
WHITE PAPER

Turbo Charging Cabling Infrastructures

HPE SMART RATE MULTI-GIGABIT ETHERNET TECHNOLOGY



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INTRODUCTION

With the advancement in wireless technologies, enterprise networks are being stressed by the ever increasing number of wireless devices. 1000BASE-T Ethernet is limited in bandwidth to handle these new demands while 10GBASE-T Ethernet requires costly upgrades to the majority of cabling installed today—Cat5e and Cat6 cables. This new reality requires the addition of new cost-effective 2.5GbE and 5GbE link speeds to scale network bandwidth and to deliver increased security to enterprise IEEE 802.11ac Wave 2 Access Points. There is also a need for other new technologies that would provide IT professionals with more data rate options to handle the increased network access demands.

The Aruba 5400R and Aruba 3810 series switches include Smart Rate port options. HPE Smart Rate provides higher bandwidth connectivity and PoE+ power for next generation IEEE 802.11ac devices utilizing existing cabling infrastructure. Smart Rate ports support auto-negotiated speeds of 1, 2.5, 5, and 10 Gbps with PoE+, and operate over existing Category 5e, 6, and 6A cabling.

HPE SMART RATE TECHNOLOGY

Operational modes

Smart Rate interfaces support four modes of operation:

- Standards-based IEEE 802.3 1000BASE-T Gigabit Ethernet on Category 5e or better twisted-pair cabling
- 2.5 Gigabit Ethernet on Category 5e or better twisted-pair cabling
- 5 Gigabit Ethernet on Category 5e or better twisted-pair cabling
- Standards-based IEEE 802.3 10GBASE-T 10 Gigabit Ethernet on Category 6 or better twisted-pair cabling

Smart Rate uses IEEE 802.3 twisted-pair auto-negotiation to advertise and determine mutually supported modes of operation with link partners at startup. This enables Smart Rate to connect to standard-based Ethernet equipment and establish links at 1000BASE-T and 10GBASE-T speeds. When connected to other Smart Rate interfaces or systems that support NBASE-T 2.5/5G technology, 2.5 Gbps and 5 Gbps connections can additionally be established.

Table 1. ArubaOS-Switch Smart Rate configuration options

Setting	Link Speed (s) advertised during auto-negotiation	Link duplex modes advertised during auto-negotiation
auto	1, 2.5, 5, and 10 Gbps	Full-Duplex
auto-1000	1 Gbps	Full-Duplex
auto-2500	2.5 Gbps	Full-Duplex
auto-5000	5 Gbps	Full-Duplex
auto-2500-5000	2.5 and 5 Gbps	Full-Duplex
auto-10G	10 Gbps	Full-Duplex

Compatibility

By default, Smart Rate ports use IEEE 802.3 twisted-pair auto negotiation and are set to advertise all four modes of operation during link-up. This enables Smart Rate to connect to all standard-based Ethernet equipment and establish link at 1000BASE-T and 10GBASE-T. When connected to other Smart Rate or similar NBASE-T equipment, 2.5 Gbps and 5 Gbps connections can additionally be established.

As mentioned in the previous section, the 2.5 Gbps and 5 Gbps modes are based on AQrate multirate PHY technology. This is the same technology selected by Cisco for its multigigabit technology and has been adopted by the NBASE-T Alliance.

Interoperability testing between 5400R v3 Smart Rate and multigigabit was completed successfully with Cisco' s 3850-X switches. In the lab, a 3850-X multigigabit switch has been tested with Smart Rate on 5400R v3. This included successfully verifying link-up at all four supported speeds as well as basic L2 traffic passing. Physical layer robustness has also been tested with a variety of cabling types and lengths at the different speeds, and the link performance was found to be robust.

In addition to the internal testing, HPE also participated in the first NBASE-T Alliance plugfest in September 2015, and the 5400R v3 switch successfully interoperated with every vendor' s systems at 2.5Gbps and 5Gbps speeds (1G and 10G are IEEE standards, those were not tested). This included linking up at 2.5G and 5G speeds with every vendor' s systems using various cable types/lengths and successfully forwarding line-rate L2 traffic. Cisco was there with their 3850-X switches (no multigigabit APs).

In addition to NBASE-T based products, there will be products in the market that use a competing 2.5 Gbps and 5 Gbps multirate technology from Broadcom known as MGBASE-T. MGBASE-T is also the name of the alliance started by Broadcom built around this technology. The 2.5 Gbps and 5 Gbps modes in MGBASE-T and NBASE-T are not compatible with each other. When Smart Rate interfaces are connected to equipment using MGBASE-T technology, the link will autonegotiate and only establish at IEEE 802.3 defined modes of operation (1000BASE-T or 10GBASE-T).

The final adoption by the industry of multigigabit technologies will be from the IEEE's 802.3bz 2.5/5GBASE-T Task Force who is overseeing the standardization of the 2.5G and 5G Ethernet.

Rate adaptation

Smart Rate supports rate adaptation. This capability enables the Ethernet link to adjust to the highest achievable speed with a link partner port.

At start-up, a Smart Rate port and its link partner port exchange information about each other's capabilities – supported link speed, duplex modes, flow control – using IEEE 802.3 auto-negotiation. Once the information exchange has completed, both interfaces apply a common set of rules to take maximum advantage of common capabilities by selecting the highest common speed supported by both ends, and start a process called link training, to determine if cable performance can support this speed.

If link training is successful, the link is then established at the highest common speed. However, if the link training process fails, the rate adaptation feature will try up to three additional times to auto-negotiate and re-establish the link at the same speed. If the connection experiences four consecutive failures, rate adaptation will remove that speed from being advertised. During the next auto-negotiation attempt, the two ports will then attempt to link at the next speed down.

The process then repeats itself until a link-up is successful, or all commonly advertised speeds are exhausted.

Power over Ethernet

Smart Rate switch systems provide up to 30 watts per port of Power over Ethernet for all port speeds using standards-based IEEE 802.3at PoE+, providing power over twisted-pair structured cabling to PoE powered devices.

Power over Ethernet within Smart Rate provides the same capabilities found in 10/100BASE-TX and 10/100/1000BASE-T ports in Aruba OS switch systems—allocation of port power, setting of port priorities, configuring of switch-level PoE redundancy, et cetera.

MACsec

Smart Rate provides link-level security through standards-based MAC security, with support for both 256-bit and 128-bit GCM-AES cipher suites as defined by IEEE 802.1AE and 802.1AEbn.

Cabling

One of the key factors of Smart Rate is determining if existing 1000BASE-T cabling will support the higher data rates of Smart Rate ports. Some initial considerations are:

- 2.5 Gbps transmission is very robust and should work for the vast majority of installed cabling
This is important because the first implementations of Smart Rate are going to operate at 2.5Gbps..
- 5 Gbps transmissions can present challenges for Smart Rate deployments on existing cabling

At first this seems counter-intuitive because it isn't the highest data rate, but, as the "5 Gigabit Ethernet (5 Gbps Smart Rate)" section will describe, the requirement to operate on installed 1000BASE-T cabling makes 5 Gbps more challenging than 10GBASE-T. 5 Gbps deployments will require care and likely need testing of existing cable installations to determine if they are suitable for reliable operation.

Note: This is not a vendor specific challenge but an industry-wide issue.

The following sections provide detail about the cabling support/requirements for each of the four modes.

Gigabit Ethernet (1000BASE-T)

The 1000BASE-T mode within Smart Rate is the most robust of the four modes. Its cabling requirements are identical to the requirements for all 1000BASE-T interfaces:

- Up to 100 meters on Cat5e, or better, unshielded twisted-pair (UTP) or shielded twisted-pair (STP) cabling.
- Cabling must meet the requirements for Cat5e described in ANSI/TIA/EIA 568-B.2 standard.
- With very few exceptions, Cat5e installations in the field use UTP cabling to save cost, and because 1000BASE-T doesn't require the additional noise protection provided by STP cabling.

Note: ANSI/TIA/EIA-568 is the set of standards that deals with cabling requirements in commercial buildings for telecommunications applications (what is often referred to as structured cabling).

10 Gigabit Ethernet (10GBASE-T)

10GBASE-T has been on the market for several years, and although its cabling requirements are well understood, compared to 1000BASE-T, 10GBASE-T is significantly more challenging to deploy. 10GBASE-T is inherently a noise-dominated technology. What this means is that under ideal conditions, 10GBASE-T can operate error-free even beyond 100 meters. However, the presence of environmental noise (often referred to as alien noise or alien crosstalk) significantly degrades the link's signal-to-noise ratio (SNR) and can restrict the maximum cable reach of the link.

In practice, long 10GBASE-T links do not run bit-error free. Because of this, 10GBASE-T has much more demanding cabling requirements than 1000BASE-T. When 10GBASE-T was originally developed by the IEEE, a new category of cabling (augmented Cat6 [Cat6A]) and new cable installation procedures with noise mitigation techniques were also developed to specifically support it. As a result, cable installers pay special attention to how the cables for 10GBASE-T are bundled and laid out during installation to maintain appropriate cabling performance and minimize the impact of environmental noise on the link.

Cabling requirements: the cabling requirements for Smart Rate's 10GBASE-T mode are identical to the requirements for all 10GBASE-T interfaces:

- Up to 55 meters on Cat6 UTP or STP cabling
- Up to 100 meters on Cat6A or better UTP or STP cabling

From a technical specifications point-of-view, cabling for 10GBASE-T must meet the requirements for Cat6/6A described in ANSI/TIA/EIA 568-C.2 standard, or the requirements for class E/EA described in ISO/IEC standard 11801. These two standards deal with structured cabling performance parameters and were updated to include information needed to support 10 Gbps transmission. The first standard is used predominantly in North America, while the latter is used in Europe and other parts of the world. For all intents and purposes, they are the same.

In addition to the 568-C.2 and 11801 standards, Cat6 installations must also meet alien crosstalk requirements described in ANSI/TIA/EIA technical service bulletin TSB-155, or ISO/IEC technical report TR-24750. These two documents deal specifically with noise and gives guidance on cable installation techniques to mitigate alien crosstalk/alien noise when using Cat6 cabling for 10GBASE-T operation. This requirement is unique to 10GBASE-T—the cabling guidelines for 1000BASE-T have no such requirements.

2.5 Gigabit Ethernet (2.5 Gbps Smart Rate)

Cabling for the 2.5 Gbps Smart Rate mode is not defined today by a Standards body. HPE R&D testing has shown that the 2.5 Gbps mode performs as well as 1000BASE-T and operates robustly on structured cabling that meets the requirements for 1000BASE-T operation. Put simply, if the cabling works reliably for 1000BASE-T, it works for 2.5 Gbps. This robustness can be attributed to three main factors:

- 2.5 Gbps Smart Rate uses a coding and modulation technique that is leveraged from 10GBASE-T. This technique is more advanced than what is used by 1000BASE-T and has significantly more powerful error correction capability to deal with errors caused by cable impairments and external noise.
- 2.5 Gbps Smart Rate operates on 100 MHz bandwidth. This is the channel bandwidth that Cat5e cabling is specified, designed, and tested for. Cat6 also supports 2.5 Gbps operation as it extends that bandwidth to 250 MHz.
- At 100 MHz, the electromagnetic coupling between adjacent cables in a tight bundle of cables is fairly minimal.

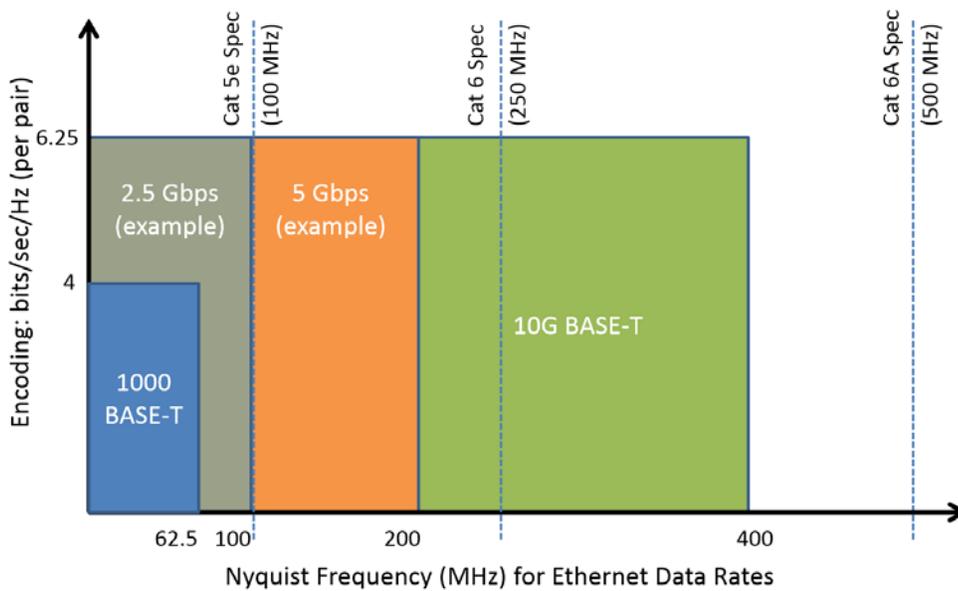


Figure 1. Relationship between cable category, frequency and Ethernet data rates - source: http://www.ieee802.org/3/cfi/1114_1/CFI_01_1114.pdf

Cabling in the field that is certified for 1000BASE-T operation has enough channel bandwidth to support 2.5 Gbps Smart Rate operation. While 2.5 Gbps operates at a higher frequency than 1000BASE-T (62.5 MHz), its coding, modulation, and error correction technique compensates for additional performance impairments.

Most importantly, its 100 MHz frequency of operation results in minimal impact from external noise. This is key because the majority of older Cat5e and Cat6 installations give no consideration to mitigating alien crosstalk, minimizing how tightly multiple cables are bundled together, using shielded twisted-pair cables, and/or taking care to avoid routing cables

through noisy environments. In fact, in an effort to keep cable installations easy to work with when routing through conduits and cable trays, most cable installers have gotten into the habit of “grooming” the cable bundles for 1000BASE-T applications to keep them neat and tidy. This creates significant amounts of alien crosstalk between the cables due to the tight bundling. Fortunately, this electromagnetic coupling is frequency dependent, and is fairly minimal at 100 MHz.

Cabling requirements: Cat5e cabling for 2.5 Gbps Smart Rate is identical to the requirements for 100BASE-T. It must meet the requirements for Cat5e, as described in ANSI/TIA/EIA-568-B.2.

This keeps the cabling guidelines simple and consistent, helps ensure quality cabling continues to be installed/deployed in the field, and should provide a positive experience when customers drop 2.5 Gbps Smart Rate into their environment.

5 Gigabit Ethernet (5 Gbps Smart Rate)

5 Gbps Smart Rate can be technically challenging, particularly when deployed on Cat5e cabling. There are two main reasons for this:

5 Gbps mode operates on 200 MHz bandwidth. The previous section showed that Cat5e cabling has a specified channel of bandwidth of 100 MHz, making it insufficient for 5 Gbps operation. However, higher quality Cat5e cabling has acceptable performance in the 100–200 MHz range, allowing it to support 5 Gbps operation. Note that Cat5e cable quality varies greatly between cable vendors, so there are existing Cat5e installations that meet 1000BASE-T operation, but will have insufficient performance in the 200 MHz range to support reliable 5 Gbps operation. Moving to Cat6 solves this issue since Cat6 is specified and tested to 250 MHz.

- The 200 MHz operating bandwidth used by 5 Gbps falls into a frequency range where electromagnetic coupling between cables in a tight cable bundle can be significant. This makes the alien noise issue much more problematic. Because most legacy Cat5e and Cat6 cable plants were installed without regard to alien crosstalk mitigation, the potential for noise degradation at 5 Gbps on legacy cabling can occur.

5 Gbps deployments in existing cable installations involves a trade-off between the cabling loss and noise. With shorter cables, the link has greater SNR and can tolerate more noise. With longer cables, the link has less SNR and can tolerate less noise. For example, testing in the HPE R&D lab has shown that 5 Gbps link with a 100 meters of reach can only tolerate about 40 meters worth of coupled noise in a 6-around-1 cable bundle configuration. When the same link was shortened to 60 meters, it could tolerate the entire 60 meters worth of coupled noise in the same 6-around-1 configuration.

Cabling requirements: both Cat5e and Cat6 installations, should be tested for acceptable alien crosstalk if the cabling plant is laid out with significant cable bundling. Guidance for bundled and unbundled 5 Gbps deployments is broken down below, by category of cabling:

On Cat5e:

- If the cabling is mostly unbundled (minimal alien crosstalk), 5 Gbps Smart Rate can support up to 55 meters without any testing
- If the cabling is mostly unbundled, 5 Gbps Smart Rate can support up to 100 meters if the channel is tested and passes the ANSI/TIA/EIA 568-B.2 limit lines for Cat5e when extrapolated out to 200 MHz
- If the cabling is significantly bundled with other cables, the cabling must additionally pass the alien crosstalk requirements described in ANSI/TIA/EIA TSB-155 or ISO/IEC TR-24750

On Cat6:

- If the cabling is mostly unbundled, 5 Gbps Smart Rate can support up to 100 meters of Cat6 without any required testing, assuming it was previously tested during installation to meet the ANSI/TIA/EIA 568-C.2 Cat6 requirements
- If the cabling is significantly bundled with other cables, 5 Gbps Smart rate can support up to 100 meters of Cat6 if the cabling passes the alien crosstalk requirements described in ANSI/TIA/EIA TSB-155 or ISO/IEC TR-24750

On Cat6A:

- 5 Gbps can support up to 100 meters provided the cabling was previously tested to Cat6A ANSI/TIA-EIA 568-C.2 or class EA requirements in ISO/IEC 11801 requirements.

Deployment recommendations

2.5 Gbps Smart Rate is the recommended default. It is as robust as 1000BASE-T and has been demonstrated to run on many cabling configurations that support 1000BASE-T operation. This mode should meet the wired link bandwidth needs for the majority of IEEE 802.11ac Wave 2 Access Point designs.

In many cases 10 Gbps Smart Rate may link up successfully on Cat5e configurations or Cat6 configurations of less than 55 meters, but reliable operation is not guaranteed. It is recommended to use the interface speed-duplex configuration setting to disable 10 Gbps advertisements so that the Smart Rate interface doesn't attempt to link at 10 Gbps. 10 Gbps Smart Rate is recommended when the cabling meets the ANSI/TIA/EIA or ISO/IEC requirements for 10GASE-T operation.

If 5Gbps is expected to be deployed on an existing Cat5e cabling plant, testing for both the individual cable/channel performance and alien crosstalk should be planned and budgeted for. In some cases, the results may show that the cabling does not meet the requirements for reliable 5 Gbps operation. It is recommended that 5 Gbps be deployed in Cat6 cabling plants that have sufficient alien crosstalk performance.

Table 2. Cabling recommendation summary

Mode of Operation	Cabling	Link Distances
1Gb/s (1000BASE-T)	CAT5e / Class D	Up to 100m
2.5 Gb/s	CAT5e / Class D	Up to 100m
5 Gb/s	CAT5e / Class D	Up to 55m (high noise environment)
		Up to 100m (low noise environment)
	CAT6 / Class E	Up to 100m
10 Gb/s (10GBASE-T)	CAT6 / Class E	Up to 55m
	CAT6 / Class EA	Up to 100m

Flow control

Smart Rate ports support IEEE 802.3x port-based flow control. This is the same user-port flow control functionality that supported today on all ArubaOS-switch based switch systems.

Smart Rate ports do not support IEEE 802.1Qbb priority-based flow control. This is not an issue today since 802.1Qbb is used predominantly in data center applications, and ArubaOS-switch systems do not have software support for priority-based flow control. If 802.1Qbb becomes a requirement for the Enterprise and Campus in the future, be aware that the Smart Rate ports cannot support it.

Frame size

Smart Rate ports support 9 KB (9216B) jumbo frames. This is identical to the maximum jumbo frame size supported on existing ArubaOS-Switch devices. Jumbo frame size is disabled by default.

SUMMARY

HPE Smart Rate technology allows for Aruba switches to provide 1, 2.5, 5, and 10 Gbps Ethernet connectivity over existing copper cabling and PoE+.

Enterprise networks can expect to see the benefits of supporting the next generation of mobile infrastructure and IEEE 802.11ac Wave 2 APs by deploying HPE Smart Rate technology in the network.

APPENDIX

5 Gigabit Smart Rate cable specification

Cable installations for 5 Gbps Smart Rate must meet two sets of parameters: Transmission and alien noise. The transmission parameters define the performance characteristics of a single 4-pair cable needed to support 5 Gbps data transmission. The alien noise parameters define the maximum allowable coupling from external noise sources that can be imparted onto the cable-in-question without negatively impacting the overall distance/reach of the data link.

Relationship between ANSI/TIA/EIA, ISO/IEC, and IEEE

Before we dive into the cabling specification, it is worth briefly discussing the relationship between these three standards bodies as it relates to structured cabling.

ANSI/TIA/EIA 568 and ISO/IEC 11801 are both telecommunication standards that define general-purpose balanced copper and optical fiber cabling in commercial buildings (structured cabling) for a variety of applications. This includes not only Ethernet but also a number of other data communication standards, telephony, facility control, etc. ANSI/TIA/EIA 568 is most commonly used in North America, whereas ISO/IEC is use predominantly in Europe and other parts of the world.

The Telecommunications Industry Association (TIA) develops the 568 standard, while the American National Standards Institute (ANSI) endorses it. Likewise, the International Electro Technical Commission (IEC) develops the 11801 standard, while the International Standards Organization (ISO) endorses it.

802.3 is the working group within the IEEE that is responsible for developing the Ethernet physical and data link layer standard. The key is that 802.3 does not develop cabling standards. Instead, when it comes to balanced twisted-pair and fiber optic cabling to support the various Ethernet physical layers, 802.3 references the ANSI/TIA/EIA 568 and ISO/IEC 11801 cabling standards.

5 Gbps transmission parameters on cat 5e/class D

For installations using cat 5e twisted-pair cables, the primary transmission parameters are insertion loss, return loss, and differential impedance. These three parameters must meet the IEEE’ s link segment limits for 1000BASE-T, but are extended to 200 MHz.

Table 3. Transmission parameters to support 5 Gbps operation

5 Gbps transmission parameters	Frequency (MHz)	Limit (dB)
Insertion loss	$1 \leq f \leq 100$	$IL(f) < 2.1f^{0.529} + \frac{0.4}{f}$
	$100 \leq f \leq 200$	$IL(f) < 2.1f^{0.529} + \frac{0.4}{f}$
Return loss	$1 \leq f \leq 20$	$RL(f) < 15$
	$20 \leq f \leq 100$	$RL(f) < 15 - 10\log_{10}\left(\frac{f}{20}\right)$
	$10 \leq f \leq 200$	$RL(f) < 15 - 10\log_{10}\left(\frac{f}{20}\right)$
Differential characteristic impedance	$1 \leq f \leq 100$	$Z_{DIFF} = 100 \Omega$
	$100 \leq f \leq 200$	$Z_{DIFF} = 100 \Omega$

Table 2. Specifies the transmission parameters to support 5 Gbps operation.

The values in Black are the limits for 1000BASE-T in the IEEE 802.3 Ethernet standard. The values in Red are the frequency extensions out to 200 MHz to support 5 Gbps operation. Notice that the limit line questions for the extended frequency range are identical to the 1000BASE-T equations.

5Gbps transmission parameters on cat 6/class E

5 Gbps operation is supported on cat 6/class E installations whose transmission performance meet the cat 6 limits specified in ANSI/TIA/EIA-568-C or the class E limits specified in ISO/IEC 11801.

Alien crosstalk

Alien crosstalk is tested using what is referred to as a “6-around-1” cable bundle configuration. The victim cable-under-test is surrounded by noise sources comprised of six other cables that are tightly bundled to the victim’s cable for a specific length. Data link traffic is transmitted on all seven links while monitoring the status of the victim link to determine its ability to function properly—autonegotiate, link-train, transmit/receive traffic error-free or with acceptable bit-error rate, etc). A cross-section of the 6-around-1 bundle configuration is shown in figure 4.

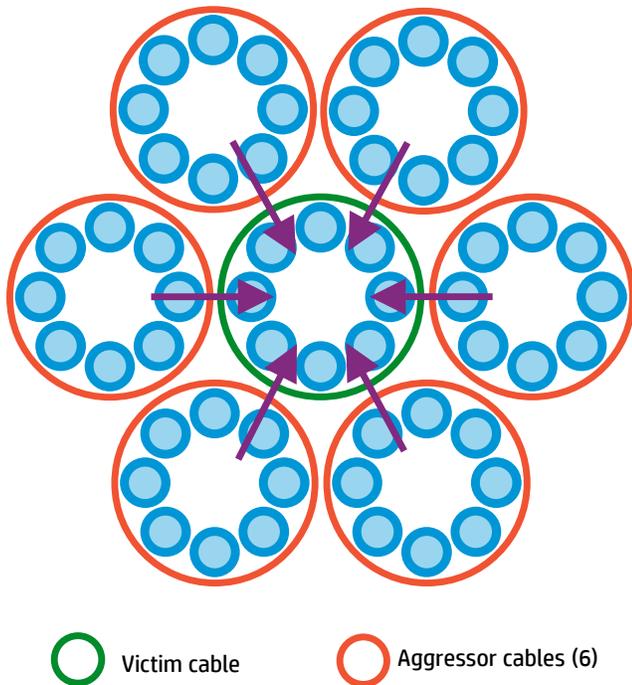


Figure 2. 6-around-1 alien crosstalk test configuration for cat 5e cabling

Lab testing covered for alien crosstalk used cat 5e cables in nine test configurations:

- Victim link operating at 1 Gbps, with six Aggressor links operating at 1 Gbps, 2.5 Gbps, and 5 Gbps
- Victim link operating at 2.5 Gbps, with six Aggressor links operating at 1 Gbps, 2.5 Gbps, and 5 Gbps
- Victim link operating at 5 Gbps, with six Aggressor links operating at 1 Gbps, 2.5 Gbps, and 5 Gbps

For each test configuration, two tests were conducted to help understand the performance limits and the trade-offs between alien crosstalk and insertion loss.

The first test sets the coupling distance of the victim and its six aggressors at 60 m. 60 m was chosen to represent a realistic worst-case coupled length that one would see in field installations. Length is then added to the victim's link to determine how much cable reach (insertion loss) can be added while still achieving error-free operation.

The second test sets the victim cable length (insertion loss) at 100 m. The coupling distance of the victim and its six aggressors start at 100 m and is reduced until the victim link can operate reliably. This tests how much alien crosstalk coupling can be tolerated with a worst-case 100 m link.

An example of the 6-around-1 test setup is in Figure 4.



Figure 3. HPE Smart Rate v3 zl2 module test bed

Alien noise

Alien noise (alien crosstalk) has a significant impact on 5 Gbps performance. Alien crosstalk is defined by two parameters: **powersum alien near-end crosstalk (PSANEXT)**, and **powersum alien equal level far-end crosstalk (PSAELFEXT)**.

- **PSANEXT** is the amount of crosstalk imparted on a cable (victim) by noise sources (aggressors) at the transmitting-end (near-end) of the cable.
- **PSAELFEXT** is the ratio of the insertion loss of the channel (victim) to the amount of alien crosstalk imparted on it at its receiving-end (far-end) by noise sources. Because PSAELFEXT is a ratio, the amount of tolerable noise is effected by the transmission loss of the cable. The less insertion loss a channel has, the more alien far-end noise it can tolerate. The more insertion loss it has, the less alien far-end noise it can tolerate.

The alien crosstalk parameters in Table 3 apply for all cabling configurations: Cat 5e, 6, 6A, or 7. However, from a practical point of view, the limits really apply to UTP cat 5e or cat 6 cable installations. In the case of STP, cat 5e or 6 cabling also generate alien noise, but the victim is protected from the aggressor noise by its shielding, and there is no net effect on its traffic.

UTP and STP cat 6A installations that meet the requirements for 10GBASE-T operation are guaranteed to meet the limits as mentioned.

Table 4. Alien crosstalk limits for various lengths of cat 5e cable configurations

Victim link speed	Test condition	1 Gbps noise aggressors (6)	2.5 Gbps noise aggressors (6)	5 Gbps noise aggressors (6)
1 Gbps 1000BASE-T	Maximum victim length 60 m aggressors	100 m (error-free)	100 m (error-free)	100 m (error-free)
	Maximum aggressor length 100 m victim	100 m (error-free)	100 m (error-free)	80 m (error-free)
2.5 Gbps Smart Rate	Maximum victim length 60 m aggressors	100 m (error-free)	100 m (error-free)	100 m (error-free)
	Maximum aggressor length 100 m victim	100 m (error-free)	100 m (error-free)	80 m (error-free)
5 Gbps Smart Rate	Maximum victim length 60 m aggressors	90 m (error-free)	90 m (error-free)	77 m (error-free)
	Maximum aggressor length 100 m victim	55 m (error-free)	55 m (error-free)	40 m (error-free)

Cabling bundling examples in terms of alien crosstalk



Figure 4: Good/Decent/Bad from an Alien Crosstalk point of view
Source: Google image search



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