PACKET-OPTICAL TECHNOLOGY

INFINERA'S PACKET-OPTICAL TECHNOLOGY

Introduction

Packet-optical networks have boomed in recent years, driven by the well-documented traffic growth in many sectors of the telecom market and the migration to Ethernet-based services. Vendors have taken various approaches to address this packet-optical evolution, with different technologies being deployed at different places in the network, each offering different advantages to the network operator. Infinera was an early adopter in this transition to packet, bringing Layer 2 Ethernet functionality directly into metro and regional optical networks. Infinera's packet-optical technology is deployed by a wide variety of network operators for a broad range of applications. With the belief that standards-based implementations bring the best value, Infinera is committed to continuing development and investment in this architecture. Developments such as Carrier Ethernet 2.0 (CE 2.0) from the Metro Ethernet Forum (MEF) have led to a step change in the level of functionality available from packet-optical. Infinera's packet-optical technology combines the best of the optical and Ethernet worlds to deliver full-functioned, end-to-end packet-optical capability from access to the long-haul core.

Definitions and Layer Terminology

Figure 1 shows the traditional Open Systems Interconnect (OSI) model layers, including more recent "additional layer" terminology, and a brief definition of each layer.

Different types of devices that can be deployed in the transport network to support packet-optical services, so it is important to understand exactly what an optimized "packet-optical" device is and is not. IHS Markit is one of the leading analyst firms in this subject area, and their definition of a packet-optical transport system for the metro edge can be summarized as:

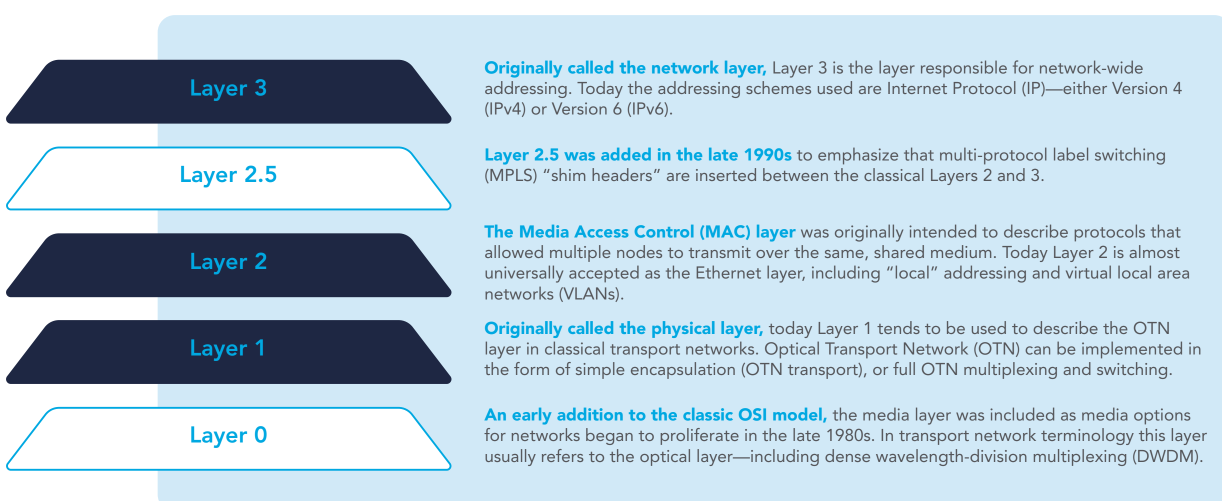

Figure 1: The Original (Blue Rectangle) and Enhanced (White Rectangle) Layers of the Open System Interconnection (OSI) Model.

> ***"Optical equipment designed and used for hybrid circuit and packet based transport […] capable of OSI layers 0-2 […including] layer 2 switching features."***

Within this definition, the role of OTN is ambiguous – should it be used for full-service multiplexing and switching, or is OTN transport sufficient? Given that packet technologies – and particularly Ethernet – are so dominant in the metro edge, IHS concedes that the role of OTN for a metro edge packet-optical platform should be limited to service encapsulation and transport.

Key Drivers for Packet-Optical

The market demands specific service providers' strategies, which in turn may require an architectural shift. This process must begin with a clear vision of the ultimate benefits derived from that shift. In the case of packet-optical in the metro, there is a rapidly increasing demand for the number and type of packet services, while existing packet services are simultaneously being driven to higher data rates, such as the move from 10 Gigabit Ethernet (GbE) to 100GbE. The best strategy to deal with this demand is to treat packet as an end-to-end service, with packet switching support at all points in the network architecture, from access through aggregation, metro core and even long-haul core. This end-to-end approach allows network operators to optimize the balance of investment in high-cost platforms, such as core routers, with lower-cost transport platforms, such as CE switches. At the same time, the wider trend of network functions virtualization (NFV) is creating "cloud scale" shifts in demand that make it essential to be able to balance and rebalance network platform investment as smoothly as possible.

Infinera refers to the set of dynamics within the cloud as Layer C, the cloud services layer, while the underlying dynamic transport network is referred to as Layer T. The more intelligence that can be designed into Layer T, the better-matched investment can be to support changes in demand. The end result becomes a service-agile architecture that actually lowers operational costs through high levels of automation. By closely matching network capacity to service demand, capital expenditure (CapEx) can be optimized through the reduction of fibers, modules, and entire boxes in the network.

In the metro edge, therefore, the most important aspect of the above definition for packet-optical platforms is that the inclusion of Layers 0 to 2 in a single platform allows network operators to transition features and services from one layer to another as the evolution of network service requirements continues to evolve. For example, if a given network operator has a business strategy of migrating services from pure Layer 1 to a Layer 2 portfolio mix, then the ability to seamlessly move these services within the same platform and management system is extremely important. Another example in which an integrated platform would be essential would include the need to support both pure, point-to-point services and a variety of multipoint packet services within the same network infrastructure.

Application Areas

There are several well-characterized application areas for packet-optical solutions that start out at the edge of the network and continue in toward the core. These include:

- Mobile backhaul
- Mobile fronthaul
- Business Ethernet
- Broadband/multiple-system operator (MSO) backhaul
- Packet-optimized transport network

Mobile backhaul networks are experiencing dramatic growth as demand for high-resolution video and other high-capacity data services to mobile devices continues to drive technology evolution from 2G to 2.5G, to 3G, 4G and now 4.5G and 5G, with all of these being generations within the Group System for Mobile (GSM) cellular communication standards group's mobile communication standards. Each step of this evolution delivers a dramatic increase in capacity to the mobile terminal and, in turn, places increasing demands on the network infrastructure that carries this data.

A new trend in mobile networks as tower densities must increase is the idea of "tower sharing," in which multiple mobile network operators agree to share radio masts in order to maximize their own network coverage. While the masts themselves may be shared, the data streams from them have to be carried through the backhaul as separate mobile network provider information so that it can be carried to, and terminated on, separate mobile gateways.

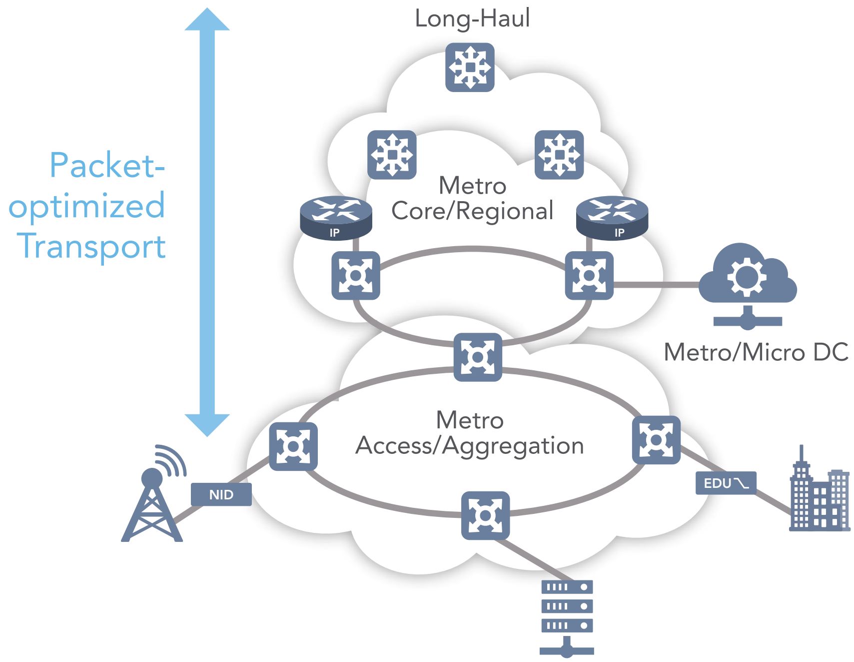

Figure 2: The Classic Application Areas for Packet-Optical Services: Mobile, Cable/MSO, Business Ethernet and the End-to-end, Packet-optimized Transport Network

At the same time, there are increasingly stringent sync requirements driven by each successive generation of GSM, with the 5G standards body proposing a hundredfold reduction in round trip latency versus 4G. These networks are almost entirely packet-based, and thus there is a specific need for a combination of low-latency DWDM coupled with a low-latency packet forwarding data plane.

Mobile fronthaul is a relatively new architecture for next-generation networks beyond the initial 4G architecture, and is designed to allow mobile operators to migrate small cell and micro cell networks to an architecture known as a cloud radio access network (C-RAN). Initial implementations of fronthaul are analog-based, but these will evolve in time to 5G networks with Ethernet transmission out to the radio tower. Please refer to Infinera's application note "Enabling Cloud-RAN with Mobile Fronthaul" for more information.

Business Ethernet services may have multiple requirements, including low latency, simple service provisioning and cost-effective service protection. A key requirement is to comply with, and be certified for, standard service interfaces such as CE 2.0 services, and the availability of self-installing customer premises devices to reduce the cost of service activation and allow operational scaling as the number of customers rises.

Broadband/MSO backhaul network operators are also experiencing massive growth in demand, driven by dramatic improvements in video resolution from standard definition to high definition and now 4K video streams. Many of these network operators are also faced with the need to support other kinds of markets and services, including enterprise users and mobile backhaul. For this reason, an integrated platform that allows optimized service delivery for all kinds of applications is extremely important.

Packet-optimized transport networks operate from the metro core, extending end to end across long-haul and subsea backbones. A key function in this part of the network is service aggregation, and the long-term trend is toward Layer 2, 2.5, and sometimes Layer 3 as the service aggregation technology. At the same time, there has been a long-term migration away from legacy Synchronous Optical Networking (SONET)/Synchronous Digital Hierarchy (SDH) service interfaces, transport and multiplexing. OTN has historically been used as a means of legacy migration because of its support for SONET/SDH transport, but solutions now exist to allow legacy services to be transported over a modern packet-optical network, as described below.

According to IHS reports, this part of the network is experiencing an even faster transition to packet services than access and metro networks. A key requirement here is to provide an efficient on-ramp from the packet-dominated world of metro into the OTN-dominated world of the long-haul core. Network architects must be given free choice of where the operational boundary between packet and OTN is made, and not be forced down a particular technical route because of the limitations of the solution.

End-to-end Packet-Optical Technology

As part of an end-to-end portfolio for transport networks, Infinera's packet-optical technology solution focuses on three specific key values:

- Transport optimization
- Service agility
- End-to-end programmability

Transport-optimized platforms not only comply with the original definition of a packet-optical transport system (P-OTS) by integrating Layers 0/1/2 and 2.5 (i.e. multi-protocol label switching – transport profile [MPLS-TP]) into a single platform, but they also operate on a "transport network philosophy" with features such as industry-leading levels of density and power consumption. Application-specific features can be implemented to deliver extremely low latency, superior synchronization, and integrated OTN for transport, multiplexing, switching and service protection.

Service agility is a vital capability in the packet world because one of the key reasons for moving to a Layer 2 solution is to enable faster service creation and more flexibility to respond to changes in demand. Standard service support must include CE 2.0 and MPLS-TP, but also should offer flexible options to allow network operators to support legacy time-division multiplexing (TDM) services over the packet-optical platform. The goal of this migration to packet would be a much more efficient use of network resources while offering the service mix that customers are demanding.

End-to-end programmability is a capability that delivers a more rapid response to changing demands, and ultimately lowers the operational cost for the packet-optical network. A key trend is the movement toward a software-defined network (SDN) architecture for end-to-end service provisioning, and this capability is part of Infinera's Xceed Software Suite.

Packet-Optical Solution Building Blocks

Figure 4 shows the building blocks of Infinera's packet-optical technology, and how they can be matched to the location of that unit in the network and the network operator's choice of metro architecture.

Working from left to right, the Infinera Network Interface Device (NID) and the range of Ethernet Demarcation Units (EDU) provide a number of plug-and-play customer premise devices for CE service termination/demarcation. The XTM Series chassis options include 1 rack unit (1RU), 3RU and 11RU, with the mix-and-match compatibility of a family of Layer 0, 1, 2 and 2.5 traffic modules that allows right-sized deployments for the metro access as well as metro core.

Packet-optical metro access requires application-specific aggregation interfaces in the form of the EMXP range of packet-optical transport switches, which fit within the XTM Series chassis. The EMXPs support Ethernet data rates from Fast Ethernet through to 100GbE, and

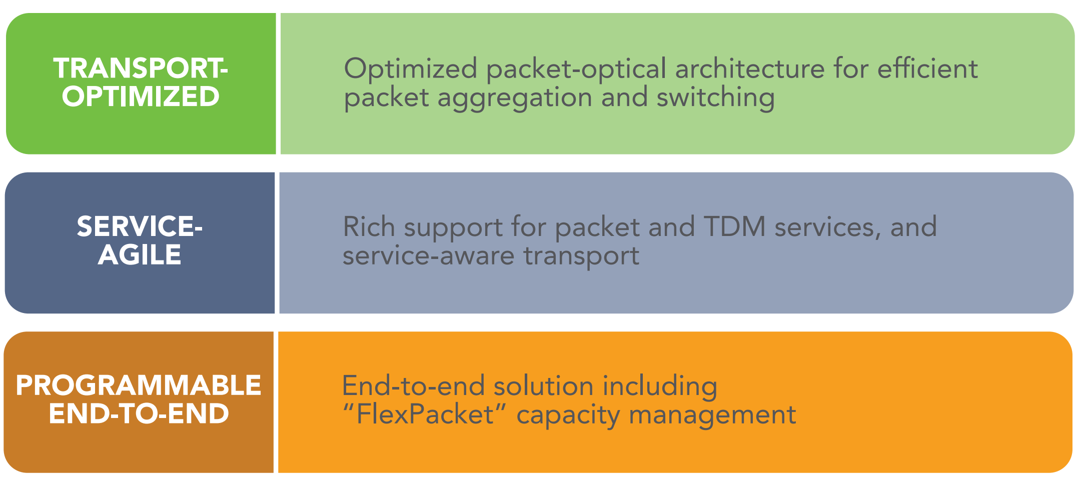

Figure 3: Key Characteristics of the Infinera Packet-Optical Solution

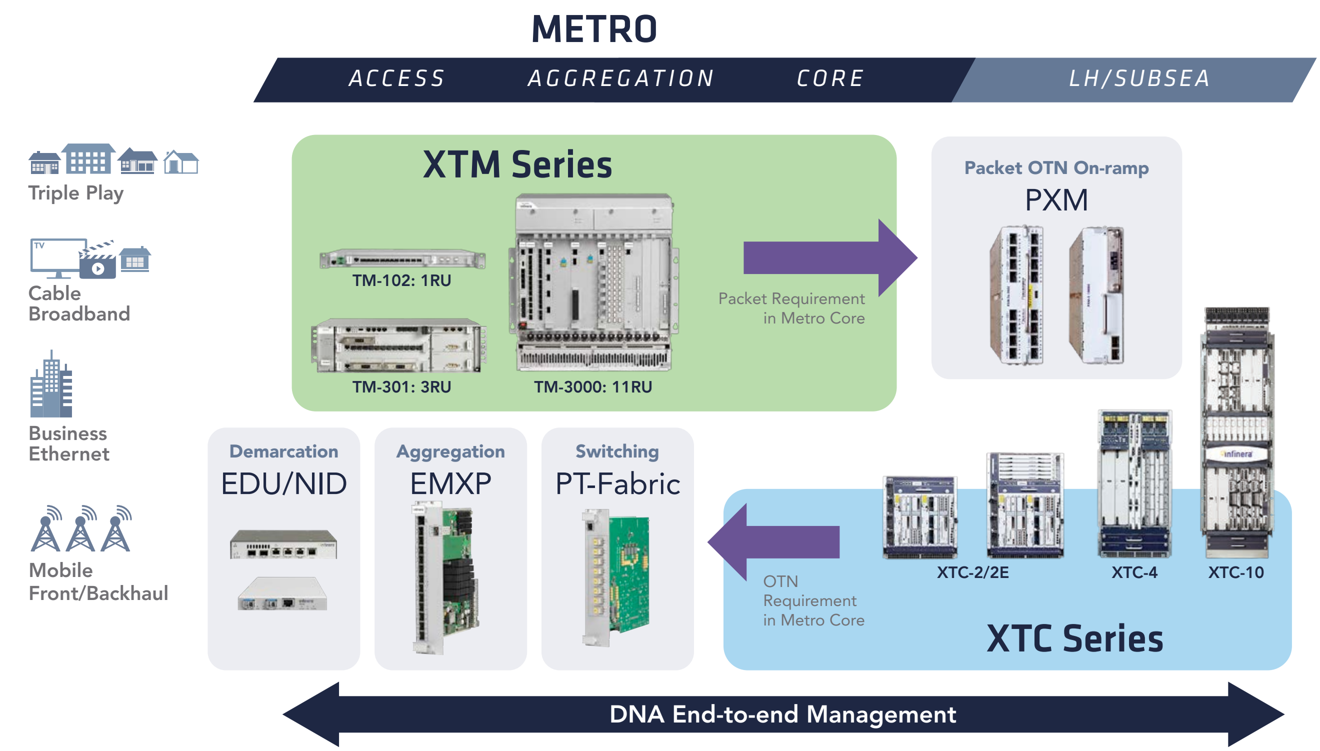

Figure 4: Building Blocks of the Infinera Packet-Optical Solution

include onboard switching with full traffic management for all ports, as well as an extremely low-latency data path. The EMXP allows the creation of CE 2.0 or MPLS-TP services at the edge of the network, and by using special pluggable transceivers it is possible to support legacy TDM services over the packet-optical network. Traffic from the EMXPs is then carried over the metro DWDM network.

At this point the network operator can make an architectural decision. They may prefer to retain a packet management approach through the metro aggregation network and into the metro core at data rates up to 100 gigabits per second (Gb/s). To aggregate and switch traffic at these data rates, the PT-Fabric provides terabit-scale switching, and is located in an XTM Series chassis.

Alternatively, the network operator may wish to push an OTN architecture into the metro core, and to facilitate this the XTC-2/2E chassis can be deployed. This is a member of the DTN-X XTC Series, and provides a carrier-grade transport platform as an on-ramp to the OTN core. The packet switching module for the XTC Series is called the PXM, and is compatible with any of the XTC chassis units (XTC-2/2E, XTC-4, and XTC-10).

Regardless of the balance between packet and OTN, end-to-end management allows full control of the packet-optical network from a single location.

Packet-Optical Technology: Key Advantages

Infinera's packet-optical technology has a number of key advantages. These include:

- High density
- Low power
- OTN on-ramp
- Application optimization
- End-to-end management
- SDN enablement

High density and low power are essential in metro deployments because nodes must often be placed in space- and power-constrained locations. The PT-Fabric supports up to 400 Gb/s of Layer 2/2.5 switched capacity per RU while consuming around 0.17 watts (W) per Gb/s.

OTN on-ramp into the long-haul core offers the cleanest route to end-to-end integration and management of services. While packet technologies are the ideal solution in the metro network, the sheer volume of services being aggregated into the long-haul core demands the use of carrier-grade technologies such as OTN. The XTC Series is designed to integrate high-capacity DWDM with non-blocking OTN switching in a variety of chassis sizes so that the network operator can "right-size" the network more efficiently.

Application-optimization applies to different deployment scenarios, and can include capabilities such as:

- Low latency, low jitter and excellent synchronization for appropriate applications
- Application-aware capabilities, such as switched video transport
- Excellent service support
- Architectural optimization through router offload
- Simplified service deployment

In a mobile transport network and in other networks transporting time-sensitive services, the key requirements include extremely low latency and excellent sync capabilities. The EMXP has an incredibly low latency of 2 microseconds, with near zero jitter. This is a key advantage in latency-sensitive applications because it approaches the performance of a pure Layer 0 transponder, and is actually lower latency than a traditional DWDM muxponder. OTN transport can be switched on for enhanced end-to-end integration, or off to reduce latency (at the cost of reduced reach). The EMXP also has class-leading Synchronous Ethernet (SyncE) capabilities for frequency assurance in mobile networks, and supports the Institute of Electrical and Electronics Engineers (IEEE) 1588 Transparent Clock and Boundary Clock functions for phase assurance.

In video distribution networks, such as those found in MSO and broadband backhaul, transport efficiency is dramatically enhanced by support for Internet Group Management Protocol Version 3 (IGMPv3) and source-specific multicast capabilities. This can remove the need for a high number of expensive routers from the metro edge network, allowing operators to optimize router investments. Infinera's EMXPs also improve network performance with much lower latency and jitter than a router-based solution, which is critical for high-definition video distribution.

Metro networks are driven by the need to support specific service types. Infinera's packet-optical technology is fully CE 2.0-certified, including up to 100GbE data rates. It supports the full range of MEF service types, such as E-Line, E-LAN (local area network), E-Tree and E-Access, with interconnection between operators facilitated by standardized interfaces in E-Access.

MPLS-TP is also supported as an alternative to a pure Layer 2 architecture, providing connection-oriented service transport for

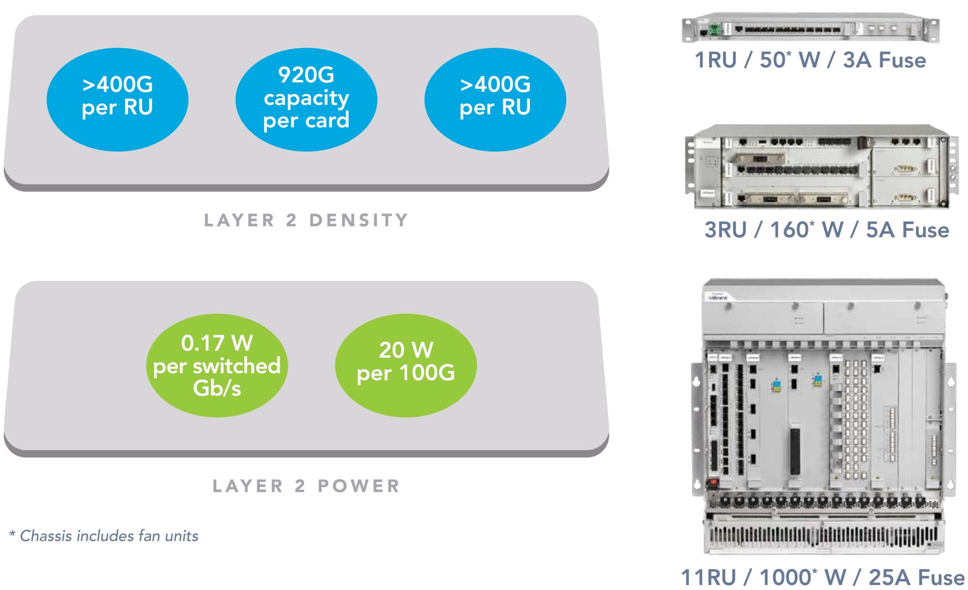

Figure 5: Examples of the Class-leading High Density and Low Power Consumption of Infinera's Packet-Optical Technology

packet-optical networks. Traffic engineering can be used to ensure deterministic service behavior and balance network resources against traffic demands. An additional advantage of MPLS-TP is that service scalability is not limited by Layer 2 VLAN field ranges.

For legacy TDM traffic, Infinera offers the iSFP range of intelligent small form-factor pluggables, offering circuit emulation over packet-optical modules. These allow a network operator to support a set of TDM services over a newer packet infrastructure. Data rates supported include E1, STM-1/OC-3, and STM-4/OC-12.

Simplified deployment is a widely-held requirement, and iAccess is an integral part of Infinera's packet-optical technology solution. In a simple, three-stage process:

1. The user-installable NID operates as a port extension device to the EMXP blade in the packet-optical switch.
2. After the NID is delivered to the customer location, it is plugged into the power and the Ethernet port.
3. Any NIDs attached in this way will then automatically download the configuration from the EMXP.

The key advantage of this process is that the delivery of CE services can be scaled to many thousands of endpoints.

End-to-end management becomes particularly important with the move from simple Layer 0/1 transport networks to more sophisticated packet-optical networks. The corresponding need for flexible optical networking capabilities usually brings with it considerable additional complexity in terms of network management. Infinera addresses this requirement and removes potential complexity using the Digital Network Administrator (DNA). Infinera DNA helps simplify network operations, speed service provisioning, and rapidly isolate problems on multi-layer networks. Other key capabilities include the consolidation and centralization of network management information from across multiple network layers for use within the Network Operations Center (NOC), including equipment inventory, alarms and event notifications, circuit and endpoint inventory, and historical performance data. With a bird's-eye view of the network, Infinera DNA facilitates the coordination of a number of administrative tasks over multiple network elements and across Layers 0 to 2.5, presenting users with intuitive graphical interfaces to ease workflow activities, speed fault isolation and root cause identification, and reduce overall operating expenses.

SDN enablement is vital as the world moves toward this exciting new management approach. With the most programmable transport data plane in the industry, Infinera is well-placed to deliver end-to-end SDN control of this network, integrating the planning and provisioning of packet-optical capacity from the megabit range to the terabit range. The key advantages that SDN control brings include the option for multi-layer path computation, customer-driven development of network features within an open software environment and multi-vendor, multi-domain service provisioning, all with the goal of enhancing network efficiency, lowering operational costs and enhancing service velocity.

While SDN was born in the university campus, over the past five years it has been most widely commercialized inside the data center. Today SDN is moving beyond the data center, being developed as a next-generation control plane for the transport network to solve four critical pain points:

- The dominance of proprietary systems
- Inefficient network utilization
- Inefficient network operations
- Slow service velocity

Infinera's Xceed Software Suite addresses all these issues, and allows SDN to flourish and deliver real value in the Intelligent Transport Network.

Summary

Infinera's packet-optical technology is transport-optimized, service-agile and programmable from end to end. This is achieved by delivering high-density, low-power packet-optical platforms in the metro access and aggregation networks, with these platforms fully integrating Layer 0/1/2 and 2.5 functions. Flexible architectural options are given for the metro core network – either continuing a pure packet strategy into the long-haul core, or implementing a scalable OTN on-ramp. The result is a highly programmable transport network data plane that offers flexible capacity scaling from the megabit range right up into the terabit range and that supports SDN control, allowing open interfaces for customer-driven feature development and integration into a multi-vendor environment.

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