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PUTTING 2.5 & 5 GIGABIT ETHERNET TO THE TEST

OVERVIEW

In offices all over the world, the use of WI-FI connected devices like laptops, smartphones and tablets and bandwidth-hungry applications has grown rapidly while many companies support a Bring Your Own Device (BYOD) policy, permitting employees to use personally owned, WIFI connected devices at work. To alleviate performance bottlenecks a new WIFI standard IEEE 802.11ac increases data rates between the WIFI Access Points (AP) and the connected end devices. And as the industry moves to 802.11ac Wave 2 even more bandwidth between the APs and switches in the access network will be needed.

In most WI-FI installations the connection between AP and switch is a 1 Gigabit/s Ethernet link carried over an electrical cable. The need for bandwidth could be solved by upgrading the connection between AP and switch to 10 Gigabit/s Ethernet, being the next higher data rate with the current standards. Unfortunately the cables between AP and switch will in most cases be unable to support 10 Gigabit/s Ethernet reliably. Refitting buildings with cables supporting 10 Gigabit/s Ethernet will be an expensive option. This has created a need for Ethernet rates higher than 1 Gigabit/s, which can run on existing cables and provide increased bandwidth.

As a result 2.5 Gigabit/s Ethernet (2.5GE) and 5 Gigabit/s Ethernet (5GE) over electrical cables are now standardized providing 2.5 or 5 times more bandwidth on existing cables allowing companies to protect their infrastructure investment. This creates a demand for test solutions that can verify the new speeds.

2.5 & 5.0 Gigabit Ethernet promise up to 500% performance boosts over existing cabling. But how do you qualify and verify that windfall?

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Introduction

Many different types of equipment can be connected to an enterprise network, e.g. desk top PCs, laptops, smartphones and tablets. In many cases the devices are connected through WIFI Access Points (APs). The structure of a typical enterprise networks is shown in figure 1.

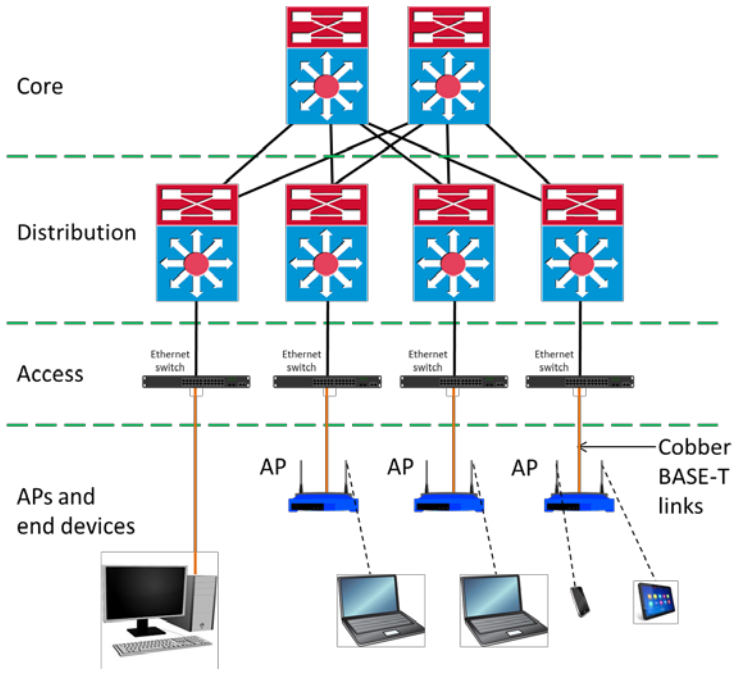
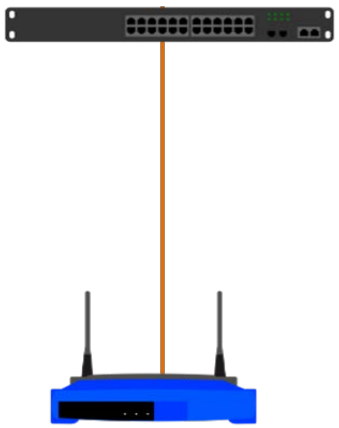


Figure 1: Typical Enterprise Network structure



Ethernet Access Switch

- Typically equipped with 1000BASE-T ports
- May support Power over Ethernet (POE)

Cables

- Large installed base of 100m Cat 5e/6 cables
- New installations move to Cat 6A(or Cat 7)

WIFI Access Point

- Connects WIFI end devices to the enterprise network
- May be PoE powered
- 802.11ac drives Ethernet backhaul traffic > 1 Gbps

Figure 2: WIFI access network elements

IEEE 802.11ac, which operates in the 5 GHz band, is the new standard for the WIFI interface between APs and end devices and it is rapidly being deployed in the networks as it provides more bandwidth for the connected end devices. For IEEE 802.11ac maximum air interface data rate is:

- First wave (from 2013): 1.3 Gigabit/s
- Second wave (from 2017): 6.9 Gigabit/s

To have sufficient capacity, the connection speed between AP and the access switch should be approx. 75% of the maximum air interface data rate. Consequently first wave IEEE 802.11ac will require a connection speed of approx. 1 Gigabit/s, while second wave IEEE 802.11ac will require approx. 5.2 Gigabit/s. Upgrading the connections between AP and switch to 10GBASE-T would provide the required capacity for 802.11ac Wave 2. However the cobber BASE-T links between the APs and the switches are in most cases (more than 85%) 100 meter long Category (or Cat) 5e/6 cables.

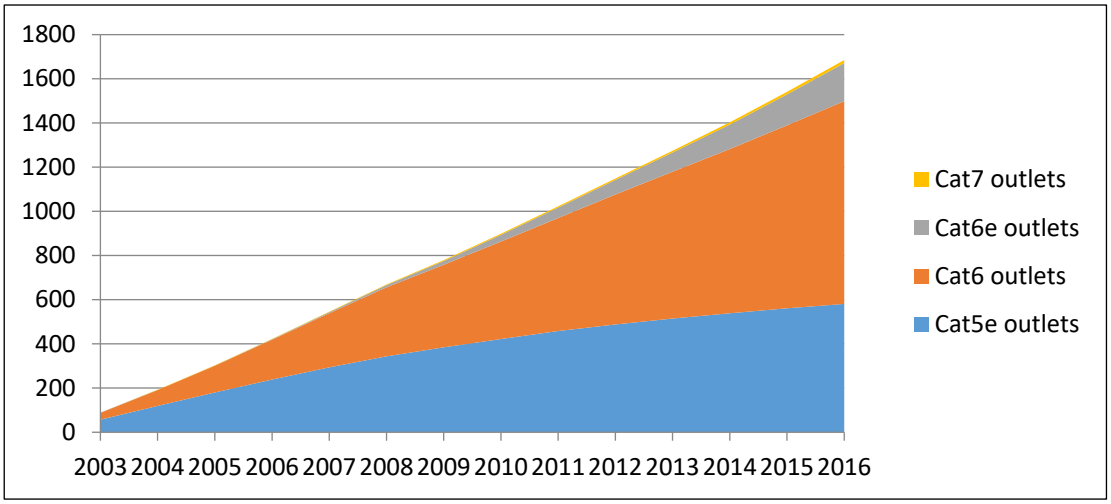


Figure 3: Installed Cat 5e/6/6e/7 Base: Estimated Outlets (millions) Source: BSRIA

Table 1 shows how far a 10GBASE-T signal can reach on Cat 5e/6/6e/7 cables:

Cable type	Max. distance for 10GBASE-T
Cat 5e	N/A
Cat 6	55 m
Cat 6A	100 m
Cat 7	100 m

Table 1: 10GBASE-T reach on Cat 5e/6/6e/7 cables

This means that 10GBASE-T is unable to work over the vast majority of the installed base of 100 meter long Cat 5e and Cat 6 cables. To overcome this, companies could upgrade their network to Cat 6A cables between the APs and the access switches, which however will be quite expensive in existing networks. As an alternative they can ask for definition and standardization of data rates between 1 Gigabit/s and 10 Gigabit/s that can run on the Cat 5e and Cat 6 cables. This has recently been completed with the IEEE 802.3bz 2.5GBASE-T and 5GBASE-T standards, which specifies 2.5 Gigabit/s Ethernet (2.5GE) and 5 Gigabit/s Ethernet (5GE). 2.5GBASE-T and 5GBASE-T can run 100 m on unshielded Cat 5e and Cat 6 twisted-pair cables because the lower speeds

reduce the spectral bandwidth of the signals compared with the 10 Gigabit/s signal, reducing the requirements on the cables.

Twisted pair based Ethernet technologies

Unshielded Twisted Pair (UTP) cables transfer Ethernet data as balanced electrical signals over 4 twisted pair cobber wires (i.e. 8 wires in total) in one cable. Cables with different levels of performance are defined; each level has been assigned a Category (or Cat) number. For transfer of Ethernet at rates from 100 Mbit/s to 10000 Mbit/s through a 100 m cable the following cable categories are required:

Standard	Transfer speed	Channels per direction	Bits per Hertz per channel	Spectral bandwidth	Cable req. 100 meter
100BASE-TX	100 Mbit/s	1	3.2	31.25 MHz	Cat 5
1000BASE-T	1000 Mbit/s	4	4	62.5 MHz	Cat 5e
2.5GBASE-T	2500 Mbit/s	4	6.25	100 MHz	Cat 5e
5GBASE-T	5000 Mbit/s	4	6.25	200 MHz	Cat 6
10GBASE-T	10000 Mbit/s	4	6.25	400 MHz	Cat 6A

Table 2: Cable requirement for Ethernet speeds up to 10000 Mbit/s

Notes on table 2:

- Transfer speed is calculated as channels × bits per hertz × spectral bandwidth.
- For 100BASE-TX one twisted pair in the cable is used for transmission and another for reception, leaving two unused pairs. The other speeds use all four pairs simultaneously (bi-directional) for transmission and reception.
- Bits per Hertz per channel are effective bits per Hertz excluding encoding overhead. Advanced modulation techniques are used to achieve the listed values.

Cable type	Max. spectral bandwidth
Cat 5	100 MHz
Cat 5e	100 MHz
Cat 6	250 MHz
Cat 6A	500 MHz

Table 3: Max. spectral bandwidth per cable type

Compared with the Cat 5 specification the Cat 5e (enhanced) specification includes new and improved crosstalk specifications. This is needed to reliably transfer 1000BASE-T over a 100 meter cable.

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2.5GE and 5GE Standardization

2.5 Gigabit Ethernet (2.5GE) and 5 Gigabit Ethernet (5GE) are new data rates aimed at reusing existing Cat 5e and Cat 6 cables in enterprise networks for the interface between WIFI Access Points (APs) and switches in the access network at data rates above 1 Gigabit/s. The work was started in the IEEE standards body with a Call for Interest (CFI) in November 2014. Based on this the IEEE 802.3bz 2.5G/5GBASE-T Task Force started working on the 2.5GBASE-T and 5GBASE-T standards in March 2015.

The IEEE 802.3bz standard is based on technology defined for 10 Gigabit Ethernet, but of course running at lower rates. As the main application of 2.5GE and 5GE are connections between APs and switches in the access part of enterprise networks, the IEEE 802.3bz standard focus on connections over Cat 5e and Cat 6 cables that are typically connecting the APs and the switches. The IEEE 802.3bz standard objectives (approved March 2015) included:

- Support MAC data rates of 2.5 Gb/s and 5 Gb/s
- Support Auto-Negotiation (IEEE 802.3 Clause 28)
- Support optional Energy Efficient Ethernet (IEEE 802.3 Clause 78)
- Support PoE (Power over Ethernet) (IEEE 802.3 Clause 33)
- Define a 2.5 Gb/s PHY for operation over
  - Up to at least 100m on four-pair Cat5e balanced copper cabling
- Define a 5 Gb/s PHY for operation over
  - Up to at least 100m on four-pair Cat6 balanced copper cabling
  - Up to 100m on four-pair Cat5e balanced copper cabling

The IEEE 802.3bz standard was approved in September 2016.

In addition to the IEEE 802.3bz 2.5G/5GBASE-T Task Force two separate industry alliances, the NBase-T Alliance and the MGBase-T Alliance, have since 2014 been developing specifications for Ethernet speeds at 2.5 Gigabit/s and 5 Gigabit/s. Both alliances aim to have their specification compatible with IEEE 802.3bz. Cisco now markets Multigigabit Ethernet products, which support Ethernet speeds at 1, 2.5, 5 and 10 Gigabit/s and the NBASE-t specification. Furthermore Aruba, a Hewlett Packard Enterprise company, has defined the HPE Smart Rate, which is a 1, 2.5, 5, 10 Gigabit/s twisted-pair network interface interoperable with the NBASE-T 2.5GE and 5GE products and 1GE and 10GE devices based on current standards.

Protocol Stack

The Ethernet protocol stack is based on the seven-layer OSI model of computer networking:

Layer 7	Application layer
Layer 6	Presentation layer

Layer 5	Session layer
Layer 4	Transport layer
Layer 3	Network layer
Layer 2	Data link layer
Layer 1	Physical layer

Table 4: The OSI model of computer networking

The 2.5GE and 5GE specifications address Layer 1, containing the following sublayers:

Sublayer	Functions
PCS (Physical Coding Sublayer)	• auto-negotiation • determine that a functional link has been established (Link Training) • coding (64b/66b encoding in the case of 2.5 Gigabit and 5 Gigabit Ethernet) • FEC (Forward Error Correction) using LDPC (Low Density Parity Check) codes
PMA (Physical Medium Attachment Sublayer)	• framing • octet synchronization/detection • scrambling/descrambling
PMD (Physical Medium Dependent Sublayer)	• the transceiver for the physical medium

Table 5: Layer 1 sublayers

The NBASE-T Alliance specification in many cases refers to 10GBASE-T standard to define the layer 1 functions for NBASE-T 2.5G and NBASE-T 5G (NBASE-T Alliance equivalents to 2.5GBASE-T and 5GBASE-T).

Both NBASE-T 2.5G and NBASE-T 5G may support Low Power Idle (LPI) as part of Energy-Efficient Ethernet (EEE) as specified in IEEE 802.3 Clause 55.

2.5GE and 5GE switches

Several vendors offer switches with 2.5GE and 5GE capabilities, often implemented as solutions supporting 10GE, 5GE, 2.5GE, 1GE and 100 Mbit/s electrical Ethernet from one port. Some examples are:

Product	Maximum number of ports				
	10GE	5GE	2.5GE	1GE	100ME
Aruba 5400R Switch Series	96	96	96	96	288
Broadcom BCM56821	10	N/A	8	8	N/A

Brocade ICX 7450-32ZP	N/A	N/A	8	8	8
Cisco Catalyst WS C4510R+E	96	96	96	96	288
Netgear M4200-10MG-PoE	*2*	*N/A*	*8*	*8*	*N/A*

Table 6: Switches supporting 2.5GE and 5GE

2.5GE and 5GE NICs

A Network Interface Controller (NIC) (or network interface card, network adapter) connects a computer to a network. NIC products supporting 2.5GE and 5GE include:

- Startech.com: ST10GSPEXNB 1-Port PCIe 10GBase-T / NBASE-T Ethernet Network Card supporting five network speeds: 10G, 5G, 2.5G, 1G and 100Mbps
- IOI Technology Corporation: GE10-PCIE4XG201 Multi-Gigabit (10G/ 5G/ 2.5G/ 1000BASE-T/ 100BASE-TX) Ethernet to PCI Express x4 Gen 2 Host Card
- Tehuti Networks: TN9510: 5-speed 10GBase-T / NBASE-T™ NIC supporting 10G, 5G, 2.5G 1G and 100Mbps over unshielded twisted pair (UTP)

Access points

WIFI access points with 5GBASE-T and/or 2.5GBASE-T interfaces include:

- Aruba 330 Series Access Points. Link speed between AP and switch: 5G, 2.5G, 1G and 100Mbps BASE-T
- Cisco Aironet 3800 Series Link speed between AP and switch: 5G, 2.5G, 1G and 100Mbps BASE-T
- Cisco Meraki MR53 Access Point. Link speed between AP and switch: 2.5G and 1G
- Cisco Meraki MR84 Access Point. Link speed between AP and switch: 1x 100/1000/2.5G BASE-T Ethernet & 1x 10/100/1000 BASE-T Ethernet (RJ45)

2.5GE and 5GE Test Requirements

Testing Ethernet systems is required to ensure the proper functioning and quality. This of course also applies to the new 2.5GE and 5GE solutions as they are developed and deployed. To test the layer 1 functions defined in the IEEE 802.3bz specification verification of functions like auto-negotiation, Link Training and EEE must be performed.

In addition a Signal-to-noise ratio (SNR) should be measured to ensure that the cables carrying the 2.5GE and 5GE signals have sufficient quality.

As 2.5GE and 5GE capable NICs and switches typically are implemented as flexible products supporting 10GE, 5GE, 2.5GE, 1GE and 100 Mbit/s Ethernet from one port it is of course also important to test Ethernet at all rates supported by the port under is test.

Xena Networks 2.5GE and 5GE Test Solutions

The Xena Odin-10G-5S-6P-CU 5-Speed 6-port 10G L2-3 test module provides powerful testing capabilities to test and verify the layer 1 functions defined for 2.5GE and 5GE.

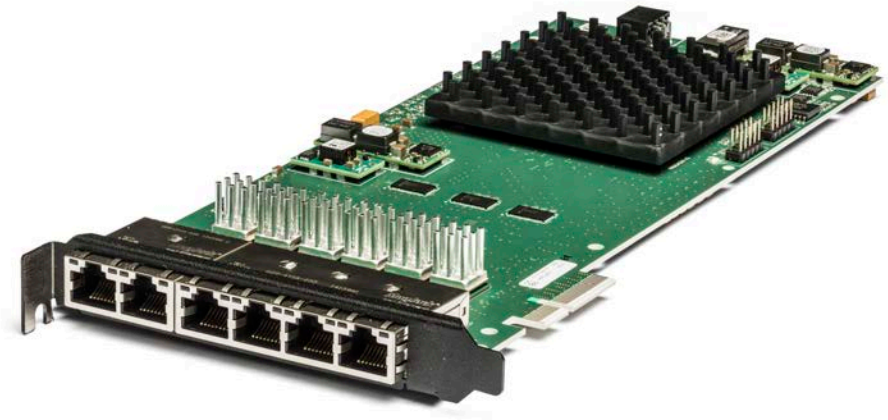

Figure 4: The powerful and versatile Xena Odin-10G-5S-6P-CU 5-Speed 6-port 10G L2-3 test module

You can set the Odin-10G-5S-6P-CU to perform auto-negotiation so when connected to a Device Under Test (DUT) the Odin-10G-5S-6P-CU can verify that the DUT reacts correctly to the auto-negotiation process. The Odin-10G-5S-6P-CU will also do Link Training with the DUT, verifying the correct functioning of this feature. Energy Efficient Ethernet (EEE) can be checked, as the Odin-10G-5S-6P-CU can:

- Enable/Disable EEE
- Enable/Disable low-power mode in the TX direction (independently of the RX direction)
- Monitor active/low-power mode transition activity in both TX and RX direction

Furthermore Signal-to-noise ratio (SNR) can be measured with the Odin-10G-5S-6P-CU, which can read out the SNR for each of the four electrical BASE-T channels.

Testing Above Layer 1

Ethernet testing with the Odin-10G-5S-6P-CU is of course not limited to the layer 1 tests described in the previous section. Based on Xena's advanced architecture, the Odin-10G-5S-6P-CU is a proven solution for Ethernet testing at Layers 2-3.

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Advanced layer 2 and layer 3 test scenarios can be performed using the free test applications for the Odin-10G-5S-6P-CU:

XenaManager-2G test software is used to configure and generate streams of Ethernet traffic between Xena test equipment and Devices Under Test (DUTs) and analyze the results.

- **Xena2544** offers full support for the 4 test-types specified in RFC2544
  - Throughput
  - Latency
  - Frame loss
  - Back-to-back frames
  - Jitter (Frame Delay Variation) is also supported
- **Xena3918** makes it easy to create, edit and execute all test-types specified in RFC 3918. RFC3918 describes tests for measuring and reporting the throughput, forwarding, latency and Internet Group Management Protocol (IGMP) group membership characteristics of devices that support IP multicast protocols.
- **Xena2889** is an application for benchmarking the performance of Layer 2 LAN switches. The following RFC 2889 test types are supported:
  - All Throughput and Forwarding rate tests (both Fully and Partially meshed)
  - Congestion Control
  - Address Caching Capacity
  - Address Learning Rate
  - Broadcast Frame Forwarding and Latency
  - Forward Pressure and Maximum Forwarding Rate
- **Xena1564** provides full support for both the configuration and performance test types described in Y.1564 for complete validation of Ethernet service-level agreements (SLAs) in a single test

Another free application for the Odin-10G-5S-6P-CU:

- **XenaScripting** is a powerful and easy-to-use command-line-interface (CLI) scripting API that makes test automation easier for test engineers.

Testing from 100 Megabit/s to 10 Gigabit/s

In addition 2.5GE and 5GE testing Odin-10G-5S-6P-CU also supports test of 10GE, 1GE and 100 Mbit/s Ethernet electrical interfaces, so both the new and the existing Ethernet rates in the range from 100 Megabit/s to 10 Gigabit/s can be tested. This is needed to test and verify many devices with 2.5GE and 5GE capable ports as they support all five rates. The Odin-10G-5S-6P-CU is

equipped with 6 RJ45 test ports, whereby up to 6 electrical ports can be tested simultaneously with the Odin-10G-5S-6P-CU.

The powerful capability of Ethernet testing up to layer 3 at five different Ethernet network speeds makes the Odin-10G-5S-6P-CU a versatile solution for performance and functional testing of network infrastructure and Ethernet equipment such as switches, NICs and Access Points in enterprise networks with IEEE 802.11ac WIFI.

CONCLUSION

2.5 Gigabit/s and 5 Gigabit/s Ethernet is a reality today and growing rapidly, driven by the need for cost effective expansion of infrastructure capacity to fulfil the increased bandwidth supported by new WIFI standard IEEE 802.11ac Wave 2. More capacity is required for the interface between the IEEE 802.11ac capable WIFI APs and the access network switches. The new Ethernet speeds can run on the most common electrical cable types in enterprise networks, whereby companies can avoid costly upgrade of the infrastructure cabling and protect their infrastructure investment.

Switches and NICs with 2.5GE and 5GE capabilities are typically implemented as flexible solutions that support 10GE, 5GE, 2.5GE, 1GE and 100 Mbit/s Ethernet from one electrical port. To thoroughly test the product all rates need to be tested.

With the Xena Odin-10G-5S-6P-CU 5-Speed 6-port 10G L2-3 test module the user gets powerful and versatile Ethernet test capabilities up to layer 3 to test and verify both new and existing Ethernet rates in the range from 100 Mbit/s to 10 Gigabit/s: 100 Mbit/s, 1 Gigabit/s, 2.5 Gigabit/s, 5 Gigabit/s and 10 Gigabit/s on electrical Ethernet interfaces.

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