Testing 100 G Networks and Services

Service activation testing provides the best guarantee of a high-quality service

Fueled by bandwidth capacity growth, 100 G connectivity forms the basis of most network backbones today. Depending on cost and transmission distance requirements, even higher transmission rates at 200 and even 400 G are becoming available. However, when it comes to high-speed client interconnectivity, the use of 100 Gigabit Ethernet (GE) is growing to the point where 100 GE is being deemed 'the new 10 GE.' Currently, 100 GE is heavily used in core networks although it remains in its infancy in terms of usage by classic business customers. Key 100 GE near-term growth will be data—related both inside the data center and to connect to wide area networks. This white paper considers some of the fundamentals of 100 G transport network architectures, describes client interfaces, and covers service activation test applications.

Network Topology

The main two categories of interfaces are typically called client side and line side. Generically, line side refers to interfaces used for information transmission over longer distances from hundreds to thousands of kilometers, typically using wavelength division multiplexing (WDM). At 100 G, this implies the use of advanced modulation techniques that are relatively complex and vendor specific. By comparison, client interfaces focus on interconnectivity and are multi-vendor: they can interoperate. For Ethernet interfaces at 10 GE and lower rates, client interfaces are characterized primarily by reach and signal wavelength. At 100 GE, such client interfaces mostly use 4 multiplexed wavelengths and hence a different terminology is used to identify them.

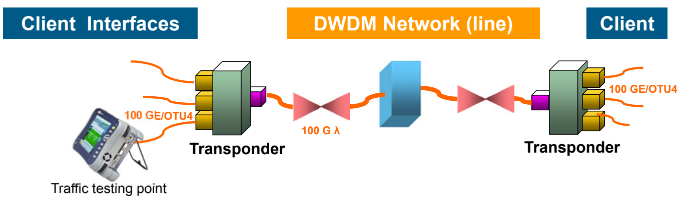

Figure 1. Transponder configuration

The use of 100 G for transport has been based on two topologies: transponder and muxponder configurations. Figure 1 shows the transponder configuration where the transport equipment uses 100 GE on client interfaces and 100 G per wavelength in the DWDM core. In such a case, a 100 GE link that carries multiple Ethernet/IP connections is transported across the network using WDM. This is in contrast to a muxponder configuration where multiple lower-speed links, typically multiple 10 G links on 10 GE interfaces, connect into a core backbone where they are aggregated onto 100 G wavelengths over WDM. The client traffic goes through a multiplexing stage to take advantage of the efficiencies provided by higher-rate core links. Testing to activate such muxponder-based links implies generating and analyzing traffic into the network from one or multiple 10 GE sources rather than from a 100 GE source in the case of transponders. Figure 2 shows sample connectivity in a muxponder configuration.

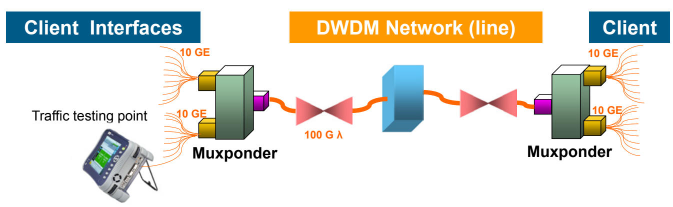

Figure 2. Muxponder configuration

Interfaces

Although 100 G line interfaces are vendor specific, long-haul transmission systems at 100 G typically use the same modulation format based on polarization multiplexed quadrature phase shift keying (PM-QPSK), also called dual polarization QPSK (DP-QPSK). This modulation technique is used in conjunction with coherent detection at the far-end receiver; this implies the receiver is equipped with a frequency-locked local oscillator laser and the signal phase and amplitude is recovered via digital signal processing.

An advantage of such coherent receivers is that they can electronically compensate for dispersion in the fiber, which greatly increases the resiliency of the transmitted signals to chromatic dispersion and polarization mode dispersion. Alternative, lower-cost modulation schemes are also used for metro deployments. Figure 3 shows a high-level diagram of DP-QPSK modulation. The transmitter generates two independent optical QPSK signals, each with four different optical phases, which are combined in two orthogonal polarization states. This results in a signal where the baud rate is a quarter of the bit rate.

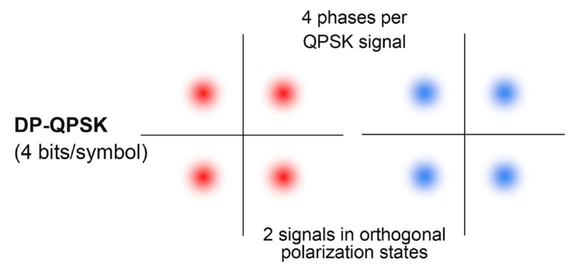

Figure 3. DP-QPSK signal

Client interfaces are interoperable between vendors and provide connectivity into the network. This is the point where test traffic can be inserted for service activation and troubleshooting. With 100 GE transport, the most common interface is 100GBase-LR4, which provides fiber connectivity using 4 multiplexed wavelengths over a maximum distance of 10 km. Each wavelength, spaced by 4.5 nm in the vicinity of 1310 nm, carries roughly 25 G of bandwidth to provide an aggregate of 103.125 G.

The LR4 interface has clearly been the most common telecom interface and this will remain. LR4 optics are available today in the CFP2 and CFP4 form factors, and soon QSFP28, which represents an evolution from the first generation and larger CFP form factor. The client interface offering the longest reach, up to 40 km, is 100GBase-ER4. Due to cost considerations, there are also variants often called ER4-Lite which offer 20 to 25 km of reach. Table 1 summarizes the main IEEE and industry multi-source agreement interfaces for 100 GE based on reach.

Table 1. 100 GE interfaces

Interface	Reach	Medium	Parallelism	Standard
100GBASE-ER4	40 km	SMF	4 λ/dir	802.3ba
ER4-Lite	20-25 km	SMF	4 λ/dir	Variation on 802.3ba
100GBASE-LR4	10 km	SMF	4 λ/dir	802.3ba
CWDM4	2 km	SMF	4 λ/dir	CWDM4 MSA
CLR4	2 km	SMF	4 λ/dir	CLR4 Alli-ance
PSM4	500 m	SMF	4 fibers/dir	PSM4 MSA
SWDM4	~100 m	MMF	4 λ/dir	SWDM Alliance
100GBASE-SR4	70 m 100 m	OM3 MMF OM4 MMF	4 fibers/dir	802.3bm
100GBASE-SR10	100 m 125 m	OM3 MMF OM4 MMF	10 fibers/dir	802.3ba

The key evolution currently underway is to adapt 100 GE connectivity to the requirements of data centers. The most common higher-speed datacenter interface has so far been 40 GE on QSFP+, in part due to cost considerations. The key change taking place is to evolve 100 GE to provide more client interface choices. As client interface cost is linked to distance requirements, several interfaces are becoming available for data centers, mainly on QSFP28 optics. To bridge the gap between the 100 m reach offered by 100GBase-SR10 and 100GBase-LR4, several intermediate reaches have been developed, mainly by industry alliance groups. These interfaces take the form of CWDM4 and CLR4 at 2 km, PSM4 at 500 m, and the IEEE 100GBase-SR4 at around 100 m. The 100GBase-SR4 interface is set to replace 100GBase-SR10 as it is based on the same core 25 G-per-lane technology used by all other interface types. From a test standpoint, adaptability to be able to support these different interface types is an important consideration.

Line-Side Testing

Line-side testing refers to analyzing the parameters related to the optical signal and the fiber optics medium. When it comes to dispersion testing, a higher line rate such as 100 G implies a higher level of sensitivity. For chromatic dispersion, the sensitivity grows proportionally to the square of the line rate while polarization mode dispersion grows linearly with the line rate. However, because 100 G systems use coherent detection coupled with high-speed electronic signal processing at the receiver, the signal distortions caused by chromatic and polarization mode dispersion are well mitigated. That means the tolerance of these signals to chromatic and polarization mode dispersion is higher than that of conventionally-detected 10 G or 40 G signals. However, characterization and documentation of the fiber infrastructure for dispersion remains an important step in all system turn ups. This is especially important in WDM systems with mixed data rate signals where 10 G and 40 G signals are multiplexed with 100 G signals through the same optical fiber.

An important parameter to consider when commissioning 100 G line-side links is the optical signal to noise ratio (OSNR) of the signal along the fiber link and in particular at the end of the link. Ensuring that the OSNR of a 100 G signal falls within the tolerance limits is critical in ensuring network operation with a minimal information error rate. The classic method to determine OSNR is to compare signal power to the extrapolated noise level measured within the same WDM channel. However, because high-speed 100 G modulation broadens the signal beyond the 50 GHz width of each WDM channel, it is not possible to read and extrapolate the noise value.

In addition, the other main in-service OSNR measurement technique, called polarization nulling, can only be used on single-polarization signals which are not used at 100 G. With DP-QPSK modulation, separating the dual polarization states to extract the signal prevents measuring equipment from obtaining accurate noise information to determine the OSNR. At this time, measuring OSNR either implies obtaining noise information from a neighboring channel, which introduces inaccuracies, or measuring OSNR using an out-of-service on-off technique. Research is underway to derive an effective in-band OSNR measurement method for DP-QPSK signals.

Network Testing with Traffic

The basis of 100 GE client interface activation testing involves the generation and analysis of traffic while monitoring alarms and errors. To run network tests, the typical approach is to use a test suite which simplifies and automates execution. IETF RFC 2544 and ITU-T Y.1564 define the most-common traffic service activation test suites. These test suites are often run with a logical loopback at the far end of the network, although it is also possible to use dual uni-directional connectivity with test units at each end. A far-end loopback may take the form of a hard loop, typically a fiber optics patch cord, with configurations involving pure Layer 1 transmission networks. When Layer 2 or 3 functions are present, namely Ethernet switching or routing, the far-end loopback must be a logical function where Layer 2 and/or Layer 3 source and destination addresses are swapped to prevent routing loops.

The choice in using RFC 2544 or Y.1564 depends on the nature of the activation test or on the existing procedures used by the commissioning team. RFC 2544 is a well-established method which includes tests for throughput, latency, frame loss rate, and bursting. It is generally accepted and expected that although outside of the recommendation, a packet jitter test is added. The main role fulfilled by RFC 2544 is to help activate a new link or a single service. The execution time of RFC 2544 test suites actually depends on specific implementations; optimizations are possible to increase the speed and efficiency of this test. Viavi Solutions® has optimized its enhanced RFC 2544 suite to reduce overall test time.

The focus of ITU-T Y.1564 primarily is on service activation for connections differentiated by varying classes of service or for multiple services concurrently. A Y.1564 automated test suite simulates connections as traffic streams characterized by network addresses, priority levels, and bandwidth parameters. Y.1564 focuses on three key performance indicators (KPIs) that provide metrics in the form of frame loss rate (FLR), frame delay (FD, latency), and frame delay variation (FDV, packet jitter). The service performance tests from Y.1564 are well-suited to service level agreement (SLA) testing by verifying each stream against its bandwidth profile. Such profiles always include committed information rate (CIR), with the possibility of extended tests for excess information rate (EIR) parameters and committed burst size (CBS). The Viavi Y.1564 test suite is called SAMComplete. Table 2 provides a high-level summary comparison of RFC 2544 and Y.1564.

Table 2. RFC 2544 and Y.1564 test suites

	RFC 2544	Y.1564
Main 100GE Application	Turn up new backbone link or single end-to-end connection	Turn up Ethernet connection(s) or service(s) in the core
Parameters Measured/ Validated	Throughput Latency Frame loss rate Bustability (Extra: CBS) Extra: packet jitter	FLR Latency: FD Packet jitter: FDV CIR EIR Traffic policing CBS
Key Focus	Test one stream (address pair); identify maximum performance	Test one or multiple service, validate frame transfer performance including against SLA parameters

An important item to consider as part of RFC 2544 and Y.1564 is the accuracy and resolution of latency measurements. Accuracy refers to how close a measurement is to the true value, and resolution refers to the level of information provided, for instance 100 ns or 0.01 μs resolution. To accurately correlate fiber length to latency requires both high resolution and accuracy. This correlation is important, especially when supporting end customers involved in applications such as high-frequency trading (HFT) in the financial sector or time-sensitive wireless services. At 103.125 G, the actual 100 GE rate, it takes 100 ns to assemble and transmit a 1289 byte frame, providing frame-level latency accuracy is within the reach of current technology.

The purpose of service activation testing is to ensure service quality. When identifying problems, the key question is what to do next. Just as with slower speeds, typical sources of errors remain dirty fibers and configuration issues. When it comes to fiber cleanliness, the need to inspect before you connect only grows at 100 GE due to tighter signal power tolerances. However, because pluggable optics have increased in complexity at 100 G, an important troubleshooting consideration is to be able to validate the performance of such pluggable optics. As a result, Viavi has developed a unique automated test suite, called optics self-test, to validate the field performance of high-speed optics. The key concept is to troubleshoot optics found in network devices and ensure that the relevant performance parameters meet the required quality thresholds. A common misconception is the use or inclusion of skew testing to evaluate optics performance. Because pluggable optics do not buffer information, skew testing should instead be used in lab testing of systems or line cards. The main parameters to evaluate the field performance of pluggable optics center around BER evaluation, tolerance to clocking variations, and optical level parameters.

An additional recommended procedure for service activation is Layer 2 transparency testing. In Ethernet networks, where there are elements of switching, this test can eliminate long and arduous troubleshooting. Ethernet switches generate a relatively small amount of traffic destined for other switches called the control plane. When providing bandwidth services in a network, the idea is to ensure that all control-plane protocols will be tunneled, peered, or discarded as per MEF 6.1.1. Layer 2 control-plane protocols are identified by their protocol type from the Ethertype and subtype fields or logical link control (LLC) code. Examples of such protocols include spanning tree protocol (STP) and link layer discovery protocol (LLDP). An effective method to run this type of test is to emulate these control plane protocols in the network while making sure that corresponding frames do not get improperly intercepted or modified. An additional application example for Layer 2 transparency tests is when an operator provides bandwidth services that traverse a third-party network. The Viavi tool to test Layer 2 transparency is called J-Proof.

The Optical Transport Network (OTN)

The evolution to 100 G networks is promoting the deployment of a greater number of OTN ports. The OTN was created more than a decade ago with the primary purpose of carrying SONET/SDH clients over long distances. It features a forward error correction (FEC) algorithm associated with each OTN frame that helps extend the distance between terminating nodes. The main standard, ITU-T G.709, has evolved to accommodate diverse payload clients such as Ethernet, Fibre Channel, and common public radio interface (CPRI); this is where the 100 G, technically 118 G, OTU4 interface is defined.

Most legacy OTN applications, in particular digital wrappers where a client signal is wrapped in OTN, apply to line-side ports where test-traffic generation is often not achievable due to interface compatibility issues. These arise on line-side ports for two main reasons: the use of vendor-specific advanced modulation techniques and the use of proprietary FEC algorithms. All OTU4 client ports support the generic G.709 RS(255,239) FEC; this is mandated in G.709, thereby providing common interfaces usable as test access points.

Going forward, the main change from a test perspective is that more OTN ports are being deployed as client interfaces for use by business customers. In practice, this takes the form of customer premise devices connected to the core operator network with an OTN link; such devices are equipped with customer-facing Ethernet ports for business customer use. This application, along with cross-operator OTN handoffs, creates requirements for OTN test applications that did not exist previously. Viavi has developed an OTN service activation test suite called OTN Check which assists field technicians with easy-to-use tools to activate OTN services. This is similar to an RFC 2544 service activation suite, but here, the suite tests OTN payload integrity, latency, and message transparency.

Summary

Deployments based on 100 G technology are commonplace in all regions of the world. A significant difference with 100 G compared to 10 and 40 G transport is the use of more complex line-side modulation schemes with coherent detection. Because of the higher transmission rate that lowers tolerances, one of the most important line-side parameter to measure is OSNR. On 100 GE client interfaces, the most significant development taking place is the availability of more diverse interface types providing different reaches, especially for data center applications. The main traffic-based tests on 100 GE remain RFC 2544 and Y.1564 to measure throughput, latency, and packet jitter. Additional considerations on account of increased complexity include pluggable optics troubleshooting and Layer 2 transparency testing. Testing 100 G networks only gains in importance with a constantly increasing amount of mission-critical bandwidth carried in high-speed transport networks.

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