ethernet alliance

White Paper
Why 2.5GBASE-T and 5GBASE-T?

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Table of Contents

Table of Contents

Introduction

Since its inception in 1973 by Dr. Robert M. Metcalfe at Xerox PARC (Palo Alto Research Center), Ethernet has undergone significant evolution. Initially, Ethernet supported speeds of 10Mbps using thick coaxial cables. Over the last 50-plus years, Ethernet has adapted to enable many higher speeds:

- **Fast Ethernet (100Mbps):** Fast Ethernet increased the speed tenfold, making it suitable for more demanding applications. 100BASE-TX was standardized in 1995 and requires Category 5 copper cable.

- **Gigabit Ethernet (1Gbps):** Gigabit Ethernet further increased speeds, initially over fiber and later over twisted pair cabling, making it a mainstream technology for high-speed networking. 1000BASE-T was standardized in 1999 and requires Category 5e copper cable.

- **10 Gigabit Ethernet:** This marked a significant leap in Ethernet speeds, initially over fiber and later over copper cables. 10GBASE-T was standardized in 2006 and requires Category 6a copper cable.

- **2.5/5 Gigabit Ethernet**: Products were introduced to the market in early 2015, and 2.5GBASE-T and 5GBASE-T were standardized in 2016 (IEEE 802.3bz™).

The need for speeds beyond Gigabit Ethernet arose from several factors such as increasing data demands, advancements in wireless technologies, data-center requirements and future proofing to accommodate emerging applications and services. The main driver for the development of 2.5GBASE-T and 5GBASE-T was the bottleneck of 1Gbps in much of the existing enterprise and premise cabling infrastructures, combined with the demand for the faster data rates enabled by advancements in wireless technologies like IEEE 802.11ac™ Wave 2 (also known as "Wi-Fi 5").

2. The Rise of 2.5GBASE-T and 5GBASE-T

Speeds vary greatly in different places in the network. While switch-to-switch links (mostly fiber) moved to 10 Gigabit Ethernet and beyond, campus access links were stuck at 1Gbps because the installed base of premise cable was dominated by Category 5e and Category 6 cabling. Rewiring the access layer of an existing building is a very costly and time-consuming process. As the industry looked forward to wireless access points (APs) that could exceed 1Gbps throughput, it needed to find an answer that didn't require re-wiring buildings.

Many vendors began equipping their APs with dual Gigabit Ethernet ports to overcome bandwidth limitations. Link aggregation (LAG) was often employed to utilize both ports simultaneously, allowing APs to achieve higher throughput. However, this approach significantly increased costs—not only because it utilized more complex and expensive AP hardware, but also because it required additional cabling and consumed more switch ports at the access layer, reducing overall port efficiency and increasing infrastructure expenses.

The industry chose to do a new thing for Ethernet and run faster on installed cable infrastructure, exceeding the original design points for Cat5e/Cat6. While 2.5GBASE-T and 5GBASE-T were derived from the 10GBASE-T standard, the signaling wasn't simply a matter of reducing the line rate to 25% or 50%. Instead, the modulation scheme was adapted to better suit lower speeds while maintaining robustness. Specifically, these standards use a square PAM-16 (Pulse Amplitude Modulation with 16 levels) constellation, fully covered by a powerful LDPC (Low-Density Parity-Check) code.

This approach ensures high reliability and performance over existing cabling. This was a key differentiator from competing proposals that merely reduced the baud rate of 10GBASE-T without modifying the modulation or coding schemes. The adopted method offered better noise resilience and compatibility with Cat5e/Cat6 cabling, making it more practical for widespread deployment.

Compared to 1000BASE-T, 10GBASE-T used significantly better (also more complex) coding techniques, which made the "running faster over old cable" challenge more tractable. The other key assumption is it didn't have to work in all the worst cases (e.g., 100M of Cat5e, "6-Around-1 Bundle," tight cable bundling). Ethernet was taking an idea from the Wi-Fi world, to run as fast as you can over the channel you have.

Standard	Transfer speed	Channels per direction	Bits per Hertz per channel	Spectral bandwidth	Cable req. 100 meter
100BASE-TX	100Mbps	1	3.2	31.25 MHz	Cat5
1000BASE-T	1000Mbps	4	4	62.5 MHz	Cat5e
2.5GBASE-T	2500Mbps	4	6.25	100 MHz	Cat5e
5GBASE-T	5000Mbps	4	6.25	200 MHz	Cat6
10GBASE-T	10000Mbps	4	6.25	400 MHz	Cat6A

Table 1: Cable Requirement for Ethernet Speeds Up to 10000Mbps

2.1 NBASE-T Alliance and the IEEE 802.3bz Standard

The NBASE-T Alliance focused on pre-standard specifications for 2.5GBASE-T and 5GBASE-T Ethernet, as well as market education and development. This enabled companies to start developing and deploying products based on these specifications, facilitating early adoption and building market readiness.

Many individuals working in the NBASE-T Alliance were also key contributors to IEEE 802.3bz. Their active participation in the development of the standard resulted in its compatibility with the NBASE-T specifications and enabled products that were developed before the standard to be compliant with the eventual standard, once IEEE 802.3 was finalized.

The NBASE-T Alliance published several documents. Among them, a white paper, NBASE-T 2.5G/5G Ethernet Technology Basis for the IEEE 802.3bz Standard, provides particularly valuable context in this area. After the standard was published, the NBASE-T Alliance merged with the Ethernet Alliance, and its documents can be found at https://archive.nbaset.ethernetalliance.org/library/.

2.2 Technical Specifications and Features

2.2.1 Speeds

IEEE 802.3bz/NBASE-T provides a good trade-off between cost and performance:

- 2.5Gbps and 5Gbps data rates are supported over existing Cat5e and Cat6 cabling, enabling cost-effective speed upgrades without requiring infrastructure replacement. For new installations, Cat6A is recommended to ensure optimal performance and future scalability.

- 2.5GBASE-T and 5GBASE-T are power efficient compared to 10GBASE-T, which simplifies wiring closet deployment.

- Growing demand for higher network speeds is accommodated in a practical and efficient way, while scalability and cost-effectiveness are maintained.

2.2.2 NBASE-T Downshift

The NBASE-T Alliance additionally specified a feature to aid in deployment on existing wiring, NBASE-T Downshift. It enables devices to select the highest achievable data rate within channel constraints.

NBASE-T Downshift adjusts the data rate based on the quality of the channel. In BASE-T auto-negotiation, the link speed chosen is the Highest Common Denominator (HCD) supported by both ends of the link. If the channel is bad enough (i.e., too noisy), the link cannot be reliably established and maintained. When this occurs, NBASE-T Downshift removes the highest speed from the negotiation advertisement, resulting in the next lower speed being chosen. This ensures that the highest reliable data rate is chosen for the current channel conditions.

This is crucial because channel conditions vary over time. This is particularly true of alien crosstalk, a dominant impairment for multigigabit BASE-T Ethernet. When the channel is first installed and tested, the noise environment is very likely to be benign, as this is often done when the rest of the network is idle. It is quite possible for testing to complete successfully when the network is idle but to have issues when the network is active. This is because, as more channels become active in the network, alien noise from adjacent cables in a cable bundle degrades the channel.

By preventing persistent link failures and ensuring a stable connection, NBASE-T Downshift enhances the overall user experience. It ensures that network links remain operational even under suboptimal conditions. Having a slower link is much better than having no link.

2.2.3 Universal Serial XGMII (USXGMII)

USXGMII is the de-facto industry standard for supporting multiple data rates (100M, 1G, 2.5G, 5G, and 10G) over a single serializer/de-serializer (SerDes) interface between switch application-specific integrated circuits (ASICs) and physical-layer (PHY) devices. The availability of this interface—both specifications and implementations—made it simpler for the industry to adopt 2.5G BASE-T and 5G BASE-T.

Some key properties include:

- Support for a range of port data rates, including 10Mbps, 100Mbps, 1Gbps, 2.5Gbps, 5Gbps, and 10Gbps, allowing for a wide variety of applications and network environments.

- Transmission of multiple data rates over a single SerDes interface, simplifying the design and reducing the complexity of network hardware.

- Scalability in terms of power and cost, making USXGMII an efficient technology for building Ethernet switches.

3. Industry Adoption and Applications

3.1 Enterprise Networks

Supporting higher-bandwidth wireless LAN APs and addressing the backhaul requirements for Wi-Fi 5 were key drivers for the development of 2.5GBASE-T and 5GBASE-T. Even as early as 2013, the trend toward Wi-Fi as users' default network connection was clear, and, since then, this trend has only accelerated. The "Wi-Fi first" office and applications like video conferencing, voice over Internet Protocol (VoIP), and real-time collaboration demand both higher-bandwidth wireless LAN APs with increased device density and enhanced user experience with minimal latency and faster data-transfer rates.

Today's Wi-Fi 5/6/7 (IEEE 802.11ac™/802.11ax™/802.11be™) APs require robust backhaul connections to handle the increased data rates required in these environments. 2.5GBASE-T and 5GBASE-T over existing Cat5e/Cat6 cabling provides a cost-effective solution for upgrading backhaul infrastructure to meet these needs.

3.1.1 Use Cases in Specific Verticals

The use cases for 2.5GBASE-T and 5GBASE-T are varied across vertical industries. For example, high-resolution machine-vision systems are used in industrial automation and quality control, requiring large image files to be transferred quickly. Workstations for media-production tasks such as video editing and 3D rendering need faster network access to large files. Enterprise desktops and docking stations must support high-speed internet or large internal file transfers. A sampling of other vertical-industry use cases is detailed in the following sections.

3.1.1.1 Medical Imaging and Telemedicine

- High-bandwidth APs enable the seamless transmission of large medical imaging files, such as for radiology and cardiology, directly to doctors' tablets and workstations.

- Reliable and fast Wi-Fi connections are critical for telemedicine applications, ensuring high-quality video consultations and real-time data sharing between patients and healthcare providers.

3.1.1.2 Higher Education

- Universities and colleges can support the high-density connectivity needs of students and faculty, who often use multiple devices simultaneously for learning and research.

- Enhanced Wi-Fi performance supports smart classroom technologies, such as interactive whiteboards, digital textbooks, and online assessments.

3.1.1.3 Corporate Campus/Remote Worker

- High-bandwidth APs support unified communications platforms, including video conferencing, VoIP, and instant messaging, ensuring smooth and uninterrupted communication.

- With the rise of remote work, robust Wi-Fi networks are essential for supporting employees who need reliable access to corporate resources and collaboration tools while away from the office.

3.1.1.4 Retail/Hospitality

- "Hot-spot" access is becoming a basic store service. Supporting large numbers of guest devices (along with the employees, in-store devices, etc.) requires high speed uplinks for the Wi-Fi infrastructure.

- Smart devices (e.g., cameras) are proliferating in retail areas, and some of these devices generate significant upstream traffic.

- Many hotel properties have gone digital using QR codes to convey in-room and on-property amenities removing the cost and logistics of printed material. So, too, many restaurants today favor the use of digital menus, keeping only a few printed versions for the occasional customer without a smartphone.

3.2 Home/Prosumer

- Supporting network attached storage (NAS) for tech-enthusiast users with large amounts of data, 2.5GBASE-T Ethernet can significantly speed file transfers and backups, improve multi-user access, and future proof.

- Home-media streaming with high-resolution video, such as 4K or 8K content, demands substantial bandwidth to ensure smooth playback without buffering. 2.5G Ethernet is well-suited for this purpose, offering higher speeds and more reliable connections compared to lower-speed

- Online network gamers benefit from lower latency and faster download speeds, enhancing the overall gaming experience with 2.5G Ethernet. Larger game files and updates can be downloaded much faster, minimizing downtime.

- Home servers with high-quality technical products for various applications (e.g., Self-hosted media platform such as Plex, Emby, Web hosting, virtual machines, game servers, remote access, and virtual private networks) can be more efficient with 2.5G Ethernet.

- Many Internet service providers (ISPs) with high-speed plans offer connection options which may exceed 1Gbps. Using 2.5G Ethernet ensures users can fully realize these speeds for enhanced performance for multiple devices, as well as improved streaming and gaming.

- While 5Gbps Ethernet has been virtually nonexistent in home and prosumer devices, the landscape is shifting. As consumer broadband connections increasingly exceed 1Gbps—especially with modern cable modems and fiber-optic services—network equipment is beginning to include ports capable of support 2.5GBASE-T. These are commonly found on newer Wi-Fi 6/6E routers, mesh systems, and high-end motherboards, enabling users to take full advantage of multi-gigabit internet speeds without requiring enterprise-grade infrastructure.

3.3 Cost and Practicality

2.5GBASE-T and 5GBASE-T provide a practical upgrade path for increasing network throughput while maintaining compatibility with existing cabling infrastructure. These technologies are specifically designed to operate over Cat5e and Cat6 twisted-pair cabling, which was originally specified for 1GBASE-T and lacks alien-crosstalk performance requirements. 2.5GBASE-T and 5GBASE-T convey a host of valuable benefits for multiple application spaces:

- **Channel compatibility**—2.5GBASE-T and 5GBASE-T PHYs are engineered to tolerate the electrical characteristics of legacy cabling, including insertion loss, return loss, and crosstalk, up to 100 meters. In many cases, performance exceeds this distance, depending on installation quality and environmental conditions.

- **Deployment efficiency**—By reusing existing horizontal cabling, these technologies eliminate the need for re-cabling with Cat6A or higher, reducing both capital expenditure and installation time. This is particularly beneficial in environments where cable replacement would require significant downtime or disruption.

- **Equipment availability and cost**—Multi-gigabit Ethernet ports (2.5G/5G) are increasingly available in enterprise switches, APs, and network interface cards (NICs), often at a lower cost and power consumption than 10GBASE-T solutions. This makes them well-suited for edge deployments where 10G performance is not required but 1G is insufficient.

- **Incremental bandwidth scaling**—2.5GBASE-T and 5GBASE-T supports stepwise performance enhancements to meet evolving demands such as Wi-Fi 6/6E/7 AP uplinks, high-speed endpoint connectivity, and edge compute workloads.

- **Application throughput alignment**—2.5GBASE-T and 5GBASE-T provides sufficient bandwidth for high-throughput applications including 4K/8K video, large dataset transfers, and virtual desktop infrastructure (VDI), while improving latency characteristics for real-time services like VoIP and unified communications as a service (UCaaS).

- **Lifecycle extension**—2.5GBASE-T and 5GBASE-T offer a forward-compatible upgrade path that extends the utility of existing copper cabling plants, while aligning with long-term multi-gigabit Ethernet strategies.

4. Deployment

Reviewing the installed cabling infrastructure is recommended in preparing to deploy 2.5GBASE-T and 5GBASE-T. The NBASE-T Alliance published several helpful white papers in this area:

- NBASE-T Performance and Cabling Guidelines
- NBASE-T Downshift: Optimization of 2.5Gb/s and 5Gb/s Ethernet Data Rates Over Cat5e/Cat6 Cabling
- Impact of Crosstalk from Non-Standard Links on IEEE 802.3bz
- Best Practice Cabling for Wireless Access Points

4.1 Alien Noise

Alien noise is the interference from outside a given cable. The source of this noise is outside the control of the transceiver on the link—thus, the name. The term alien noise is generally reserved for crosstalk from other signaling systems in adjacent cabling. Cabling systems are specified for crosstalk differently than they are from electromagnetic compatibility (EMC) ingress/impulse noise immunity. There are lots of possible sources of alien noise (e.g., adjacent Ethernet cables in dense bundles, power lines, fluorescent lighting, and even nearby wireless devices), but the most worrisome is the "6-around-1 Bundle." The NBASE-T Downshift: Optimization of 2.5Gb/s and 5Gb/s Ethernet Data Rates Over Cat5e/Cat6 Cabling document helps explain this:

> *Reliable operation of a link at rates of 2.5Gb/s, 5Gb/s (and possibly 10Gb/s) over Cat5e channels is normally achievable, but some installations may have challenges. Links are potentially susceptible to noise from other cables in close contact. Unlike between the four twisted pairs of an Ethernet cable, the source of this noise is outside the control of the transceiver on the link and is therefore known as "alien noise".*

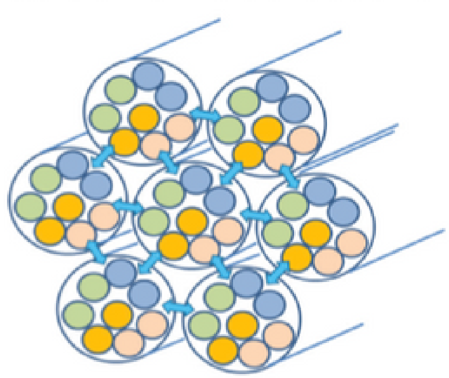

Figure 2: Alien Cross-Talk in a 6-around-1 Bundle

Figure 2 above shows an example of a challenging environment, depicting a worst-case alien crosstalk noise configuration. The noise level is affected by tightness of the binding and the cable construction, both of which affect the separation of alien pairs. The worst-case happens when you have a dense bundle (pairs very close) running over a long distance. Cable-to-cable crosstalk may cause excessive bit errors, resulting in link failure even when the end devices support the rate.

This is one area where the desire for "neat" cabling can be detrimental to the performance of the system. Tight bundling can be seen as a mark of good workmanship, but it can seriously impact system performance. As described in Section 4.3.3 below, unbundling cables can make a significant difference in system performance. This is true both when cables exit the wiring closet and for long horizontal runs.

4.1 Signaling Frequency and ALSNR

The following two tables from NBASE-T Performance and Cabling Guidelines help users to understand the likelihood of reaching their performance goals on their existing infrastructure.

	2.5G BASE-T	5G BASE-T
Installed Cat 5e	✓	Extended Frequencies Required
Installed Cat 6	✓	✓
Installed Cat 6A	✓	✓

Table 2: Internal Cabling Parameters to Support 2.5G and 5G applications

As shown in the table above, running 5GBASE-T on Cat5e uses frequencies exceeding the design specifications for the cable. Alien Limited Signal-to-Noise Ratio (ALSNR) is a key metric used to evaluate the robustness of Ethernet links, particularly in high-speed environments like 2.5GBASE-T and 5GBASE-T. It measures the signal quality in the presence of alien crosstalk—interference from adjacent cables—which can significantly impact performance and reliability.

The table below provides a simple visualization of the ALSNR risk when running specific speeds over specific infrastructure. This information helps network owners evaluate their upgrade strategies.

Bundled Cabling Length 0m to 50m	Category 5e	Category 6	Category 6A
2.5GBASE-T			Assured
5GBASE-T Assured			Assured
Bundled Cabling Length 50m to 75m	**Category 5e**	**Category 6**	**Category 6A**
2.5GBASE-T			Assured
5GBASE-T Assured			Assured
Bundled Cabling Length 75m to 100m	**Category 5e**	**Category 6**	**Category 6A**
2.5GBASE-T			Assured
5GBASE-T Assured			Assured
ALSNR Risk	High	Medium	Low

Table 3: ALSNR Support Risk for 2.5G and 5G Applications

4.3 Challenges and Mitigation Strategies

4.3.1 Cabling Limitations

Potential issues with running 2.5G/5G Ethernet over Cat5e/6 include signal quality and length limitations:

- **Interference and noise**—Twisted-pair copper cabling, including all standard category types, can be affected by electromagnetic interference (EMI) and crosstalk, which may impact signal quality, especially in electrically noisy environments.

- **Alien crosstalk**—External interference from adjacent cables (alien crosstalk) can impact the performance of 2.5GBASE-T and 5GBASE-T, especially in densely packed cable bundles.

- **Maximum distance**—Both 2.5GBASE-T and 5GBASE-T are designed to operate over distances up to 100 meters on Cat5e/6 cabling. However, the actual achievable distance can be reduced by the quality of the cabling and the installation environment.

- **Performance degradation**—As the length of the cable increases, the signal strength diminishes, leading to potential performance degradation. This is more pronounced at higher data rates.

- **Variability in cable quality**—The performance of 2.5GBASE-T and 5GBASE-T can vary depending on the quality of the Cat5e or Cat6 cables used. Higher-quality cables with better isolation from external interference will perform better.

- **Aging infrastructure**—Older or poorly installed cabling may not support the higher data rates as effectively as newer, well-maintained infrastructure.

- **Temperature and humidity**—Environmental conditions such as temperature and humidity can affect the performance of Ethernet cabling. Extreme conditions can lead to increased attenuation and reduced signal quality.

- **Physical damage**—Physical damage to the cables, such as kinks, bends, or cuts, can also impact performance and reliability.

4.3.2 Best Practices

- **Cable testing and certification**—Perform regular testing and certification of installed cabling to confirm compliance with performance specifications. This helps validate support for target data rates and identifies potential degradation over time.

- **Standards-based installation**—Adhere to recognized cabling standards (e.g., ANSI/TIA-568) during installation. Key practices include maintaining proper bend radius, avoiding excessive bundling, and ensuring adequate separation from EMI sources such as power lines and fluorescent fixtures.

- **Shielded cabling for high-interference environments**—In environments with elevated EMI, consider using shielded twisted-pair (STP) variants of Cat5e or Cat6 to enhance noise immunity and preserve signal integrity.

- **NBASE-T Downshift support**—Utilize NBASE-T Downshift functionality, which enables PHYs to automatically adjust link speed based on real-time channel conditions. This ensures stable connectivity and optimal throughput, even in marginal cabling environments.

4.3.3 Mitigation Steps

Since Cat5e and Cat6 cabling were not originally specified to handle alien crosstalk, any deployment of 2.5GBASE-T or 5GBASE-T over this infrastructure technically exceeds the original design limits. As a result, users may run into performance issues, particularly in high-density or noisy environments. Fortunately, the NBASE-T Performance and Cabling Guidelines provide mitigation strategies to help ensure reliable operation:

1. To reduce the risk of the application not being supported, the following steps may be taken to provide the best possible performance from cabling channels.

a. Separate the equipment cords.
b. Enable NBASE-T "Downshift" feature to negotiate the best rate that can be supported on a particular configuration.
c. Unbundle the horizontal cables.

2. For selective deployments of 2.5GBASE-T or 5GBASE-T applications, utilize nonadjacent patch panel positions.

3. If performance expectations are not met by the prior mitigation steps, then the alien crosstalk may be mitigated using one or more of the following:

a. Replace equipment cords and patch cords with Category 6A cords.
b. Reconfigure cross-connect cabling to more direct inter-connection.
c. Replace connectors with Category 6A connectors.
d. Replace the horizontal cable with Category 6A horizontal cable.

5. Adoption

As shown in the figures below, Enterprise campus port speeds are still dominated by 1Gbps, but 2.5GBASE-T and 5GBASE-T show the strongest growth in the current forecasts. As 2.5GBASE-T and 5GBASE-T systems are starting to approach the product maturity and optimization levels of 1000BASE-T, we see strong growth opportunities.

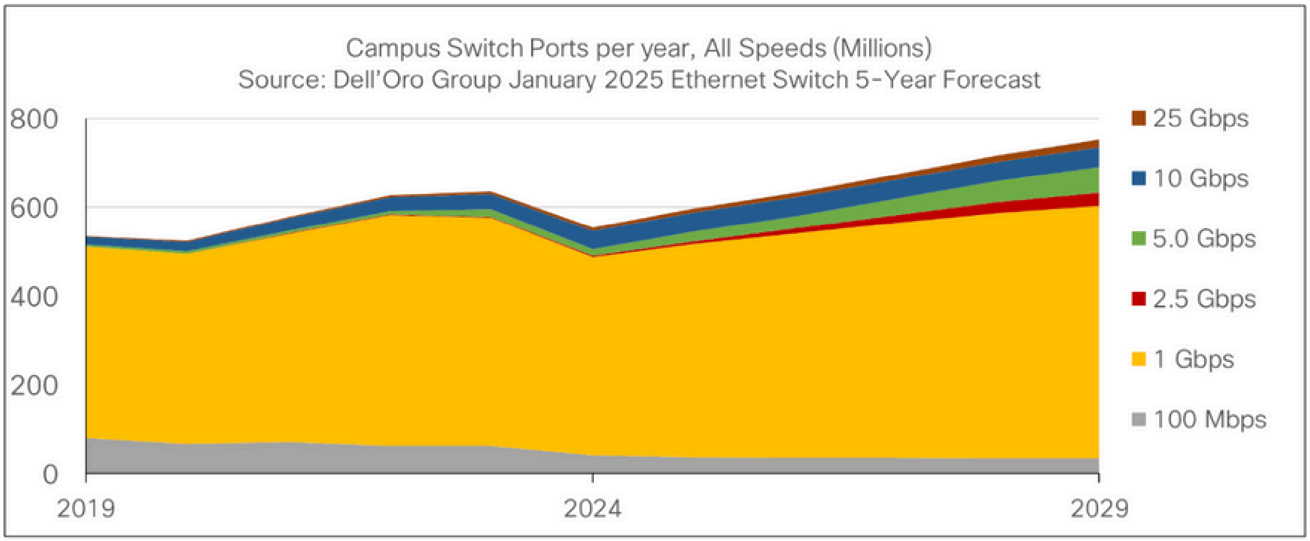

Figure 3: Campus Switch Port Forecast

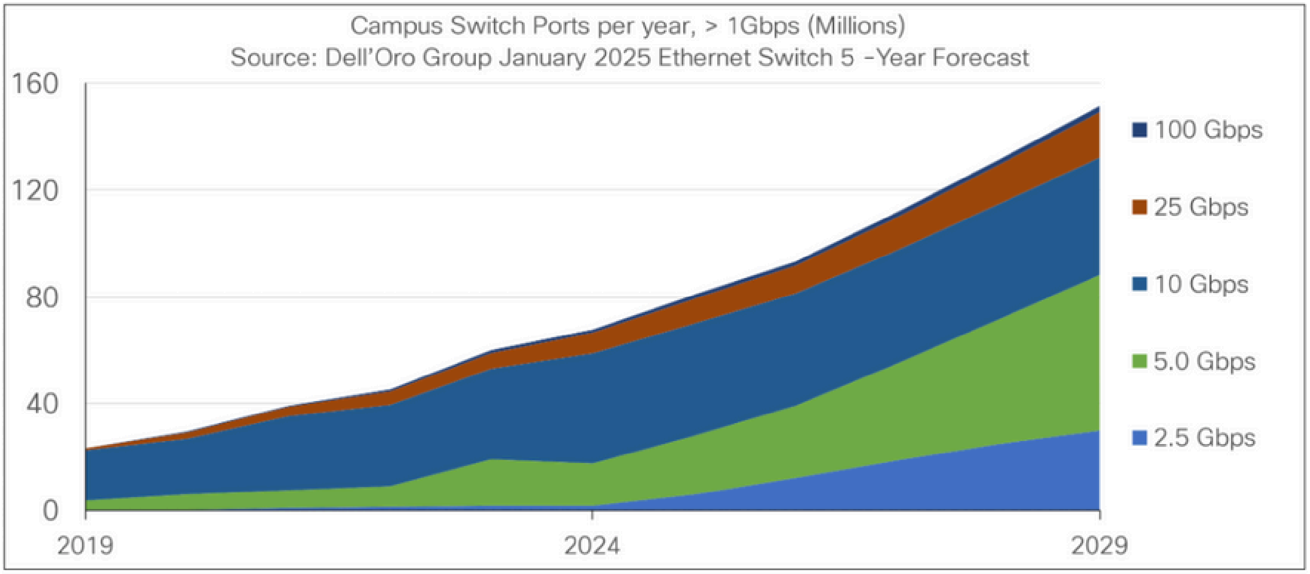

Figure 4: > 1Gbps Campus Switch Port Forecast

6. Conclusion

The ease of deploying 2.5GBASE-T makes it a compelling choice for upgrading network infrastructure, ensuring compatibility with both current and next-generation enterprise and home networking devices. This technology offers several key advantages:

- **Application flexibility**—Ideal for high-performance Wi-Fi APs, media-rich workstations, and emerging smart home and industrial devices.
- **Infrastructure reuse**—Leverages existing Cat5e and Cat6 cabling, avoiding the high costs and disruption of re-cabling.
- **Performance optimization**—When needed, simple mitigation techniques—such as unbundling cables, enabling downshift, and separating patch cords—can help maintain reliable performance even in challenging environments.

Whether for upgrading an enterprise campus or enhancing a home lab, 2.5GBASE-T provides a practical, scalable path forward for multi-gigabit networking.

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