WHITE PAPER

Infinera

EVOLVING THE AWARENESS OF OPTICAL NETWORKS

Faster, Simpler Planning/Provisioning and Increased Reach/Capacity with Infinera Aware Technology

Today's networks have limitations that increase operational cost, slow new wavelength activation times, limit reach, and prevent the network from operating at its highest possible capacity. These limitations include planning tools that lack real-time data from the optical network and therefore must stack margin to accommodate worst case scenarios, coherent receivers that are not able to measure OSNR or residual margin, and NMS, SDN, and ASON/GMPLS implementations that lack the sophisticated optical performance models of offline planning tools.

As the network becomes more dynamic with the adoption of SDN and the evolution of flexi-rate interfaces with a wider range of modulation schemes and baud rates, these limitations will impose an increasing cost. This white paper explains how Infinera technology can evolve the awareness of optical networks to address today's limitations and enable more dynamic networks that are able to fully leverage next-generation coherent technology.

WHAT IS AWARENESS?

The Cambridge English dictionary defines awareness as “knowledge that something exists, or understanding of a situation or subject at the present time based on information or experience.” As far as optical networks are concerned, awareness can have two meanings. In line with the first part of this definition, a planning tool that is able to model nonlinear effects could be said to be aware of them. Alternatively, in line with the second part of this definition, awareness could mean that the network is able to measure the actual, real-time impact of these nonlinear effects.

	Current Awareness	*Typical Limitations*
Planning Tools	Best-in-class tools offer a sophisticated model considering: ▪ Linear impairments (attenuation, CD, PMD, linear cross-talk, optical filtering, etc.) ▪ Nonlinear impairments (SPM, XPM, FWM, etc.) ▪ Amplifier characteristics (i.e., noise figure, ripple, gain, power) ▪ Network specific requirements (i.e., system aging, fiber repair margin)	▪ No real-time network data including fiber/spans, traffic/wavelengths, and optical performance
NMS	▪ Fault and PM data from the network elements ▪ Auto-discovery of nodes, topology, and services	▪ Not able to model optical impairments
SDN	▪ Able to model optical impairments ▪ Faults, PM, and Service Level Agreement (SLA)	▪ Less accurate impairment model ▪ No real-time optical performance, fiber/span data
ASON/GMPLS	▪ Able to model optical impairments ▪ Faults detected by the data and signaling planes	▪ Less accurate impairment model ▪ No real-time optical performance, fiber/span data
Optical Link Control	▪ Power levels (aggregate, per channel) ▪ Channel types (modulation, baud rate, FEC)	▪ No residual margin ▪ No OSNR
Performance Monitoring	▪ Power levels (aggregate, per channel) ▪ Linear effects (CD, PMD, PDL, etc.) ▪ Bit Error Rates (i.e., pre-FEC BER) ▪ Other OTN, SONET/SDH, Ethernet PM data	▪ No residual margin: ▪ No receive signal OSNR ▪ No nonlinear impairments ▪ No impact of linear effects on signal quality

TABLE 1 – Awareness of Today’s Optical Networks

AWARENESS LIMITATIONS OF TODAY'S OPTICAL NETWORKS

As shown in Table 1, while current optical network solutions have awareness strengths, they also have limitations. While planning tools can perform a sophisticated simulation of optical phenomena, they are not aware in the sense of having real-time knowledge of the network including fiber/span properties or optical performance. Network management systems can discover nodes, topology, and services in addition to gathering fault and performance data. However, while able to provision optical channels, most network management systems are not able to validate a path through the network based on a simulation of optical impairments, and even those network management systems that can are likely to use a less sophisticated model that requires additional margin to compensate for this lack of accuracy. SDN Path Computation Engines and ASON/GMPLS typically are able to calculate optical paths based on impairments, although they cannot currently match the sophistication and accuracy of offline planning tools. Furthermore, they also lack the awareness of real-time network data such as fiber/span characteristics and optical performance.

The awareness limitations of planning tools, SDN, and ASON/GMPLS require margin stacking in order to consider the worst case scenarios with respect to input uncertainties, the statistical variances in the network equipment and their components, system load (i.e., how many channels are running), traffic matrix (i.e., which channels of which type are running from where to where), and in the case of online tools, model limitations in order to guarantee error-free operation at the End of Life (EOL). Optical link control and performance monitoring also have awareness limitations. Optical link control is responsible for setting the power levels of each channel as well as amplifier gain and typically has visibility to power levels and even channel types. Performance monitoring data including power levels, some linear effects, and bit error rates is available from the network elements. However, what is missing is real-time, accurate visibility of OSNR and residual margin.

THE IMPORTANCE OF RESIDUAL MARGIN

Residual margin is the most useful measure of received signal quality and determines how much room there is for the signal to degrade without impacting the error-free operation. Residual margin is impacted by OSNR, linear impairments, and nonlinear impairments. Measured in dB, residual margin tells you by how many dB OSNR can be reduced, if linear and non-linear impairments remain constant, until post-Forward Error Correction (post-FEC) errors will occur. Accurately assessing the residual margin requires accurately determining the impact of all three – OSNR alone is not enough! While current coherent receivers are typically able to measure linear effects such as CD, PMD, and PDL, they are not able to measure their impact on signal quality, nor are they able to accurately measure OSNR or the influence of nonlinear penalties.

In the absence of residual margin, pre-Forward Error Correction (pre-FEC) BER and Q-factor are often used as the best available measures of signal quality. However, pre-FEC BER cannot be used to accurately predict the residual margin or the OSNR. Q-factor indicates the gap between the current pre-FEC BER value and error-free threshold in dB, however, as it is derived from the pre-FEC BER, it suffers from the same inherent limitation.

The primary reason pre-FEC BER cannot be used to accurately predict the residual margin is that the relationship between OSNR and pre-FEC BER depends on the linear and nonlinear impairments, and a change in pre-FEC BER will result in different changes in the residual margin depending on what caused the change.

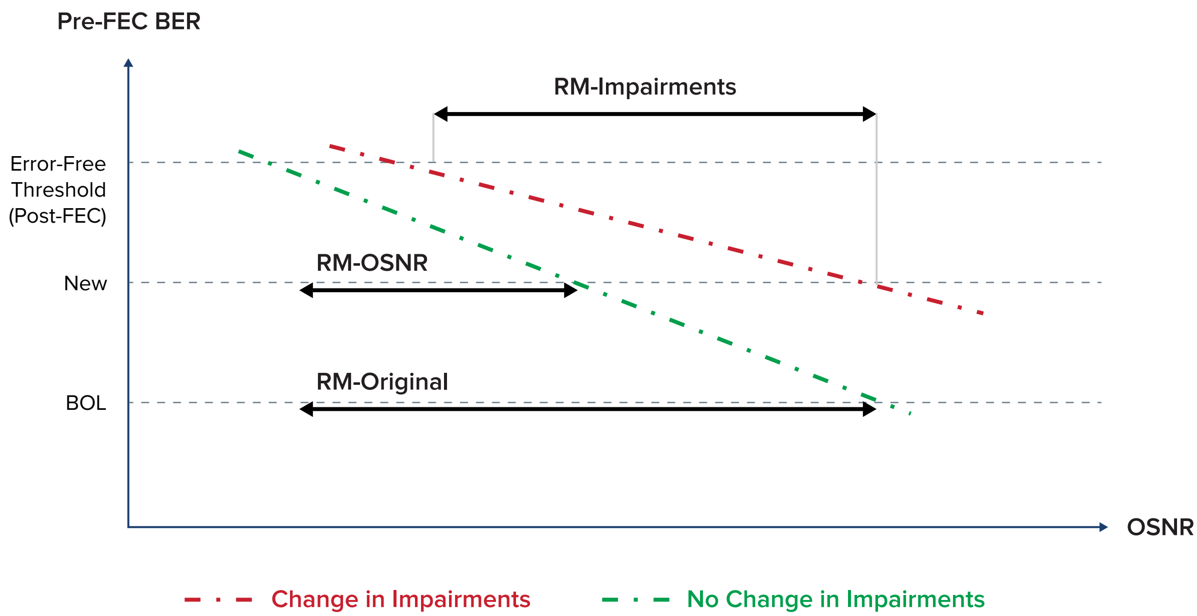

FIGURE 1 – Pre-FEC BER, OSNR, and Residual Margin

As illustrated in Figure 1, starting with the Beginning of Life (BOL) value, the pre-FEC BER changes to New. If this is because of a decrease in OSNR with other impairments staying the same, then the green slope applies and the residual margin becomes RM-OSNR. However, if the change in pre-FEC BER was caused by impairments only and the OSNR stays the same, the red slope applies. As the OSNR at the post-FEC error-free threshold increases, the residual margin decreases to RM-Impairments. RM-Impairments is, however, significantly higher than RM-OSNR. The same change in pre-FEC BER, therefore, has different impacts on the change in residual margin depending on the root cause of the change. Furthermore, these relationships will be unique for each individual transponder, as shown in Figure 2. This is true even for the same models from the same vendor due to statistical variances in the components.

Some of the current generation of coherent DSPs are able to measure the electrical signal to noise ratio (ESNR). However, these DSPs have the same inability to distinguish between OSNR, linear, and nonlinear impairments. Therefore, ESNR can only provide an accurate estimate of OSNR and residual margin for a limited range of scenarios that are dominated by OSNR, and ESNR is not useful for many other scenarios such as long haul or mixed 10G/100G environments where linear and nonlinear impairments also have a significant impact.

Next-generation DSPs promise the ability to distinguish between OSNR, linear, and nonlinear impairments delivering accurate residual margin. However, the accuracy of this approach is as yet unproven and will not help the installed base of coherent interfaces based on older generations of DSPs.

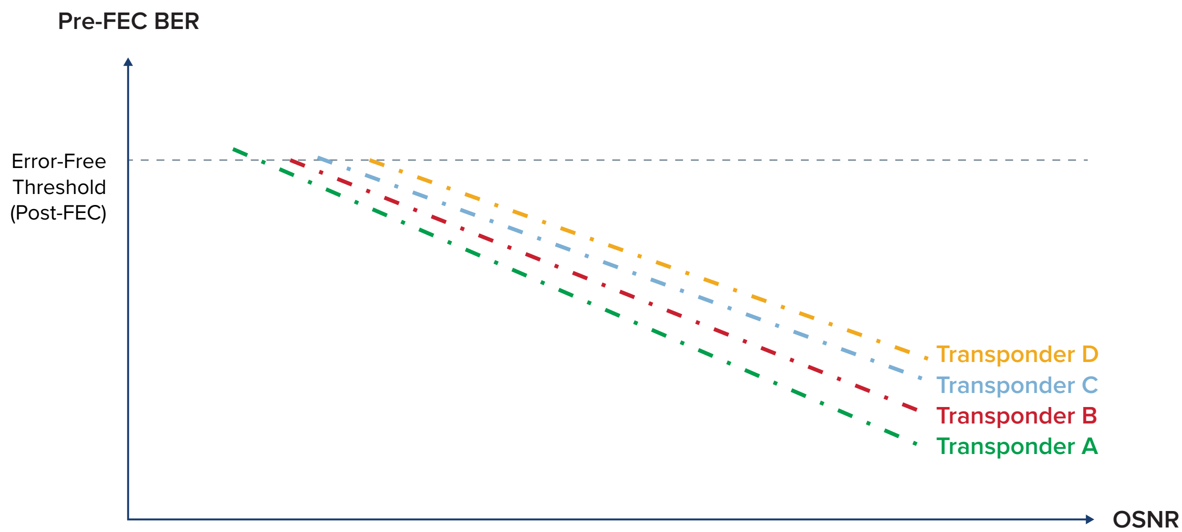

FIGURE 2 – Pre-FEC BER vs. OSNR with the same impairments for different transponders

THE NEED FOR GREATER AWARENESS

New Wavelength Planning & Provisioning

The first and perhaps most painful area for many operators relates to the planning and provisioning of new wavelengths. Given the lack of optical impairment awareness in today's network management systems, network operators are forced to plan new wavelengths in offline planning tools before either pushing the configuration from the planning tool to the network elements or provisioning the wavelength from the network management system. Activation times are slower due to the multiple steps that are required to plan and then provision the network as well as the different organizations that are potentially involved. Operational costs are also higher because of the need to involve highly skilled planning tool experts.

Coherent Optical Technology Evolution

Coherent technology continues to evolve in terms of modulation formats, baud rates, and FEC options. For modulation, 32QAM and 64QAM are being added to QPSK, 8QAM, and 16QAM. In terms of baud rates, ~45Gbaud and the 55-68Gbaud are being added to the traditional ~32Gbaud. FEC options of up to 50% will also be added to today's 7%, 15%, and 25% options. And a wider range of super-channel options will also be available to optimize reach and spectral efficiency. While this evolution promises a range of benefits including greater spectral efficiency and reduced cost per bit, it also increases the planning complexity significantly. Taking full advantage of these capabilities will require management and control planes with integrated planning together with accurate and real-time monitoring of optical performance including residual margin.

Agility & SDN

Agility, including faster service development, installation, and service provisioning, is a key enabler of competitiveness for network operators and one of the key drivers for the adoption of SDN and more flexible optical technology, including flexi-grid ROADM and colorless, directionless, contentionless add/drop. Many SDN use cases including Bandwidth-on-Demand (BoD) and Network as a Service (NaaS) depend on the ability to quickly route and reroute wavelengths. However, current SDN solutions typically provide this increased agility at the expense of decreased reach/capacity relative to best-in-class offline planning tools.

INFINERA AWARE TECHNOLOGY

Recognizing the limitation of today's optical networks and the need for greater awareness, Infinera is enhancing its optical network solutions with the addition of Infinera Aware Technology, which comprises two key elements, the Optical Performance Engine (OPE) and the Margin Processing Engine (MPE).

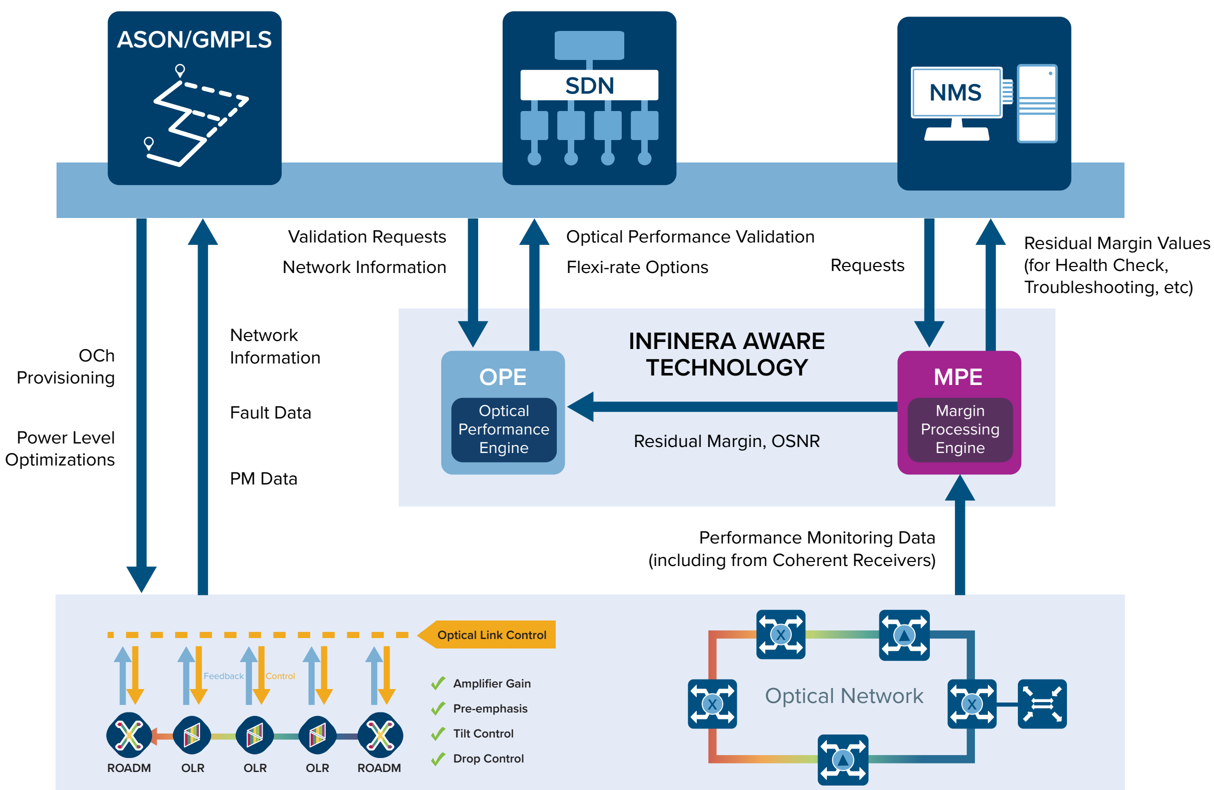

FIGURE 3 – Infinera Aware Technology

Optical Performance Engine

The OPE combines the accuracy of a best-in-class offline planning tool with the real-time speed necessary for wavelength activation, Layer 0 restoration, and other demanding optical use cases. This real-time speed is achieved by simplifying the mathematical operations. The OPE responds to path validation requests from the path computation function within the NMS, SDN, or ASON/GMPLS control plane. With optical models that consider both linear and nonlinear effects, the OPE generates the valid options for each requested path including modulation types, baud rates, FECs, frequencies, and power levels, enabling the best options, including flexi-rate interface settings and super-channel options, to be selected. The OPE can also take steps to protect channels with low residual margin by discouraging the use of adjacent channels to limit cross-talk. Furthermore, the OPE is able to provide inputs for the optical link control to more optimally set the power levels based on the current state of the network and residual margin values coming from the MPE.

Margin Processing Engine

As discussed previously, accurate residual margin is a key challenge for today's optical networks. The MPE gathers performance monitoring data from across the network including both the coherent receivers and per channel power monitoring capabilities of the optical network elements. It is then able to process this data in real-time to distinguish OSNR from signal degradation due to linear and nonlinear impairments. This enables it to deliver accurate and real-time residual margin values for each channel. In addition to unparalleled accuracy, the MPE is able to do this without the need for next-generation DSPs and can, therefore, be used with the installed base of coherent, and even non-coherent, interfaces.

BENEFITS OF AN AWARE OPTICAL NETWORK

Lower OpEx through Faster, Simpler Planning & Provisioning and Easier Troubleshooting

Infinera Aware Technology enables faster and simpler new wavelength planning and provisioning. In addition to reducing the number of steps, boundaries between planning and network management are eliminated. New wavelengths can now be planned and provisioned without needing to draw on skilled planning tool experts. Infinera Aware Technology can identify valid options for flexi-rate interface settings and super-channels, including the most optimal options. The technology can also enable wavelength automation with multi-layer ASON/GMPLS or SDN through its open APIs. Finally, Infinera Aware Technology reduces OpEx with simplified troubleshooting enabled by accurate real-time visibility of residual margin and OSNR.

CAPEX BENEFITS	**Better Reach & Capacity, Extended Network Life**	▪ Reduce or eliminate margin stacking ▪ Power level setting with visibility of residual margin, considering the most challenging channels
	Monetize Margin	▪ State-of-life optimization ▪ Turn EOL margin into capacity you can sell (without additional CapEx)
REVENUE BENEFITS	**Offer New Services**	▪ SDN use cases: BoD, NaaS ▪ Wavelengths-on-Demand (via customer portal)
	Improved Security	▪ No need to share sensitive information with 3rd parties
	Higher Availability	▪ Control plane reroute without loss of reach ▪ Relaxed margin for temporary restoration paths ▪ Pro-active downtime prevention: discouraging neighboring channels, reducing wavelength speeds, etc.
OPEX BENEFITS	**Faster, Simpler Planning/ Provisioning**	▪ Fewer steps. No need for planning experts. ▪ Automated provisioning via multi-layer GMPLS or SDN/API ▪ Identifies optimal options for interface settings (modulation, baud rate, FEC, etc.) and super-channels
	Simplified Troubleshooting	▪ Accurate, real-time visibility of residual margin and OSNR (DSP-independent) ▪ Correlation of planning (tool) data with real-time residual margin values

FIGURE 4 – Key Infinera Aware Technology Benefits

Reduced CapEx through Better Reach, More Capacity and Extended Network Life

Infinera Aware Technology enables increased reach/capacity by reducing or even eliminating margin stacking and by improving the power level setting through awareness of the residual margin. Integrating the OPE into online tools reduces the margin that is required to compensate for optical model limitations. Making the OPE aware of the network state (span loss, PMD, CD, etc.), including residual margin from the MPE, reduces the margin that is required to compensate for planning input uncertainties and component performance variations. In addition to reduced margin stacking, power-level setting with an awareness of the residual margin and considering the needs of the most challenging channels can further increase the reach/capacity. Furthermore, with real-time knowledge of the network state and residual margin, Infinera Aware Technology can identify the optimal paths, power levels, interface settings, and super-channels for state-of-life conditions, thus avoiding the need to stack margin for end-of-life conditions.

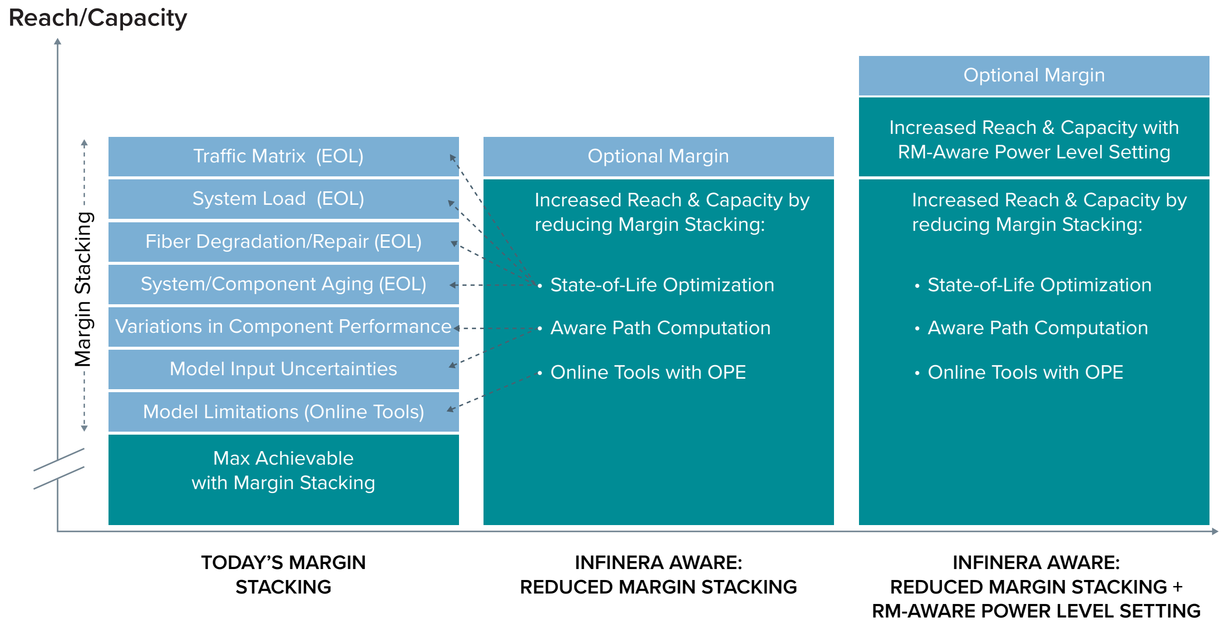

FIGURE 5 – How Infinera Aware Technology increases reach/capacity

This real-time state-of-life optimization results in the highest reach/capacity and lowest cost in the early stages of the network cycle. In reality, while technology improvements are likely to benefit the network and more than compensate for any degradations in reach/capacity/cost, state-of-life optimization can deliver significant savings in total lifetime cost of ownership.

Reach and capacity have a direct impact on network CapEx: reach by reducing the number of expensive OEO regens and capacity by minimizing the cost per bit of flexi-rate interfaces. CapEx is further reduced by extending the life of the network. Increasing spectral efficiency extends the life of optical layer assets including fiber. Furthermore, the life of the network is typically determined by its most challenging wavelengths. Infinera Aware Technology can extend the life of these challenging wavelengths, for example, by enabling the power levels to be set in order to maximize their margin at the expense of less challenging channels and/or by discouraging the use of adjacent channels to minimize crosstalk.

Increasing Revenues with Higher Availability, Improved Security, New Services, and Monetized Margin

Infinera Aware Technology can enable SDN or ASON/GMPLS restoration with reach/capacity that goes from underperforming to exceeding today's offline planning tools. The usual margin rules can be relaxed for a temporary restoration path given its short lifespan, especially if the alternative is no restoration and a service outage. Restoration could even be triggered by residual margin degradations. In addition, visibility of the residual margin can enable proactive downtime prevention such as discouraging the use of adjacent channels, optimizing power levels, or reducing the bit rate.

Infinera Aware Technology can also deliver improved security by reducing the need to share planning and provisioning data with third parties, thus enhancing the potential for sales to security conscious customers. Infinera Aware Technology can also be an enabler for SDN services such as Network as a Service, Bandwidth-on-Demand, and even Wavelength-on-Demand with self-provisioning via a customer portal. Infinera Aware Technology provides the opportunity to monetize margin as extra capacity that can be sold to customers for shorter duration services.

OPTIONS FOR IMPLEMENTING INFINERA AWARE TECHNOLOGY

While the ultimate goal might be an optical network that integrates planning and provisioning, provides the ability to accurately assess the residual margin for all channels, and optimizes the interface settings, super-channels, paths, and power levels in real time based on state-of-life conditions, network operators have the option to implement Infinera Aware Technology in phases based on their priorities for its key benefits.

As an example, for many network operators, enabling integrated planning and provisioning with the OPE will be an obvious first step. A second step could then be adding residual margin visibility with the MPE with aware path computation increasing reach/capacity. Alternatively, the order of these first two steps could be reversed, starting with the MPE for residual margin visibility and then adding the OPE as a second step. A third step might be setting the power levels based on residual margin values from the MPE, leading to the final step of real-time state-of-life optimization.

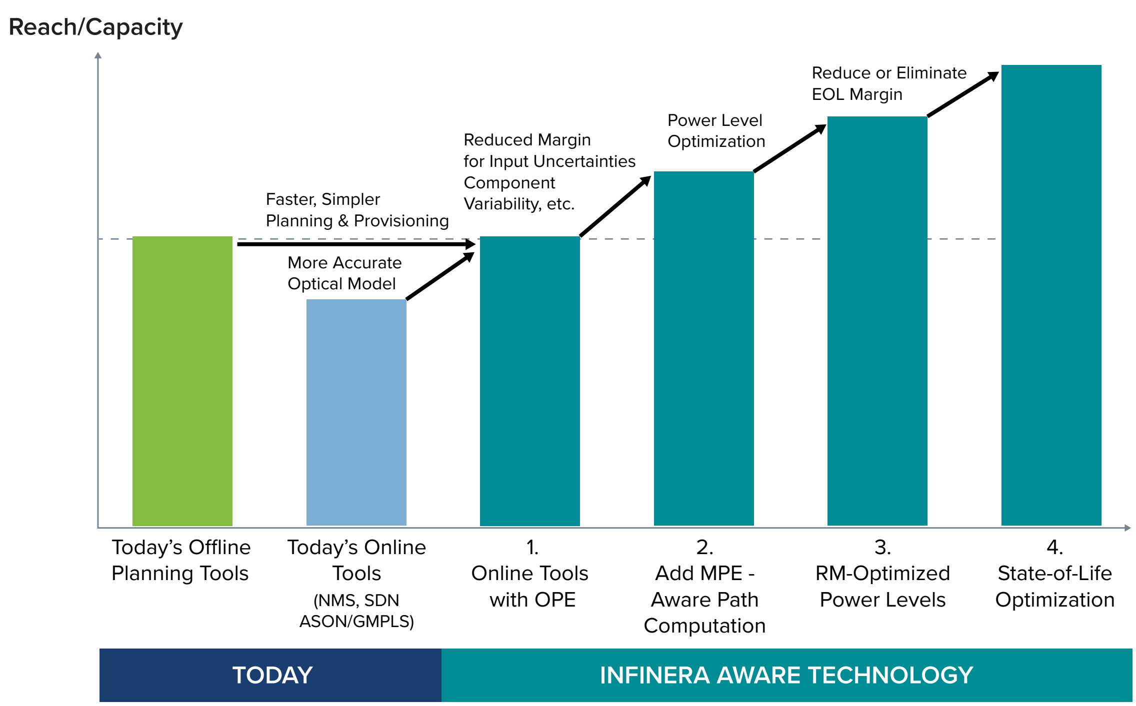

FIGURE 6 – Infinera Aware Technology can be implemented incrementally

CONCLUSION

Infinera Aware Technology enables accurate optical path computation in the management and control planes and delivers DSP-independent visibility of the residual margin. Key benefits include faster, simpler planning/provisioning and increased reach/capacity. Furthermore, as optical networks become more dynamic with the adoption of SDN, more flexible optical layer innovations, and next-generation coherent, the Infinera Aware solution will enable network operators to benefit from the full potential of these technologies.

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