APPLICATION NOTE

MOBILE BACKHAUL

EVOLVING MOBILE BACKHAUL TO SUPPORT LTE-A AND 5G

Over the last decade, wireless networks have undergone a substantial transition due to the rise of smartphone use and more recently the growing number of smart devices in an increasingly connected society. This migration has been underpinned by significant advances in handset and radio access network (RAN) technology, and enabled by major developments in mobile backhaul technology.

Now these same networks need to transition again to enable significantly better transport performance, supporting the evolution to Long Term Evolution Advanced (LTE-A) functionality and eventually 5G. At the same time, they must provide investment protection and avoid unnecessary "rip and replace" of network hardware.

This application note addresses the evolution of mobile backhaul networks that support backhaul of any cell from any location, whether the cell itself, a baseband unit (BBU) hotel or a fibered-up aggregation point where micro/millimeter-wave solutions are used for the last mile.

The Infinera Mobile Backhaul Solution operates on the same Infinera XTM Series platform as the Infinera Mobile Fronthaul Solution, and both are managed via the Infinera Digital Network Administrator (DNA) network management system. The Infinera Mobile Fronthaul Solution, which is designed to enable operators to smoothly evolve to a 5G environment, and the challenges specific to radio access networks that it addresses, are described in a ***separate application note****.*

Network Evolution

Transport networks that support mobile/wireless operators are simultaneously undergoing a number of major transitions.

First, macro cells are effectively becoming a mix of femto/pico/micro/macro cells that work together in a heterogeneous network (HetNet). These cell sites use fiber wherever available, but when fiber is not a viable option, wireless backhaul technology is utilized instead.

Mobile Fronthaul and C-RAN Networks

As transport networks evolve, network operators are evaluating and in some cases starting to deploy mobile fronthaul networks to support centralized radio access networks and ultimately cloud radio access networks (both abbreviated to C-RAN). In these networks, the BBU moves from the cell site to a central BBU hotel location. This creates a new fronthaul network between the BBU and the cell site based on the Common Public Radio Interface (CPRI) or Open Base Station Architecture Initiative (OBSAI) protocols, which are effectively digitized radio frequency (RF) signals.

These networks require fiber-based backhaul of Ethernet traffic from either the cell site or the BBU location, regardless of the last mile technology. The last mile could be the same Ethernet over fiber connection or Ethernet over some other media, such as copper, microwave or mobile fronthaul. As the cell changes from a traditional macro cell to a smaller cell, the requirements for the endpoint of the backhaul service typically become more stringent to meet environmental specifications, such as temperature range support, space and power. However, the connection remains Ethernet over fiber backhaul.

Evolving Mobile Backhaul

Wireless networks are evolving to support LTE-A features such as enhanced inter-cell interference coordination (eICIC), coordinated multipoint (CoMP) and eventually 5G. The underlying transport network must undergo a step change in performance to support the considerably tighter transport performance requirements that result, specifically in the areas of frequency synchronization, phase synchronization and latency performance.

Historically, mobile networks required good quality frequency synchronization, and while this remains important, cells also need phase synchronization and time-of-day timestamps as new features and capabilities are added.

As the performance of these backhaul networks is now even more important than before, performance monitoring capabilities are ever more critical to ensure that service level agreements (SLAs) are met.

This applies both internally within network operators and in wholesale scenarios where a third-party operator provides some or all of the backhaul connection.

Overall, next-generation mobile backhaul solutions intended to support LTE-A need to provide outstanding transport performance and also maintain or improve the cost-per-bit economics of the network.

Building on Infinera's Packet-Optical Technology

The Infinera Mobile Backhaul Solution is built around Infinera's packet-optical technology. This technology combines Layer 2 Ethernet and Layer 2.5 multiprotocol label switching - transport profile (MPLS-TP) technology with Layer 1 wavelength-division multiplexing (WDM) technology in a transport-focused architecture. This approach provides very good performance around key transport parameters such as latency performance and Synchronous Ethernet (SyncE) performance, resulting in frequency synchronization an order of magnitude better than the time-division multiplexing (TDM)-based synchronization previously used in mobile backhaul.

From a services perspective, the solution is Metro Ethernet Forum (MEF) Carrier Ethernet 2.0 (CE2.0)-certified, providing operators with a broad range of standard service options that are interoperable with other networks. Technologies such as Ethernet Ring Protection version 2 (ERPv2), Multi-Chassis Link Aggregation Group (LAG) and ERP over LAG enable a high level of resilience within the network. In addition, all services have high-quality SyncE by default.

Infinera's DNA network management system is designed to provide operators the operational simplicity they need to deliver these services in mobile networks. DNA offers service-aware network management with integrated operations, administration and management (OAM) capabilities and a scalable pay-as-you-grow (PAYG) licensing model.

Infinera's packet-optical technology also provides low power consumption and high density, which further enhance network economics.

HIGH DENSITY DESIGN

LOW POWER DESIGN

Carrier Ethernet 2.0 – Key to Service Delivery

MEF has defined eight different service types within the CE2.0 certification program, and the Infinera Mobile Backhaul Solution fully supports all eight, giving the operator a wide range of service options.

This is of particular relevance to mobile operators evolving their networks, as it provides support for levels of priority traffic as detailed in LTE specifications, such as high priority for streaming video and signaling traffic and lower priority for less time-dependent traffic such as web browsing.

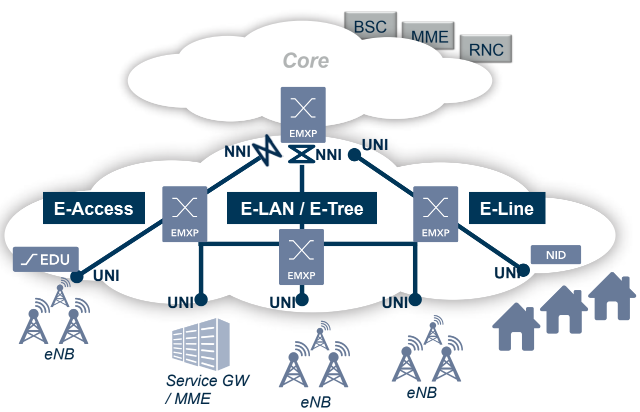


Fig 1. The Infinera Mobile Backhaul Solution Fully Supports CE2.0 Services.

The CE2.0 service definitions also include an E-Access service with a network-to-network interface (NNI) to a user network interface (UNI). This is particularly suitable for local access connections, which are often found in mobile networks in which the last mile is provided by a wholesale operator.

The Importance of Low Latency

Controlling latency is increasingly important as mobile networks migrate from LTE to LTE-A and eventually to 5G.

In the days of TDM-based mobile backhaul, latency was relatively fixed based on fiber/copper and hardware delays that were reasonably constant. As backhaul moved to Ethernet, however, hardware complexity increased, with the potential for higher latency if it was not managed carefully. Also, due to the nature of Layer 2 Ethernet hardware, the variation in latency through the hardware over time also becomes a significant factor, known as jitter.

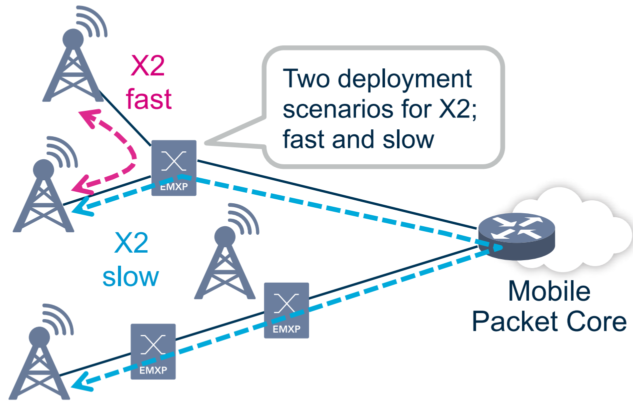


Fig 2. Low Latency in the Mobile Backhaul Solution Makes It Ideal for Transporting X2 Signaling Used in LTE Networks.

Infinera's packet-optical technology is built on the EMXP family of packet-optical transport switches. EMXPs have an output buffer-queued switch architecture, which provides very low, almost fixed latency at around 2 microseconds per node and near zero jitter.

This transport-like performance in packet-optical networks provides an excellent base for good 1588v2 phase synchronization. As networks migrate to LTE-A and beyond and new features are introduced where signaling between cells is essential, this level of performance is increasingly important. These new features, such as CoMP and eICIC, require low-latency backhaul connections and low-latency X2 interface traffic to ensure correct signaling and control.

Moving Mobile Backhaul Closer to the Cell Tower

Mobile backhaul networks will always take advantage of fiber where it exists close to cell towers due to optimal economics. However, availability of fiber does not always mean availability of suitable equipment space for telco-grade hardware, so mobile backhaul solutions need to address the challenge of deployments in street cabinets.

The Infinera Mobile Backhaul Solution includes a hardened access unit option that makes it possible to push high-capacity mobile backhaul deeper into the access network. The EMXP Access Unit provides the same packet-optical and mobile backhaul capabilities as the rest of the EMXP range in a 1 rack unit (1RU), fully self-contained access node. This access unit supports the broader environmental specifications of street cabinets and includes additional features required in access environments such as alarm handling and interface options.

Controlling Additional Costs

Beyond the cost of backhaul hardware, operators must consider the ongoing operational costs of running any mobile backhaul network. Space and electrical power are not only expensive but often a scarce resource in these networks.

To address this, the Infinera Mobile Backhaul Solution provides a high-density solution with industry-leading low power credentials. The solution options range from compact customer-premise equipment (CPE) to metro regional nodes that support aggregation and metro core nodes deeper in the network.

Service OAM in the DNA Portal

Simplified service OAM is a key component in the Mobile Backhaul Solution. It enables operators to activate, monitor and fully manage each aspect of a backhaul service through its lifetime.

Once a service is activated, Y.1731 Performance Monitoring enables the operator to monitor key service parameters such as loss measurements for user traffic, sent/received frames, frame loss ratio, two-way delay and two-way delay variation. Further, the MEF 35 standard allows service availability to be monitored, providing measurements of the number of unavailable seconds and high loss intervals. All these measurements are available via the DNA Portal, which gives network engineers quick access to network performance data and allows wholesale operators to provide such data to end-customers, in this case mobile operators.

Management of Multi-layer Mobile Transport Networks

Infinera DNA enables operators to support multiple applications and network layers across the entire lifecycle of a network in one multi-layer management system. In mobile transport networks, DNA supports Layer 2-based mobile backhaul and Layer 1-based mobile fronthaul seamlessly.

A key characteristic of mobile backhaul networks is the need to create hundreds or thousands of services with the same or similar service parameters, and DNA offers a service template feature to support this. Service templates can speed up service creation to as little as 20 seconds while reducing the risk of errors within service parameters. DNA also provides synchronization management capabilities that are critical in mobile networks.

Mobile Backhaul—It's Packet-Optical in Action

Mobile backhaul is an excellent example of an application in which packet-optical technology enables the step change from old TDM-based backhaul to the higher performance, lower cost and much greater scalability that are now required. Modern packet-optical solutions enable the optimization of IP traffic between cell site gateways and core routers, avoiding unnecessary router hops.

The Infinera Mobile Backhaul Solution supports Ethernet transport for all cell types and all locations regardless of last mile technology, whether CPRI-based fronthaul, distributed antenna systems (DAS),

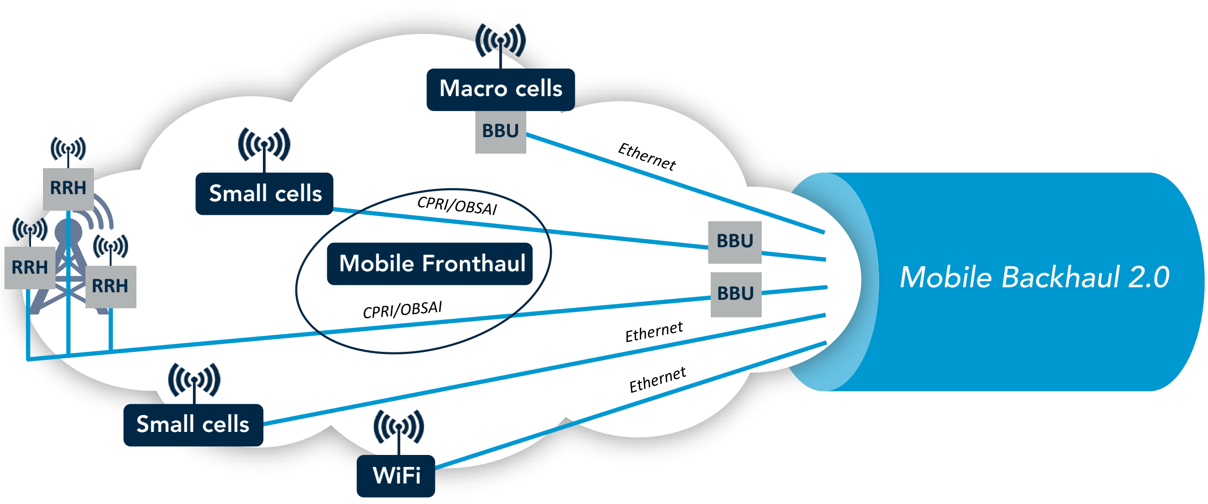


Fig 3. Mobile Backhaul Is Agnostic to Last Mile Technology Used.

fiber-connected small or macro cells, or fiber aggregation points supporting microwave backhaul in non-fiber environments.

Superior Synchronization

Superior synchronization is a cornerstone of the Infinera Mobile Backhaul Solution, providing synchronization capabilities that support demanding requirements for LTE-A and beyond. LTE specifications allow for two basic modes of operation:

- Frequency-division duplex (FDD), in which communications channels use different frequencies
- Time-division duplex (TDD), in which frequencies are shared and individual time slots are used per communications channel

FDD requires only simple frequency synchronization using methods such as SyncE or 1588v2 packet-based synchronization. TDD, however, requires phase synchronization, in which the network needs to understand the phase of the synchronization signal and receive accurate time-of-day timestamps. The more complex LTE-A features, such as CoMP transmission and reception and eICIC, also require phase synchronization.

SUPERIOR SYNC DESIGN

Application	Frequency	Phase
GSM/UMTS/W-CDMA	16 ppb / 50 ppb	None
UMTS / W-CDMA Femtocells	n/a / 250 ppb	None
CDMA2000	16 / 50 ppb	± 3 to 10 μs
TD-SCDMA	16 / 50 ppb	± 1.5 μs
LTE (FDD)	16 / 50 ppb	None
LTE (TDD)	16 / 50 ppb	± 1.5 μs
LTE-A MBSFN	16 / 50 ppb	± 1.5 to 32 μs
LTE-A eICIC	16 / 50 ppb	± 1.5 to 5 μs
LTE-A CoMP (Network MIMO)	16 / 50 ppb	± 1.5 μs to ± 500 ns

Table 1. Frequency and Phase Synchronization Requirements.

Table 1 details the differing levels of frequency and phase synchronization accuracy required by various mobile technologies and applications.

Frequency synchronization is provided through many methods, the most common of which is SyncE. It can also be provided in some regions using a global navigation satellite system (GNSS) method, such as global positioning system (GPS). Regions that use GNSS/GPS may also use those networks as backups in the event of failure or jamming.

Phase synchronization is delivered using 1588v2 precision timing protocol (PTP). There are a number of ways in which good network performance can boost PTP quality within the base station. First, using network elements with low jitter has a positive impact on the quality of the received PTP by reducing errors. Second, networks that support both SyncE and 1588v2 are able to operate in hybrid mode, with SyncE assisting the 1588v2 protocol for a better overall result. In addition, a network that provides 1588 on-path support achieves a better-quality result.

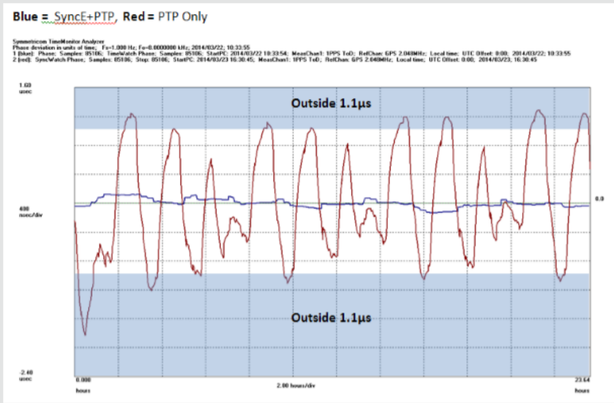
Poor synchronization has a negative impact on network performance, resulting in a less efficient radio interface, poor performance for data traffic and dropped calls.

Network operators spend considerable time and money to achieve good synchronization at all cell sites, and a mobile backhaul network with the best possible synchronization support can produce savings in both areas. Moreover, as mobile networks evolve to support 5G standards, synchronization requirements will get even tighter, and better synchronization performance today will enable networks to support these future requirements more easily.

Infinera's Range of Mobile Backhaul Synchronization Options

The Infinera Mobile Backhaul Solution offers three options to support phase synchronization as required by LTE-A standards:

- Hybrid "SyncE assist" mode to improve 1588v2 phase synchronization performance
- Full on-path support using 1588 transparent clock
- Partial on-path support using 1588 boundary clock



Red line shows 1588 Slave clock phase error, blue line shows EMXPII SyncE assisted 1588 Slave clock phase error

Fig 4. Slave Clock Error for 1588v2 With and Without SyncE Assist.

SyncE Assist

Infinera's range of EMXP units uses SyncE for frequency synchronization with industry-leading performance that improves upon TDM-based synchronization by an order of magnitude or more. In mobile backhaul networks, these units can also be used in hybrid SyncE assist mode to support 1588v2 phase synchronization, greatly improving performance as shown in Figure 4.

Getting 1588v2 phase synchronization to work in real-world mobile backhaul networks can be difficult due to scaling challenges. In large networks, it is difficult to meet the 1.1 microseconds budgeted for mobile backhaul within the total end-to-end budget of 1.5 microseconds.

Adding 1588v2 T-TC Phase Support to All Nodes

Transport of 1588v2 can be further improved by providing telecoms transparent clock (T-TC) support to the mobile backhaul network.

Rather than simply passing the 1588v2 packets through a node as normal data packets, when T-TC capabilities are enabled, a node will apply real-time correction to each 1588v2 packet to compensate for the delay added by the node. As a result, the slave clock at the cell site receives a more accurate timestamp from the 1588v2 packets, thereby providing better phase synchronization to the cell site. This mode of operation is a simple configuration that can interoperate with third-party systems.

Further, as each packet is corrected separately, this method can handle traffic asymmetry, as the flows in each direction are corrected independently. This is important, as the 1588v2 protocol relies on calculating the total round-trip delay across the network. Asymmetrical delays, due to go and return paths being routed differently or delays in individual nodes of a network, can hamper this calculation.

It is possible to avoid selecting differing go/return routes in the management system, in which case T-TC then handles any asymmetry within the nodes, leading to improved 1588v2 performance.

1588v2 T-TC reduces the packet delay variation (PDV) experienced by the eNodeB slave clock. For example, a fully loaded mobile backhaul network with 10 Gb/s links of 10 hops may have a PDV on the order of 16 microseconds, even if constructed from high-quality network elements, because each node adds to the PDV across the network.

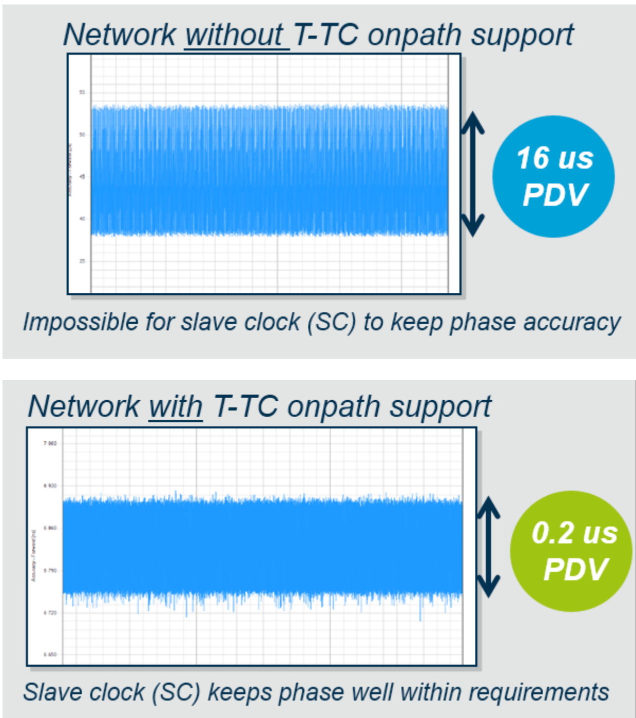


Fig 5. Measurement of Packet Delay Variation (PDV) Without and With T-TC, Showing the Significantly Reduced PDV that T-TC On-path Support Provides.

In this scenario, the eNodeB slave clock will not be able to maintain the time and phase synchronization required by LTE-A, and the phase synchronization runs off exponentially as the PDV increases.

In this 10-hop network, adding 1588v2 T-TC to the mobile backhaul network will bring the PDV experienced by eNodeB down from 16 microseconds to 200 nanoseconds. This allows the resulting phase synchronization error to go from well outside the 1.1 microsecond requirement to around 80 nanoseconds, which is well within the requirement.

All the units in the Infinera EMXP IIe range support T-TC functionality.

Bridging Non-T-TC or SyncE Assist Islands with T-BC

1588v2 T-TC and SyncE assist mode both improve phase synchronization performance. However, mobile backhaul networks are not always built using nodes that support these methods in every network element, and new nodes may need to interact with legacy nodes from multiple vendors.

To support these environments, the Infinera Mobile Backhaul Solution supports 1588v2 telecom boundary clock (T-BC) capabilities. This allows the network to realign the clock and compensate for the wander that builds up in the network.

Using the same 10-hop network as an example, in which every third node is now a T-BC node, the network can absorb errors introduced by non-supporting nodes so that the final clock is within the required specifications.

Bringing It All Together

As today's mobile networks evolve to support the LTE-A and 5G standards of the future, they must meet more stringent synchroni-

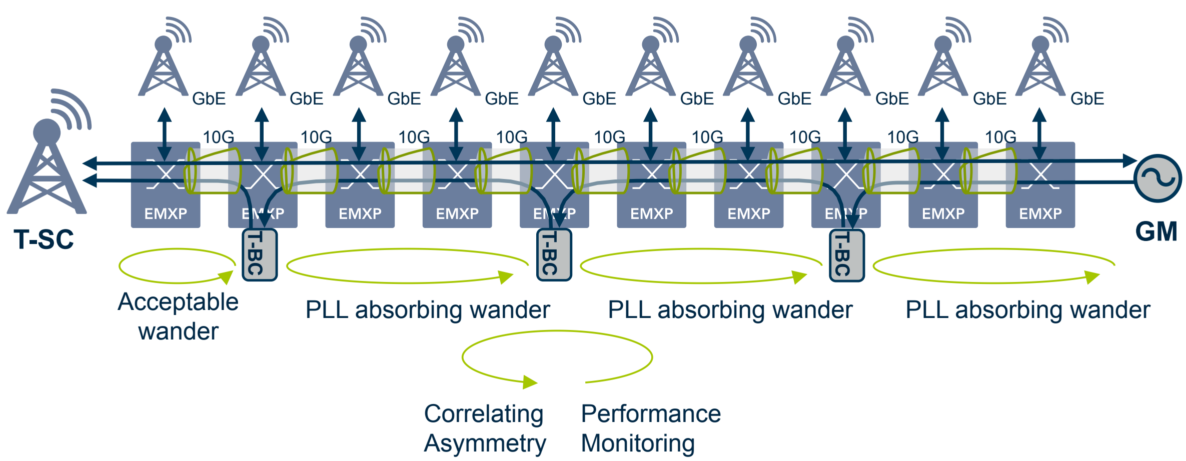


Fig 6. The Infinera T-BC Implementation Reduces Wander Significantly.

zation requirements in mobile backhaul than ever before. Infinera's Mobile Backhaul Solution builds on low-latency SyncE with 1588v2 capabilities, including hybrid 1588v2/SyncE, 1588v2 transparent clock, and 1588v2 boundary clock options. This solution provides industry-leading low power and high density capabilities, and is managed by a powerful multi-layer management suite, Infinera Digital Network Administrator.

Networks built today need to support a variety of mobile environments, including mobile fronthaul and mobile backhaul in HetNet environments. The Infinera Mobile Backhaul and Mobile Fronthaul Solutions are unique in their high performance and range of network architecture capabilities.

For more information on Infinera Mobile Backhaul and Fronthaul Solutions—**Contact Us** or visit https://www.infinera.com/applications/mobile-transport/.

ABOUT INFINERA

Infinera (NASDAQ: INFN) provides Intelligent Transport Networks, enabling carriers, cloud operators, governments and enterprises to scale network bandwidth, accelerate service innovation and simplify optical network operations. Infinera's end-to-end packet-optical portfolio is designed for long-haul, subsea, data center interconnect and metro applications. Infinera's unique large-scale photonic integrated circuits enable innovative optical networking solutions for the most demanding networks. To learn more about Infinera visit www.infinera.com, follow us on Twitter @Infinera and read our latest blog posts at infinera.com/blog.

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