy in-vehicle networking (IVN) technologies towards Ethernet are the big drivers for Ethernet adoption in cars. Meanwhile, Ethernet is reducing the weight of the vehicle of tomorrow by enabling the consolidation of multiple electrical systems into a unified zonal architecture similar to other converged networks.

ENTERPRISE and Campus applications are a huge market for Ethernet with over a billion ports shipping per year. Most of these ports are BASE-T at the access layer, with both multi-mode and single-mode fiber links (MMF/SMF) further into the network.

The changing needs of Wi-Fi access points and Enterprise class client devices are driving technology transitions. BASE-T ports are making the transition from 1000BASE-T to 2.5G/5G/10GBASE-T, and optical ports are moving from 10G/40G to 25/100G.

SERVICE PROVIDERS have driven higher speed Ethernet solutions for decades, including router connections, EPON, client side optics for optical transport network (OTN) equipment, and wired and wireless backhaul. In particular, the 5G mobile deployment is driving dramatic increases in both fronthaul and backhaul applications and continues to push Ethernet to higher rates and longer distances. With global demand by consumers for video, this shows no signs of changing. The aggregated bandwidth seen in service provider networks continues to push for increased Ethernet speeds, currently reaching for 1.6 Tb/s. SyncE (Synchronous Ethernet) has become a critical technology used in the Telco rollout of 5G networks and services, a massive adoption of this technology is expected over the next few years.



INTEROPERABILITY AND CERTIFICATION

The Ethernet Alliance is committed to building industry and end user confidence in Ethernet standards through its multi-vendor interoperability demonstrations and plugfests. Our PoE Certification Program takes this mission to the next level!

Our industry-defined PoE Certification Test Plan is based on the IEEE 802.3 (Ethernet) PoE standards, and products passing this test will be granted the Ethernet Alliance PoE Certification Logo. The trademarked logo provides instant recognition for products based on these standards, and increases multi-vendor interoperability between products bearing it. The logos indicate the power class and product type providing clear guidance on which devices will work with each other.

The first generation of the program (Gen 1) certifies Type 1 and Type 2 products that use 2-Pair of wires (PoE 1). The second generation of the program (Gen 2) certifies Type 3 and Type 4 products using 2-Pair and 4-Pair of wires (PoE 2). See table below for details:

PoE Types and Classes	PoE 1 2-Pair PoE – Type 1 / Type 2				PoE 1 2-Pair PoE – Type 2	PoE 2 4-Pair PoE			
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	71.3
		PoE 2 4-Pair PoE – Type 3 (classes 1–6)						PoE 2 4-Pair PoE Type 4 (classes 7–8)	

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https://ethernetalliance.org/poecert/

BUILDING & INDUSTRIAL AUTOMATION applications are moving from older fieldbus style networks to Ethernet. This move has been accelerating over the last decade, with Ethernet as a key enabling technology for the Fourth Industrial Revolution aka Industry 4.0. The main themes of Industry 4.0 are Interconnection, Information Transparency, Technical Assistance and Decentralized Decisions [1]. Adopting Ethernet provides these applications access to all the networking technology that IT has developed over the last 40 years, as well as physical layers developed specifically for harsh OT environments, e.g., 10BASE-T1L. Ethernet, in conjunction with IEEE. Time Sensitive Networking (TSN) is revolutionizing industrial automation. In turn, automation applications are seeing Ethernet development return to its roots such as 10 and 100 Mb/s speeds and shared media using new technology.

[1] M. Hermann, T. Pentek and B. Otto, "Design Principles for Industrie 4.0 Scenarios," 2016 49th Hawaii International Conference on System Sciences (HICSS), 2016, pp. 3928-3937, doi: 10.1109/HICSS.2016.488

ARTIFICIAL INTELLIGENCE (AI) is harnessing the power of higher 200G and 400G Ethernet speeds to support the training and inference of large language models (LLMs). AI and Machine Learning (ML) is driving the roadmap extending Ethernet speeds to 800G and beyond. The architecture within AI-driven data centers is evolving, leveraging a blend of copper and fiber solutions to meet AI's soaring bandwidth demands. Ethernet's progression towards higher speed interfaces, the widening variety of interconnect options, and advancements in power efficiency bodes well for ensuring longer term viability to meet market demands for AI and ML services.

CLOUD PROVIDERS adopted 10G servers on a large scale in 2010 for hyperscale data centers. In the 2020's, the appetites for AI and Machine Learning applications required faster connections and hyperscale moved to 25G/lane speeds and are now transitioning to 50G, 100G and beyond. Unique networking architectures within these warehouse scale data centers have driven a mix of both active and passive copper cables, traditional multi-mode fiber and single-mode optics and fiber solutions, and the new Linear Pluggable Optics for 100G, 200G, 400G and 800G. The bandwidth demands of both hyperscalers and service providers coupled with the need to reduce energy consumption and improve cooling are driving innovative interconnect technologies.

The gap in products and requirements of the Telecom and cloud services providers has rapidly closed over the last decade, and it's even more aligned than ever with the global rollout of 5G services. Historically, the telcos drive technology to keep pace with the end-users and equipment demands. Cloud and hyperscale companies require greater density and high-speed and energy efficient inter-connections in the data center to support the application demands. The result is a more collaborative and cohesive relationship between cloud and service providers to rapidly define and deploy more ubiquitous solutions meeting both their market needs.

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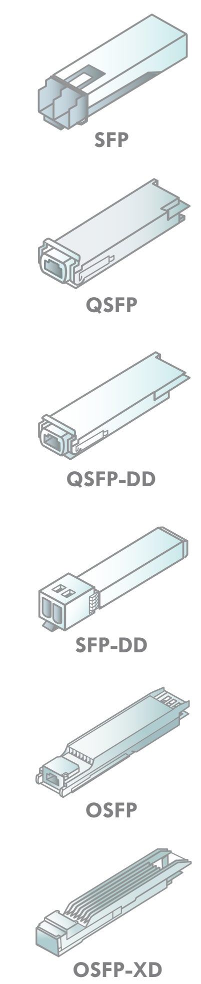
For digital version of the roadmap and for latest Ethernet industry resources, please visit: www.ethernetalliance.org

LATEST INTERFACES AND NOMENCLATURE

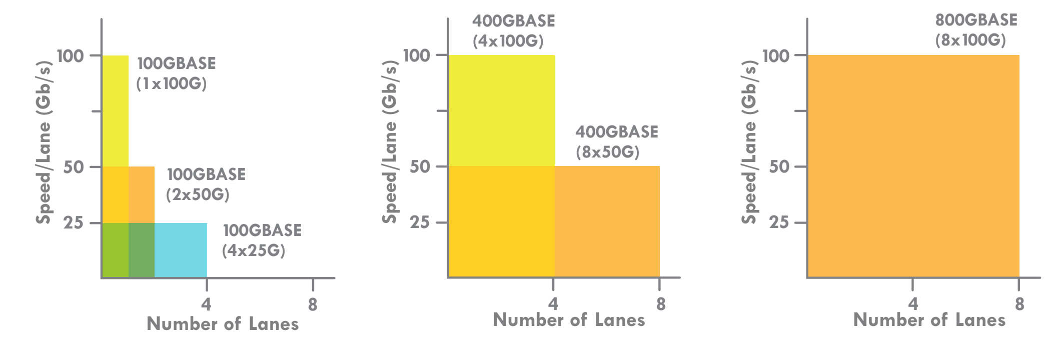
	Backplane	Twinax Cable	15-40m(OT) Single Twisted Pair	>100m (OT) Single Twisted Pair	100m (IT) Twisted Pair (2/4 Pair)	MMF	500m PSM4	2km SMF	10km SMF	20km SMF	40km SMF	80km SMF	Electrical Interface	Pluggable Module
10BASE–	T1S		T1S	T1L	T									
100BASE–			T1	T1L	T									
1000BASE–			T1		T									SFP
2.5GBASE–	KX		T1		T									SFP
5GBASE–	KR		T1		T									SFP
10GBASE–			T1		T	SR			-BR10-D/U LR	-BR20-D/U	-BR40-D/U ER			SFP
25GBASE–	KR1 KR	CR1 CR/CR-S	T1		T (30m)	SR			LR EPON -BR10-D/U	EPON -BR20-D/U	ER -BR40-D/U		25GAUI	SFP
40GBASE–	KR4	CR4			T (30m)	SR4/eSR4	PSM4	FR	LR4		ER4		XLAUI XLPPI	QSFP
50GBASE–	KR2 KR	CR2 CR				SR		FR	EPON LR -BR10-D/U	EPON -BR20-D/U	ER -BR40-D/U		LAUI-2/50GAUI-2 50GAUI-1	SFP/QSFP
100GBASE–	KR4 KR2 KR1	CR10 CR4 CR2 CR1				SR10 SR4 SR2 VR1 SR1	PSM4 DR	CWDM4 FR1	LR4 4WDM-10 LR1	4WDM-20	ER4/ 4WDM-40	ZR	CAUI-10 CPPI CAUI-4/100GAUI-4 100GAUI-2 100GAUI-1	SFP/SFP-DD QSFP/QSFP-DD OSFP
200GBASE–	KR4 KR2	CR4 CR2 CR1				SR4 VR2 SR2	DR4 DR1	FR4 FR1	LR4		ER4		200GAUI-4 200GAUI-2 200GAUI-1	QSFP/QSFP-DD SFP-DD
400GBASE–	KR4	CR4 CR2				SR16 SR8/SR4.2 VR4 SR4	DR4 DR2 DR2-2	FR8 FR4 DR4-2	LR8 LR4-6 400G-LR4-10		ER8	ZR	400GAUI-16 400GAUI-8 400GAUI-4 400GAUI-2	QSFP/QSFP-DD OSFP
800GBASE-	ETC-KR8 KR8	ETC-CR8 CR8 CR4				VR4.2 SR4.2 VR8 SR8	DR8 DR4	DR8-2 DR4-2 FR4	TBD		TBD		800GAUI-8 800GAUI-4	
1.6TBASE-		CR8				VR8.2 SR8.2	DR8	DR8-2					1.6TAUI-16 1.6TAUI-8	QSFP/QSFP-DD OSFP/OSFP-XD



Gray Text = IEEE Standard   Red Text = In Task Force   Green Text = In Study Group

Blue Text = Non-IEEE standard but complies to IEEE electrical interfaces   * Note: As of publication, subject to change

FATTER PIPES



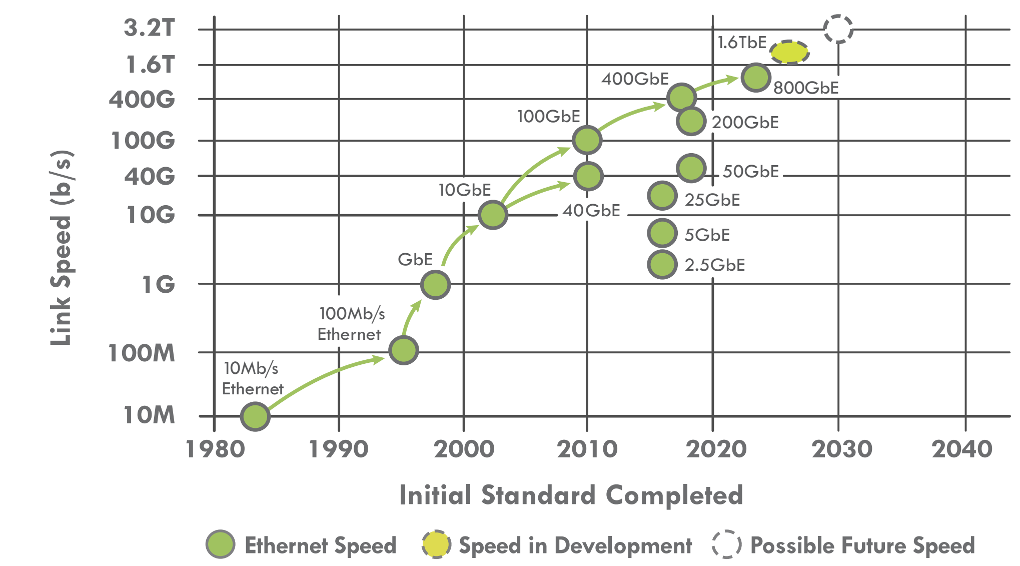
Total throughput (data rate) may be achieved in three general ways, and combinations of them:

1 Aggregating multiple lanes **2 Increasing the per lane bit rate**

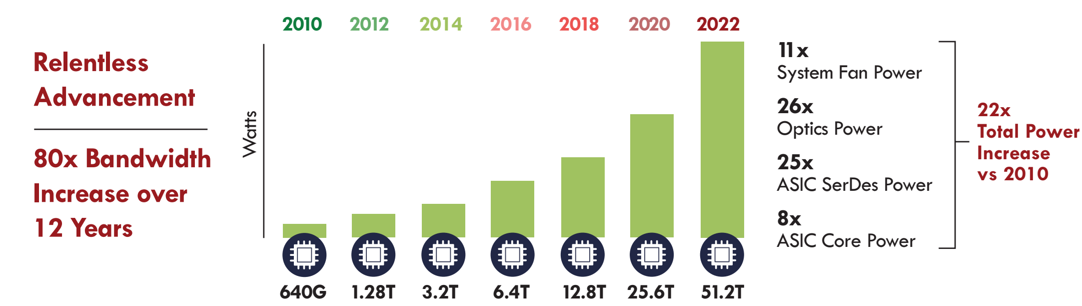
3 Increasing the bits transferred per sample (Baud)

After data rate/lane is chosen, the number of lanes in a link determines the speed. See chart on how multiple lanes can be used to generate similar speeds.

ETHERNET SPEEDS

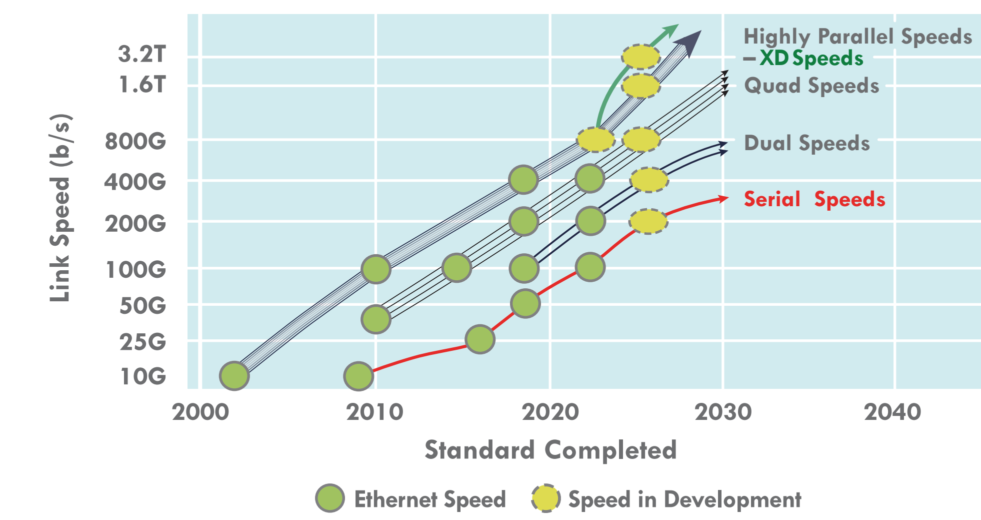


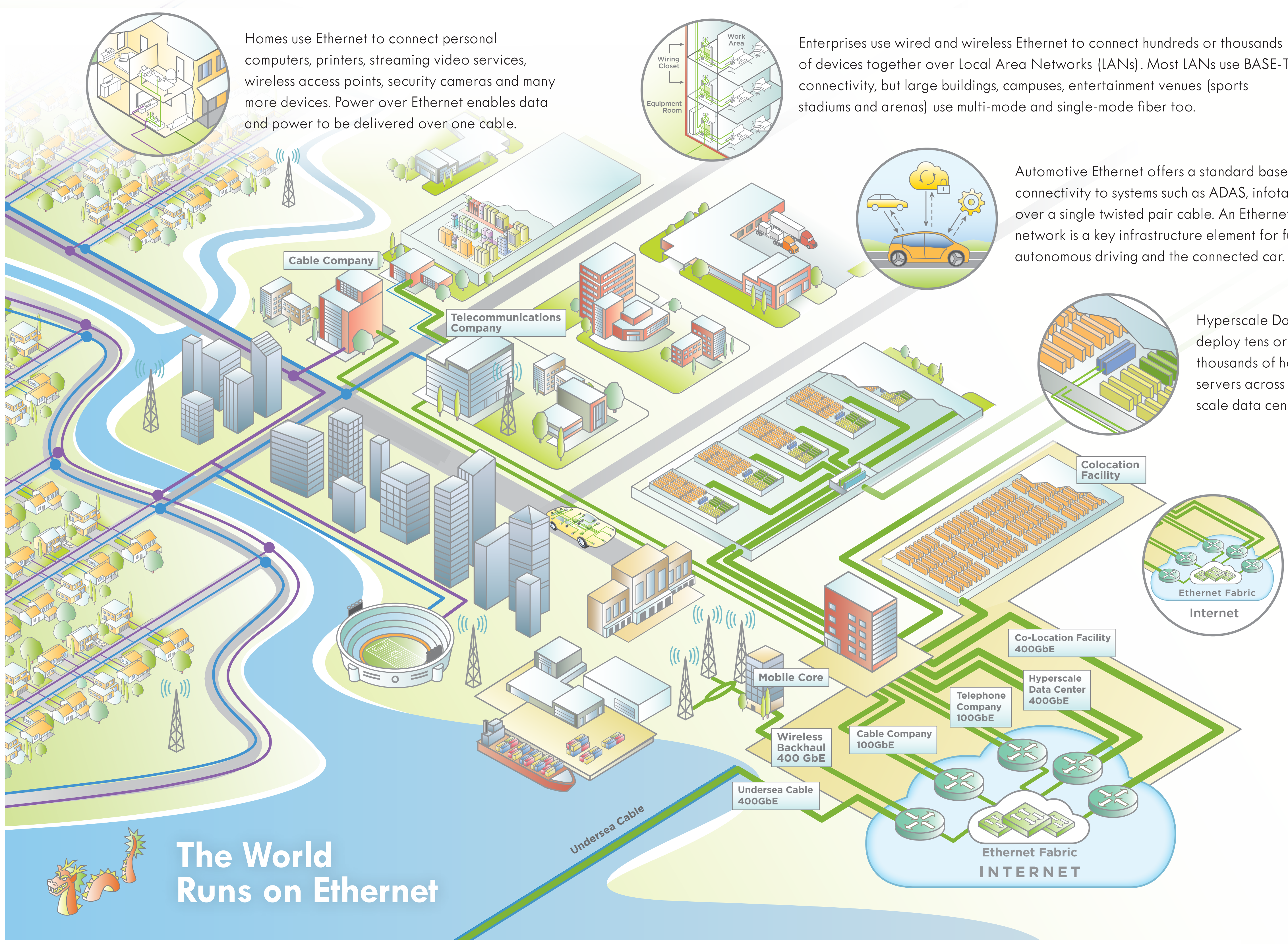
SUSTAINABILITY



Most major companies now have sustainability pledges requiring better energy efficiency. Ethernet is part of the problem (it uses power) and part of the solution (enabling more efficient facilities). Data centers account for about 1-1.5% of global electricity use. When we look at the power used by the IT equipment, the proportion used by the network has been steadily increasing. For the networking industry, power is the key problem to solve. The challenge for Ethernet is to improve the energy efficiency by reducing the picojoules per bit with new technologies.

PATH TO SINGLE LANE





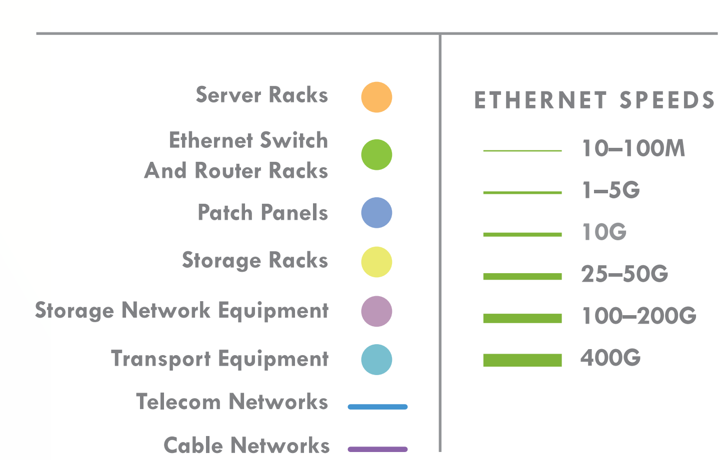
Homes use Ethernet to connect personal computers, printers, streaming video services, wireless access points, security cameras and many more devices. Power over Ethernet enables data and power to be delivered over one cable.

Enterprises use wired and wireless Ethernet to connect hundreds or thousands of devices together over Local Area Networks (LANs). Most LANs use BASE-T connectivity, but large buildings, campuses, entertainment venues (sports stadiums and arenas) use multi-mode and single-mode fiber too.

Automotive Ethernet offers a standard based in-vehicle connectivity to systems such as ADAS, infotainment, telematics, etc. over a single twisted pair cable. An Ethernet-based communication network is a key infrastructure element for functions like autonomous driving and the connected car.

Hyperscale Data Centers deploy tens or hundreds of thousands of homogeneous servers across warehouse scale data centers in pods.

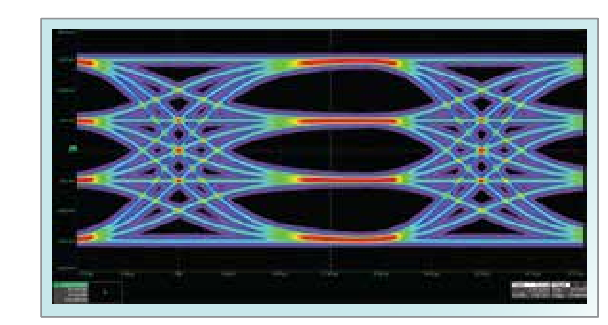
The Internet Exchange Point (IXP) is where the Internet is made when various networks are interconnected via Ethernet. Co-location facilities are usually near the IXP so that they have excellent access to the Internet and long-haul connections. 5G's next-generation network architecture is changing our connected world. It has the potential to support thousands of new applications in both industrial and consumer segments, and with speeds and throughput exponentially higher than current networks, the possibilities for 5G appear to be almost limitless.



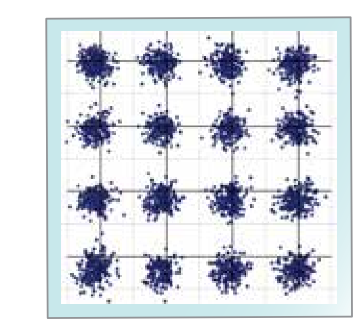
ETHERNET ECOSYSTEM

As streams turn into rivers and flow into the ocean, small Ethernet links flow into large Ethernet links and flow into the Internet. The Internet is formed at Internet Exchange Points (IXPs) that are spread around the world. The IXPs connect Telecommunications Companies, Cable companies, Providers and Content Delivery Networks over Ethernet in their data centers.

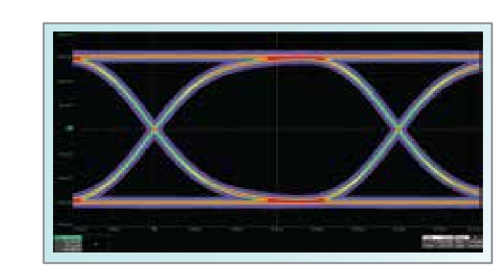
SIGNALING METHODS



PAM4



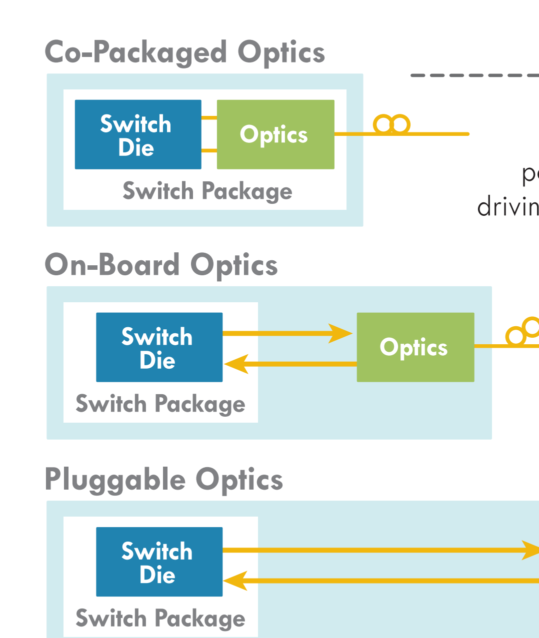
Coherent



NRZ

Signaling for higher lane rates has transitioned from non-return-to-zero (NRZ) used for 25Gb/s per lane to four level Pulse-Amplitude Modulation (PAM4) for 50 Gb/s per lane and above. Coherent signaling uses inphase and quadrature modulation for 100Gb/s per lane and above.

OPTICAL EVOLUTION



Optimal Power Efficiency

The ever-increasing demand for power efficiency in the data center is driving the transition to new interconnect solutions, like co-packaged optics, on-board optics, and the newer initiative for Linear Pluggable Optics (LPO). As link speeds increase, the demand for more cost-effective optical solutions is driving innovation and creativity in this market.