A number of different industry surveys indicate that total internet demand is growing at about 40% per year. This growth is driven mainly by increasing video traffic in the network. As an example, Netflix now takes up to 30% of the internet's bandwidth at peak hours, and new competitors like Amazon, Hulu, You Tube, and Facebook are growing rapidly.

This growth is now further accelerated by OTT mobile access, with video clients shipping on all smart phones and tablets, enabling video to be consumed more conveniently via network connections anywhere, anytime.

While this growth in traffic has resulted in increased revenues for content providers, service providers are not necessarily seeing large increases in their revenue streams. Therefore, it is essential for service providers to maximize the effective utilization of capital costs and maximize the productivity of operational costs. This is a challenge to network operators who are seeing a 50-75% increase in their network use every year.

In order to address this traffic growth, today's network operators need to carefully examine their network's optical components for efficiency gains. The two key issues for any change in optical components are optical capacity and reach. Coherent optical transmission increases both the reach and capacity of fiber networks, eliminating bulky and expensive optical dispersion compensation equipment while simplifying network management for network operators. This allows network operators to deploy flexible networks that can be scaled to 100G and beyond in an easy and cost effective way. Telecom Review recently spoke with Serge Melle, Infinera's Vice President of Solutions Marketing in order to get a good perspective on advancements in optical networking that will help network operators address their increasing network demands.
Optical Transport Network

Most service providers would agree that current and future optical transport services can be most efficiently supported over Optical Transport Network (OTN) architecture. The OTN standards have been evolving within the ITU since the early 90s, and most recently have been completely revised with respect to a standards-based transport for Carrier Ethernet services at all data rates. Infinera’s OTN architecture is based on a solid foundation of core OTN switching, plus a modern set of client interfaces on all the Infinera transmission platforms that offer a true, any to any, end to end OTN capability.

The key features of “Digital OTN” architecture include:

• Switched OTN Operation in the Core

• End to End Digital OTN

• Any Service, Minimal Hardware

• Integrated End to End Management

OTN Modulation

Remembering that reach is a key issue for optical networks, one issue with 10G, and larger, network modulation is that the transport spectrum is wider than for 2.5G, while the bit period is shorter, which makes chromatic dispersion (CD) a more significant factor for 10G and higher transport than for 2.5G. Depending on the transport distances encountered, it is common to use dispersion compensation at regular intervals along the fiber path to mitigate the effect of CD on 10G transport.
Most DWDM vendors are using higher order coherent modulation methods for 40G and 100G wave transport, which effectively reduces the symbol rate while increasing the bit rate, and thus minimizes the negative impact of these impairments. Higher order coherent modulation also is spectrally more efficient, which means the information capacity of the fiber is improved as well.

There are many higher order modulation formats which can be used for optical transport, but the most commonly used today rely on some form of coherent phase shift keying (PSK) to translate bits into optical phase states for transport across the network. The Infinera Digital ROADM architecture has always supported ODU1 switching and sub-wavelength grooming in the core network. This capability eliminates wavelength blocking, reduces the bandwidth inefficiency that comes when using point-to-point muxponders, and enables an end to end GMPLS control plane to automate service provisioning and reconfiguration.

Most DWDM transport equipment uses QPSK modulation for 40G and 100G transport waves. While QPSK is roughly twice the complexity of BPSK and requires about twice as many components to implement, it represents a good tradeoff between spectral efficiency and OSNR performance. For even better performance, polarization multiplexed QPSK (PM-QPSK) is typically used, though at the expense of greater complexity and increased component count.

Further transmission performance enhancements can be achieved if coherent detection is used at the receiver. In differential QPSK (DQPSK), detection is performed by measuring changes in the phase of the received signal rather than the absolute phase itself. Because a copy of the originating reference signal is not required, DQPSK receivers are much simpler to implement. However, DQPSK receivers provide a lower level of performance which translates into higher BER or shorter reach when compared to coherently detected QPSK. This difference is usually sufficient to justify the use of coherent detection, and the Optical Internetworking Forum (OIF) has standardized on coherent PM-QPSK for 100G wave transport. The impact of these capabilities is that far more of the transmission capacity in the core network can be used for revenue-generating services, while new services can be brought up far more quickly compared to a traditional, all-optical network.

### 40G-100G ROADM

Networks that can be turned up in days, services that can be activated in minutes and a pool of bandwidth that is always available on demand for any service from 155 Mb/s to 100 Gb/s are three simple reasons why many network operators continue to rely on the Infinera DTN Digital
ROADM. The Infinera DTN remains the first platform in the world to combine the scalability of optics with the simplicity of digital networking to deliver the world’s first WDM platform that includes a fully integrated, non-blocking, Colorless, Directionless and Contentionless Reconfigurable Optical Add/Drop Mux (CDC ROADM). Designed with Infinera’s large scale Photonic Integrated Circuit (PIC) and an integrated OTN switch, the Infinera DTN converts the network capacity into a pool of resources that can be tapped on demand. The DTN employs pluggable 100Gb/s DWDM line cards, called Digital Line Modules (DLMs), facilitating rapid automated turn-up of DWDM capacity, 100Gb/s at a time. The DLM provides full retiming, reshaping, regeneration, and recoding services for each optical wavelength. It also provides integrated sub-wavelength electronic grooming and switching capabilities for unconstrained and reconfigurable add, drop, and express of capacity through the node. The DLM also isolates all analog impairments from adjacent spans to eliminate wavelength blocking and simplify network planning. Together, these capabilities help provide more flexibility and manageability than other traditional DWDM or analog ROADM systems.

100G Waves and the “Muxponder Tax”

100G waves are needed in the network core to support an increase in bandwidth per fiber from between 800G to 1.6Terabits using 10G waves, to about 8Terabits using 100G waves. But a close look at the services being carried by those 100G waves in other words at the individual circuits being carried over the bandwidth created by 100G wave shows that most services over the next four years will continue to be 10G and below. This is in part due to the phenomenal success of 10GbE in driving down cost per bit of physical interconnect, and is in part due to the highly-meshed nature of many real world networks.

The continued growth of optical backbone bandwidth, driven by video, mobility, and inter-datacenter traffic, means that network operators around the globe are considering 100G transmission technologies. But not all 100G is created equal. Different implementations can have dramatically different implications on network economics. In fact, conventional 100G DWDM technology, implemented in muxponders using numerous discrete optical components, has two significant flaws: the first is a “muxponder tax” which is an inefficient use of network bandwidth which negates some of the bandwidth expanding capabilities of 100G waves. The second is an increase in space and power, and a loss of reliability, which stems from the manual interconnection of numerous discrete optical components used to implement the more complex coherent QPSK modulation.

Conventional DWDM systems carry 10G and smaller services over 100G waves using muxponders. Muxponders multiplex ten 10G signals into 100G wavelengths, effectively binding
them together, such that all services must share the same end points as the muxponder wavelength. This architecture is efficient for simple point to point networks, but in real world mesh networks, muxponders tend to strand bits of bandwidth as the network grows. The portion that is stranded can be termed a "muxponder tax" because it represents excess cost which does not tie to new revenue so it is effectively an economic loss inside the network. The size of the tax depends on network topology and traffic load, but it is easy to model realistic networks which incur a tax of nearly 50%! In other words, some muxponder-based networks, engineered for 8T per fiber using 100G, will only achieve 4T per fiber of useful bandwidth, while the other 4T is wasted to the muxponder tax.

Infinera’s Digital ROADM implementation, which takes advantage of their unique “Bandwidth Virtualization” architecture and integrated OTN switching to maximize fill on every wavelength, eliminates the “muxponder tax” because they don’t use muxponders. Instead, services benefit from OTN-based switching and grooming throughout the core to get maximum efficiency out of 100G waves.

**Photonic Integrated Circuit Based 100G**

In addition to bandwidth efficiency, Infinera’s Photonic Integrated Circuit (PIC) based implementation of 100G also results in space and power efficiency, plus excellent reliability. Some service providers can realize a 30-40% reduction in footprint and a 50% power savings. Infinera’s new 5x100G PM-QPSK photonic integrated circuits include around 600 optical functions on two small chips, a transmitter and receiver. When packaged, these allow the implementation of 500G super-channel transmitter and receiver modules which are about the size of an iPhone.

This represents a dramatic improvement in density compared to conventional discrete components. At the same time, photonic integration eliminates hundreds of fiber couplings between chips. Fiber couplings are the number one cause of failure in optical components, and by eliminating these potential failure points, Infinera’s PICs bring optical layer reliability to a new level. Infinera’s first generation photonic integrated circuits, first shipped commercially in 2005, have now logged well over 650 million hours of operation in the field, without a single PIC failure.
Beyond 100G

With network demand increasing at about 40% per year, this is one of the most pressing questions that service providers face today. New solutions are needed to allow them to break the link between capacity and OpEx, and ultimately help them to be profitable.

A super-channel is an evolution in DWDM in which several optical carriers are combined to create a composite signal of the desired capacity. A super-channel is a set of DWDM wavelengths generated from the same optical line card, brought into service in one operational cycle, and whose capacity can be combined into a higher-data-rate aggregate channel.

The technology addresses three critical aspects of network scale:

- **Operational Scaling.** In the face of ever-increasing internet demand, service providers need to be operating with larger units of DWDM capacity - and yet still be able to drive an optical signal across long haul, ultra long haul or even submarine distances.

- **Fiber Capacity Scaling.** Optical fiber is the most expensive resource in the transport network, and service providers have to be able to support the maximum volume of revenue-generating services over their existing fiber assets.

- **Supporting Next Generation Services.** 100Gb Ethernet standards were ratified in 2010, and the next step forward in Ethernet speeds will probably be in 2016 or 2017. But service providers need to be sure that the networks they design today will be capable of supporting both today’s services and the next generation’s with equal efficiency.
Infinera has now unveiled the DTN-X, the first multi-terabit packet-optical transport (P-OTN) network platform based on groundbreaking 500 Gb/s Photonic Integrated Circuits (PICs), and designed for global service providers facing increasing demands for bandwidth driven by video, mobile and cloud-based services. The DTN-X is purpose-built to integrate switching with DWDM without trade-offs in capacity.

The architecture of the DTN-X extends the ease of use and reliability of Infinera’s successful DTN in a new multi-terabit platform that scales for the future, is simple to operate and efficiently reduces the number of elements in the network. The third-generation 500 Gb/s PICs that integrate more than 600 optical functions and deliver the world's first 500 Gb/s long-haul super-channels, providing a foundation for the DTN-X’s superior scale, simplicity and efficiency. Infinera recently tested the fully functioning 500 Gb/s PICs on the production network of SEACOM, demonstrating 500 Gb/s of coherent transmission over a distance of 1,732 km and earlier this year the company presented test results for a 1 Tb/s PIC. Since most end-user services today are 10 Gb/s or less, global operators require integrated ITU G.709 Optical Transport Network (OTN) switching to groom traffic onto larger 100 Gb/s and 500 Gb/s pipes to maximize network utilization. The DTN-X will deliver 5 Tb/s of non-blocking OTN switching in a single bay, and in subsequent releases will be upgradeable to resilient multi-bay configurations providing 100 Tb/s of non-blocking OTN and MPLS switching. Unlike competitive offerings where integrating DWDM with switching was an afterthought, the DTN-X is designed from the ground up to combine three unique technology building blocks – PICs, custom switching ASICs and intelligent GMPLS software enabling the DTN-X platform to be flexibly configured with up to 5 Tb/s of DWDM or service interfaces in each bay, or any combination of the two, without any loss of capacity.

While the Infinera Digital Optical Network has always been scalable, simple and efficient, the combination of the 500 Gb/s PICs and integrated switching will allow the DTN-X to deliver the following benefits to global service providers:

**Scale For The Future**

- The DTN-X is designed to help operators confidently face future bandwidth demands by delivering 500 Gb/s super-channels, upgradeable to 1 Tb/s super-channels yielding up to 24 Tb/s per fiber in the future. Initially the DTN-X will offer 5 Tb/s of OTN switching capacity, upgradeable in the future to 100 Tb/s. For example, a fully-equipped DTN-X is planned to have enough capacity to stream a movie to each of Netflix’s 23.6 million members simultaneously.
• Simple To Operate For Rapid Service Deployment

– The DTN-X is designed to converge layers of the network and support DWDM transmission, OTN switching and in the future MPLS switching in a single platform. The all-digital architecture, point-and-click automation and intelligent GMPLS software are designed to enable global service providers to rapidly deploy network capacity while lowering operational costs.

• Efficiency for the Bottom Line – The disruptive nature of Infinera’s 500 Gb/s PIC will enable the DTN-X to consume 33% less space and 50% less power than alternatives in a typical configuration.

DTN-X Availability

Infinera is introducing a DTN-X full-rack, multi-bay-ready chassis and a half-rack chassis, both of which are planned for availability in the first half of 2012. The DTN-X is interoperable with the DTN platform and is planned to support 10 Gigabit Ethernet (10 GbE), 40 Gigabit Ethernet (40 GbE), 100 Gigabit Ethernet (100 GbE), 10 Gb/s SONET/SDH/OTN, 40 Gb/s SONET/SDH/OTN, 100 Gb/s OTN, 8/10 Gb/s Fiber Channel, and multiple bit rate clear-channel interfaces.

Optical Transport Networks for the Future

As the industry migrates to terabit optical transport, there will be an ever-increasing need to squeeze more bandwidth from fiber and yet to retain flexibility on how that bandwidth is used. Modulation formats will continue to evolve, with 8QAM and 16QAM being next in line for extending transport bandwidth. At the same time, it is desirable to retain the flexibility to support multiple modulation formats on the same fiber, which will allow seamless migration to higher bandwidth and allow suitable tradeoffs to be made for optical reach versus total fiber capacity.

Serge did see 100G as the next “mass market” line rate and predicted wide spread adoption in 2012 and 2013. Infinera has already trialed a terabit of super-channel capacity being transmitted over a production DWDM fiber link between San Jose and San Diego on the TeliaSonera network last November. The TeliaSonera trial used twin pre-production 500G
coherent long-haul super-channel line cards, using large-scale PIC technology. Turning up this 1 Tbps of capacity took two operational cycles, one for each 500 Gbps of capacity.

This trial compares much more favorably to the “multiple rack” implementation that’s typical for a discrete-component super-channel demonstration requiring 10 line cards of 100 Gbps of capacity. The trials have been completed so the terabit super channels could very well be the next “standard” in the next four years so one can say that optical technology will certainly continue to improve and evolve for the explosion of transport needs today and tomorrow.