Technical Summary – Optical DWDM Design

Bringing Industry Leading Technology to Our Customers

The Netsync team consistently brings industry-leading technologies to our customers and remains conscious of the customer's legacy environment to optimize and balance technology advancement with investment protection. Given the current Cisco routed/switched network, Netsync's expert team is proposing Cisco's Network Convergence System (NCS) 2006 platform. The Cisco NCS is a new flagship networking family comprising the NCS 6000, NCS 4000, and NCS 2000, which can be managed as a single, integrated system. The proposed solution supplies customers with a programmable and intelligent network that provides a network fabric that can bring together the Cisco Carrier Routing System (CRS), Cisco Aggregation Services Routers (ASR) families, and Cisco's Nexus product family, as well.

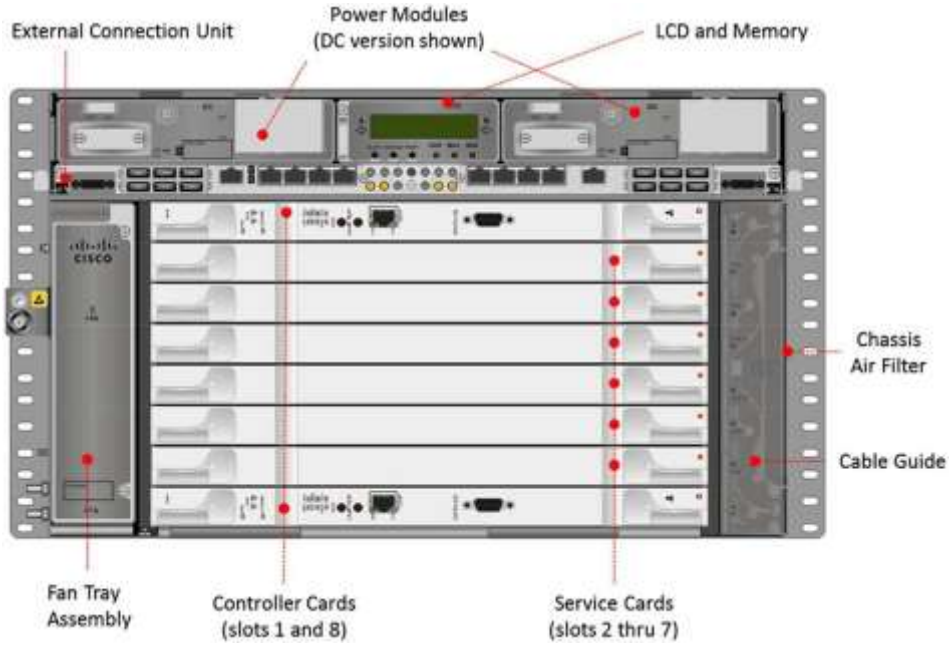
Cisco's solutions are investment protected and gracefully evolved solutions that expand capabilities while keeping familiar management and control domains to minimize impacts on personnel and back-office systems.

Netsync has formulated a response for Denton ISD with the goals to include mission-critical services, bandwidth scalability, and investment protection with a solution up to the task. Massive growth in backbone network traffic and increasing traffic patterns are causing significant economic challenges for customers. To address these challenges, they must evolve their backbone networks. Netsync's response contains a focused attention on both the existing and emerging requirements. We are proposing the most forward-looking, robust carrier-grade NCS solution that seamlessly integrates with the architecture, foundation, and system functions that Denton ISD expects from entities like Cisco. While the Layer 0–Layer 4 NCS product family is revolutionary in many respects, the foundation of carrier-grade core principles prove an evolution long present in Cisco's Optical Networking product family.

Many competitive architectural approaches rely on network layers that are built and operated independently. This model contributes to scaling, provisioning, and operational inefficiencies. An innovative approach is needed that optimizes inter-layer boundaries to create a highly converged transport architecture. This converged transport architecture must tightly integrate packet and dense wavelength division multiplexing (DWDM) layers across hardware, control planes, management planes, and administrative domains. Doing so can create a network that is much more efficient, less complex, and easier to scale and operate.

Leveraging State of the Art Optical Equipment

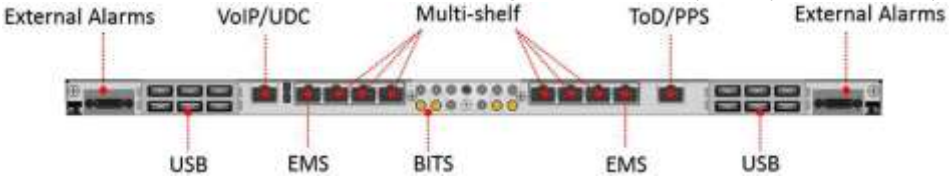
The proposed implementation, including Project Management, Installation, Provisioning and Turn-up, and Testing leverages the industry leading technology of Cisco's Network Convergence System (NCS) 2006 sites.



The Cisco NCS 2006 chassis is 6RU in height and has 6 slots for service cards.

The NCS 2006 can be mounted into 19-inch, 21-inch, or 23-inch racks or cabinets. Brackets come with the shelf assembly. Optional air deflectors in 21-inch and 23-inch installations can be used.

The AC power cable is 3 meters long and is rated for 20A – 250V with a standard IEC C19 connector at the NCS 2006 and NEMA 6-20P to connect to the existing outlets. Two cords provide power redundancy.



Cisco NCS 2006 External Connection Unit (ECU)

The NCS 2006 chassis has a built-in memory module to back up the software package, IP address, and circuit database, making simplex mode more attractive in cost-sensitive applications. This built-in backup memory improves Mean Time To Repair (MTTR) and increases operational simplicity. Also available is the ability to connect up to 12 passive devices for inventory management via USB. All NCS 2006 passive devices include ROM containing device information. When connected to the chassis

external connection unit (ECU), these devices appear within Cisco Transport Controller (CTC) inventory management. Multishelf management allows multiple (up to 50) NCS 2006 shelves to be managed as a single network element, with a single target identifier (TID) and IP address, facilitating the construction of nodes with a very large number of reconfigurable optical add/drop multiplexer (ROADM) degrees and/or service cards.

The following data on currently deployed NCS/ONS platforms demonstrates Cisco's leadership in innovatively integrating systems for large clients.

NCS 2006/ONS 15454 M6

4,000-plus customers deploying Cisco optical solutions

2,000-plus customers deploying ONS15454 Multiservice Transport Platform (MSTP)

Major Service Provider adoption worldwide

100,000-plus ONS 15454 chassis in-service

29,000-plus DWDM nodes shipped in-service

28,000-plus ROADMs shipped

1,200,000-plus add/drop ports shipped

27,100-plus 2.5G channels shipped in-service

95,000-plus 10G channels shipped in-service

5,000-plus 40G channels shipped in-service

5,900-plus 100G channels shipped in-service

Denton ISD DWDM Design Overview

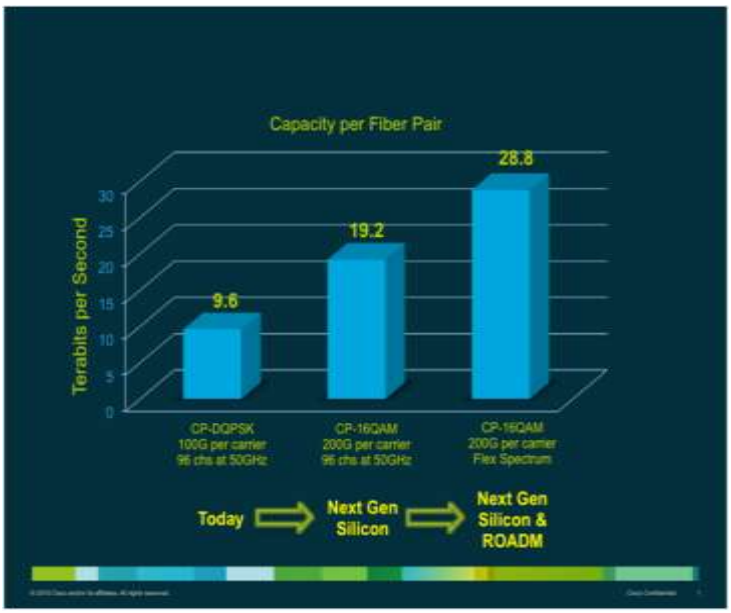
Each Denton ISD DWDM Hub Node Location will use multiple NCS 2006 chassis (one chassis per trunk fiber pair) with each NCS 2006 chassis supporting dual processors and dual AC power supplies. Client-side 100GE and 10GE connectivity is supported using Cisco single slot 100G Transponder or 10x10G transponders (metro or long-haul versions depending on distance requirements) with the 100GE utilizing the CPAK optics and the 10GE client side using LR-10 and ER-10 pluggable optics to extend to the access schools from the core nodes.

Netsync and Cisco Proposed 100G Hub Interconnect Solution

In the proposed design, the solution utilizes Cisco's 10x10G coherent transponders connecting to SMR1 ROADMs initially supporting up to 40 DWDM channels. Each channel can support a 1/10/40/100GB service using the C-Band spectrum. While initially equipped to support 40 DWDM channels, the DWDM network is expandable to a maximum of 96 DWDM channels. All 40 channels are available at each location without the need to install any additional core hardware (muxes/amplifiers). The 10GB traffic would use the 10x10G coherent transponder cards.

Technical Product Overview

Netsync's response represents a best-in-class solution from Cisco to exceed Denton ISD's goal of a highly reliable, flexible, ultra-high capacity core backbone to transport 10GE and beyond between its regional core facilities. Cisco's acquisition of CoreOptics and other investments in 100G digital signal processor (DSP) coherent technology, allows it to integrate 100G technology across the ASR 9000 Series and Nexus platforms. This in turn allows Netsync to offer the best and most comprehensive end-to-end 100G solution available. With the additional acquisition of Lightwire for its complementary metal-oxide semiconductor (CMOS) photonics technology, coupled with Cisco's ongoing commitment to invest in enhanced modulation schemes and reconfigurable optical add/drop multiplexer (ROADM) technology, Cisco's DWDM transport solution now scales to 28.8 Tbps per fiber pair, as shown in the graph below.



Cisco's Progression to 28.8 Tbps Capacity per Fiber Pair

The investments previously referenced are just a part of Cisco's focus on research and development. In the last three fiscal years, Cisco spent $5.8 billion (13.4% of revenue), $5.3 billion, and $5.2 billion, respectively, with plans to continue investment at this rate. The foundation of Netsync's proposal is the NCS 2006/ONS 15454 M6 DWDM platform. The Core DWDM Optical Network was engineered using ROADMs and amplifiers layer to start with 40 DWDM channels of 1/10/100G per channel with the capability to expand to full C-Band channel capacity of 96 channels, depending on the ROADM upgrade path.

Cisco's experience in designing and deploying ROADM-based networks is unparalleled within the industry, with more than 29,000 ROADMs shipped throughout four generations of product, and strong presence across all markets, including regional carriers, service providers, cable multiple-system operators (MSO), and enterprise and government customers.

The Netsync engineering team, along with Cisco, thoroughly reviewed the requirements and believes the provided solution can be leveraged for many years. With any solution, total cost-of-ownership (TCO) is a critical evaluation criterion. The solution provides:

- **Industry-leading density** – Positions a common infrastructure that exceeds the demands of today AND provides the capability support for the services of tomorrow, while preserving the Day One investment.
- **Flexibility** – Along with density, the flexibility of the infrastructure negates the need to rip and replace as network demands evolve.
- **Efficient provisioning** – Utilizing ROADM technology and easy-to-use Network Management, the Cisco solution enables "touchless" optical provisioning, drastically improving service velocity and lowering operational costs.
- **Ultimate scalability** – The solution scales to provide 40, 80, or 96 channels in the C-Band with any individual Lambda capable of up to 100Gbps per channel.

Optical DWDM Technical Overview
Solution Overview
The foundation of Cisco's optical design is the NCS 2006/ONS 15454 M6 Multiservice Transport Platform (MSTP). The key solution elements and values are described below:

- The Cisco NCS 2006/ONS 15454 M6 sets the industry benchmark for compact, simple, fast, and intelligent DWDM solutions. Its small form, simplicity, unique set of integrated features, and low power consumption reduces capital expenditures (CapEx) and operating expenses (OpEx).
- At six rack units in height, or 10.5 inches, the NCS 2006/ONS 15454 M6 is a small chassis, but its compact dimensions allow carriers/customers to build a fully redundant, carrier-class DWDM system expandable in an incremental fashion. The NCS 2006/ONS 15454 M6 supports the needs of edge/access DWDM sites with limited requirements or DWDM amplifier sites that require minimal space and power requirements. Larger DWDM sites are accommodated by integrated multi-shelf (multi-chassis) supporting a total of 50 NCS 2006/ONS 15454 M6 chassis that can be interconnected to form a single multi-shelf node.
- The NCS 2006/ONS 15454 M6 solution meets customer traffic demands using 1G to 100G DWDM transport and provides a flexible ROADM layer that persists as the underlying photonic transport for multiple years of growth.

Additional Product Description

The Optical Networking Solution (ONS) proposed for Denton ISD uses Cisco's most forward-positioned platform in the ONS product line. The NCS 2006/ONS 15454 M6 chassis with its small 6 RU form factor and dual AC redundant power and redundant processor is a 5–9 reliable core platform like its predecessor, the original ONS 15454 M12. The chassis has extended cooling range to support a fully populated shelf with 40/100G transponders, as well as a new active backplane to facilitate low-density 2x40G or 10x10G multiplexing. The following picture features the 15454 M6 chassis:

NCS 2006 Chassis

The Cisco DWDM Optical Solution proposal uses hardware and common components that are based on the 40/80/96 channel, C-Band DWDM grid. The Day One configuration supports 40 channels/lambdas that will allow Denton ISD to add new channels/lambdas at any location, up to 40 channels, without any service interruption. This means that all the core components are in place (filters-ROADMs, amplifiers, and other common components) to allow Denton ISD to grow to 40 channels per site (note: additional chassis will be needed as a location grows and additional channels/lambdas will need to be added).

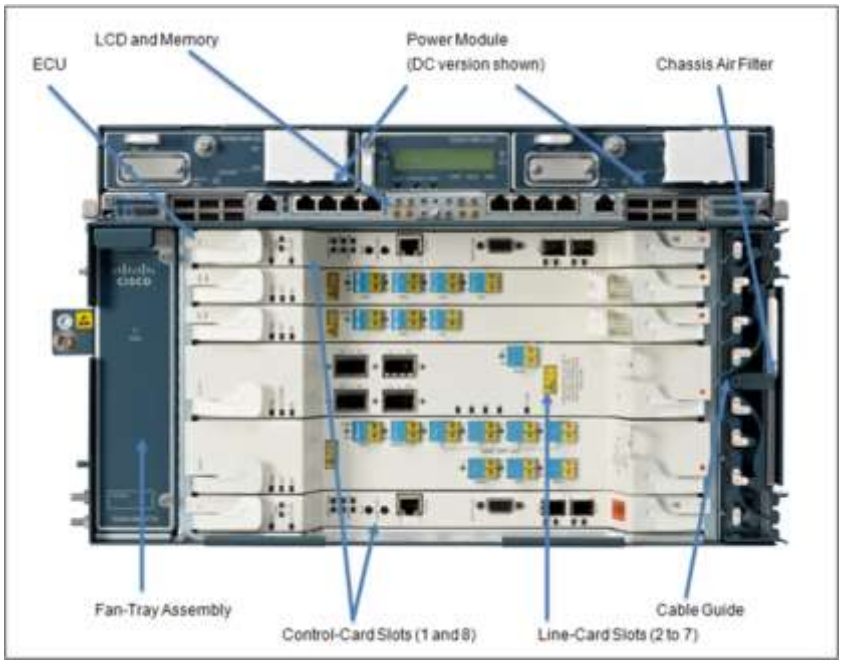
The newest generation of ROADM is proposed in all designs. The single slot form factor (SMR1 or SMR2) takes the place of four cards/functions. This new card (SMR1 or SMR2) offers a 4:1 card slot savings serving the WSS/DEMUX/PRE/BST functions. A detailed description of the SMR-ROADMs and associated hardware is given in the technical section to follow. Netsync has provided a DWDM Optical Solution to Denton ISD using the SMR1 (2-degree option) at all of the core DWDM locations. SMR2 (4-degree option) are available and if Denton ISD decides it wants to move to a mesh environment in the future, it can be accomplished with this technology.

The Denton ISD DWDM Optical Solution will support 40G/100G DWDM channels. Cisco's CoreOptics acquisition brought industry-leading talent to incorporate a superior coherent solution. CoreOptics enables Cisco to equip customers with highly advanced 40G/100G-transmission technology. This allows them to scale their networks to meet the demands of rapidly growing IP traffic driven by video, mobility, and cloud services.

The next phase of innovation in optical networking will be driven by sophisticated modulation formats and advanced digital signal processing (DSP) technologies. These new capabilities enable the efficient transmission of large amounts of data over existing fiber optic installations. By enabling high speeds across an existing infrastructure, Cisco addresses the challenge facing service providers and enterprise customers to accommodate the growth in network traffic, while managing tight capital expenditure budgets.

DWDM Platform Overview – NCS 2006/ONS 15454 M6 MSTP
The Cisco NCS 2006/ONS 15454 M6 MSTP provides a comprehensive, intelligent DWDM solution for expanding metropolitan (metro) and regional bandwidth.

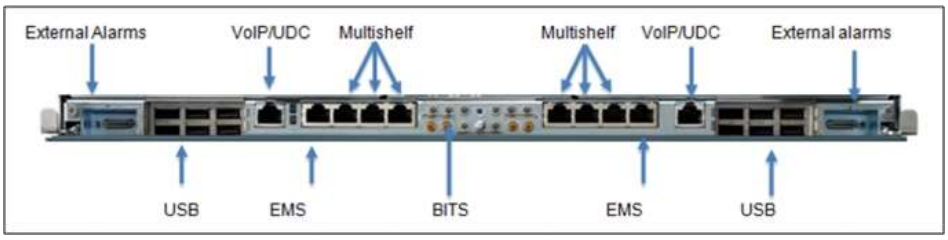
NCS 2006/ONS 15454 M6 Chassis
The NCS 2006/ONS 15454 M6 chassis has two slots for redundant control cards and six slots for service cards. These six line card slots provide increased power and cooling capability over the original Cisco ONS optical chassis and a usable high-speed backplane for future applications. The NCS 2006/ONS 15454 M6 can be configured with integrated and redundant AC and DC power inputs. The DC power module has connectors for both ANSI or ETSI style battery and battery return connections, making it universal. The AC power module has a single input and is universal in that it accepts a power input ranging from 110 VAC to 240 VAC, 50 Hz to 60 Hz.



NCS 2006/ONS 15454 M6 MSTP Chassis

The electrical connection unit is a narrow, front-facing termination panel for all management, alarm,

and multishelf connections. This platform is ideal for cabinet installations and ETSI front-connection requirements with all connections to the Cisco NCS 2006/ONS 15454 M6 being front-facing, making this a truly global platform.



NCS 2006/ONS 15454 M6 Electrical Connection Unit (ECU)

The NCS 2006/ONS 15454 M6 has a built-in memory module to back up the software package, IP address, and circuit database, making simplex mode more attractive in cost-sensitive applications. This built-in backup memory improves Mean Time To Repair (MTTR) and increases operational simplicity. Also new to the NCS 2006/ONS 15454 M6 is the ability to connect, via USB, up to six Cisco ONS passive devices for inventory management and therefore they will show up in the Cisco Transport Controller (CTC) or Cisco Prime (formerly Cisco Transport Manager [CTM]) inventory management pane.

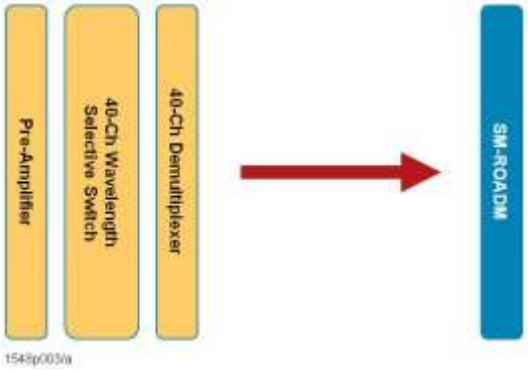
The NCS 2006/ONS 15454 M6 has a single high-capacity fan tray assembly where the three fans are individually monitored and controlled. In the unlikely event that a single fan fails, the user will receive a fan fail alarm and the other fans will increase in speed to provide sufficient airflow to allow the user time to safely replace the fan tray.

Specifically designed for these new platforms are new control cards that consolidate the functions of the control card, Optical Service Channel (OSC) termination, multi-shelf switch, and increased alarms into one card.

The Transport Node Controller (TNC) card supports and provides the following:

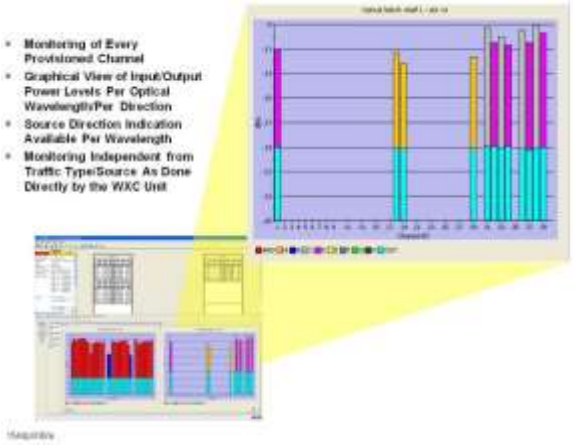
- OSC communication to implement the Optical DCN, User Data Channels (UDC), and voice over IP (VoIP) interface.
- OSC supports Fast Ethernet and Gigabit Ethernet connections, in addition to OC-3/STM-1, providing the user with more bandwidth for use with the UDC.
- Two point-to-point Ethernet channels at 10 Mbps to carry VoIP traffic.
- Two point-to-point Ethernet channels at 10/100 Mbps to carry UDC traffic.
- Passive inventory of external devices on the 15454-M2 and NCS 2006/15454 M6 shelves.
- Supports OSC, UDC, and VoIP traffic. Two UDC/VoIP ports are present on the external connection unit that can be configured to carry UDC/VoIP traffic.

The addition of 10 Mbps VoIP channels and 10/100 Mbps UDC channels allows the technician to use one 10/100 Mbps UDC channel for the corporate LAN connection, and the VoIP channel can be used for voice communication simultaneously. Cisco believes this is a key feature that will allow Denton ISD to streamline test and turn-up operations in key long-haul sites that may not have cellular coverage and in secure metro sites where cell phones are not allowed.



Card Consolidation Using the SM-ROADM

Other competing ROADM solutions on the market today are multicard solutions, consuming higher power and a greater number of service slots to provide similar functionality. The SMR1 and SMR2 devices also feature built-in amplifiers and an optical spectrum analyzer, further minimizing the slot consumption required for a ROADM-based architecture. The optical spectrum analyzer is capable of displaying the per-channel power levels of each add/drop or pass-through wavelength on the ROADM system. This built-in spectrum analyzer can be used for initial deployment and troubleshooting purposes and eliminates the need for Denton ISD to purchase a dedicated piece of test equipment to perform this function.

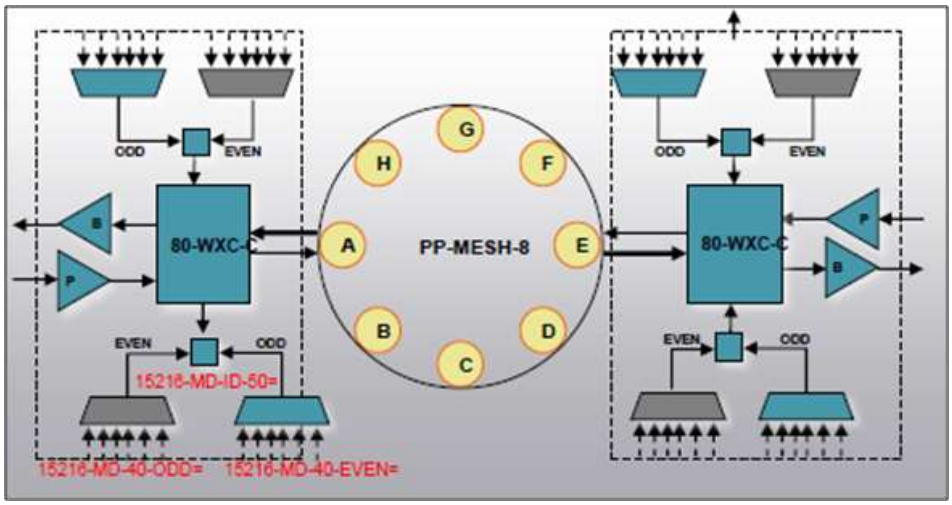


SM-ROADM Optical Spectrum Analyzer

The footprint advantages of the SMR1 and SMR2 are further highlighted by the fact that both modules offer built-in pre- and booster amplification. The two-degree SMR1 includes a built-in pre-amplifier, whereas the four-degree SMR2 features built-in pre- and booster amplifiers. The card consolidation of the single-module ROADM cards reduces the slots used for common modules and increases the number of slots that can be used for service cards (transponders/muxponders).

SMR1 and SMR2 Line Cards

The basic multidegree architecture is shown below.



Multidegree ROADM Block Diagram

The NCS 2006/ONS 15454 MSTP's single-module ROADMs extend Cisco's market leadership in ROADM technology by combining multiple functions into one card occupying only a single chassis slot. This

industry-leading form-factor simplifies cabling, reduces cost, and allows ROADM functionality to be deployed without the significant commitment in rack space and power that has traditionally been required for ROADM nodes. The 40-channel single-module ROADM with integrated optical pre-amplifier (part number 40-SMR1-C) combines the OSC add/drop filter, a pre-amplifier, and a 2x1 Wavelength Selective Switch (WSS)-based ROADM core into a single-slot unit. This unit is optimized for degree-2 reconfigurable nodes.

Cisco ONS 15454 Single-Module ROADM

The 40-channel single-module ROADM with integrated optical pre-amplifier and boost amplifier (part number 40-SMR2-C) includes the OSC add/drop filter, pre- and boost-amplifiers, and a 4x1 WSS-based ROADM core. This unit provides an effective way to support multi-degree nodes up to degree-4, allowing in-service upgrades from degree-2 up to degree-4 at a very competitive price point. The 40-SMR2-C card provides multi-degree switching capabilities at the individual wavelength level. Mesh and multi-ring network topologies can now be deployed using the Cisco NCS 2006/ONS 15454 MSTP with complete flexibility of service routing at all nodes in the network.

Individual channel separation, required on the add/drop ports to terminate local traffic, is provided by the Cisco ONS 15216 40-channel multiplexer/demultiplexer patch panel (odd channels) The use of thermal Arrayed Waveguide Grating (AWG) technology allows the removal of the multiplexer and demultiplexer function from the Cisco NCS 2006/ONS 15454 MSTP shelf. This approach simplifies connectivity to passive patch-panels (only four simplex LC cables are required) and improves density, as removing passive multiplexing and demultiplexing from the chassis frees up slots to be used for traffic.

Cisco ONS 15216 Mux/Demux Patch Panel

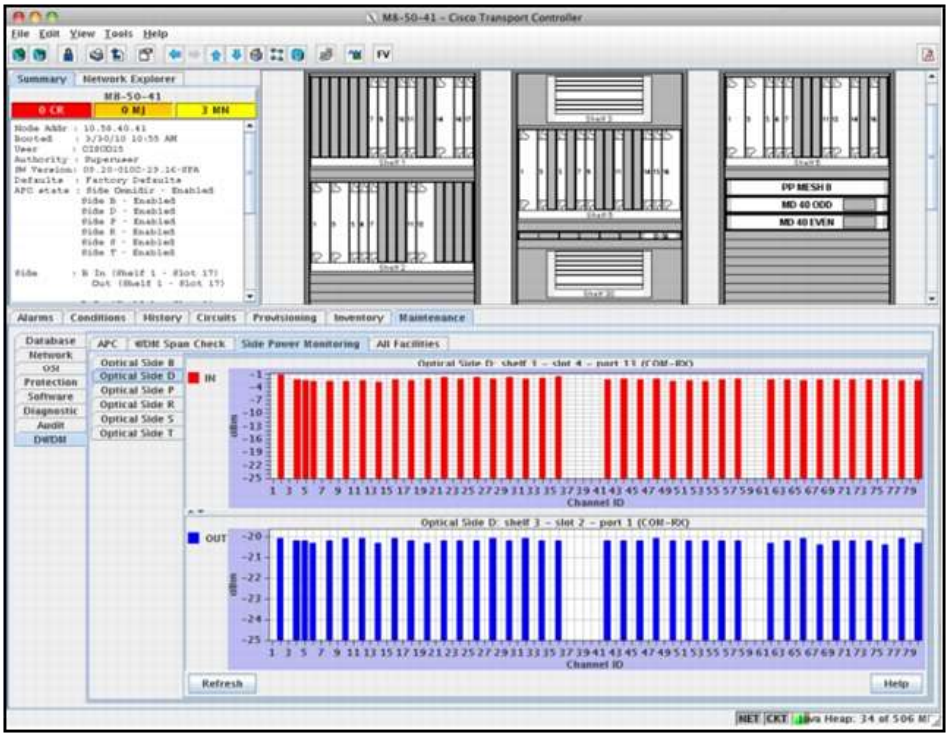
The Cisco NCS 2006/ONS 15454 single-module ROADM cards (40-SMR1-C and 40-SMR2-C) operate on the ITU 100-GHz wavelength plan. Each card integrates automatic per-channel power monitor and control capabilities, providing node- and network-based automatic-power-level management on each input and output port. Per-channel optical path selection is also done in a completely automated way through wavelength path provisioning (WPP) at the network level, featuring end-to-end, point-and-click wavelength provisioning and easy SONET/SDH-like wavelength management.

The ROADM node architecture has been specifically defined and engineered to provide:

- **High reliability** – Enables complete independence between specific direction-facing units with the possibility to house units in physically separated shelves.
- **Automatic optical power balancing** – Per-channel automatic power control allows a "self-healing" intelligent approach to DWDM, which is unique in the market.
- **Low insertion loss** – Selected technology allows direct integration of different functionalities in the same optical module, reducing to the bare minimum the number of optical connections.
- **Reduced footprint** – SMR units integrate multiple functions into a single card (amplification, OSC add/drop, ROADM, and power monitoring), reducing node power consumption and increasing shelf throughput.

The optical cards incorporate faceplate-mounted LEDs to provide a quick visual check of the operational status at the card. Printed on each of the faceplates is an icon, an orange circle, which is mapped to shelf-slot icons indicating the shelf slot where the card can be physically installed. The cards are supported by the integrated Cisco NCS/ONS 15454 Cisco Transport Controller (CTC) craft manager, which provides the user access for operations, administration, maintenance, and provisioning (OAM&P) for the system. Taking advantage of the embedded units' capabilities, CTC can also provide a per-channel graphical representation of the optical power levels associated with each individual path in the ROADM nodes.

The Cisco NCS/ONS ROADM cards are plug-in modules that deliver the flexibility to access network bandwidth from a single DWDM channel all the way to 80/96 channels.



Per-Channel Optical Power Monitoring via Cisco Transport Controller (CTC)

Commented [AM1]: Too blurry

Amplification

Midamplifier Loss (MAL)-less Erbium-Doped Fiber Amplifier (EDFA) Product Overview

The Cisco NCS/ONS MSTP offers enhanced optical amplifiers for extending the reach of a metro, regional, or long-haul network. The optical amplifier cards are part of the Cisco NCS/NCS 2006/ONS MSTP intelligent DWDM architecture engineered to reduce DWDM complexity and speed the deployment of next-generation networking solutions. The Cisco NCS/ONS Enhanced C-Band amplifier card is a plug-in module that takes advantage of the proven Cisco ONS carrier-class features.

NCS/NCS 2006/ONS MSTP Enhanced C-Band Low-Cost Amplifiers

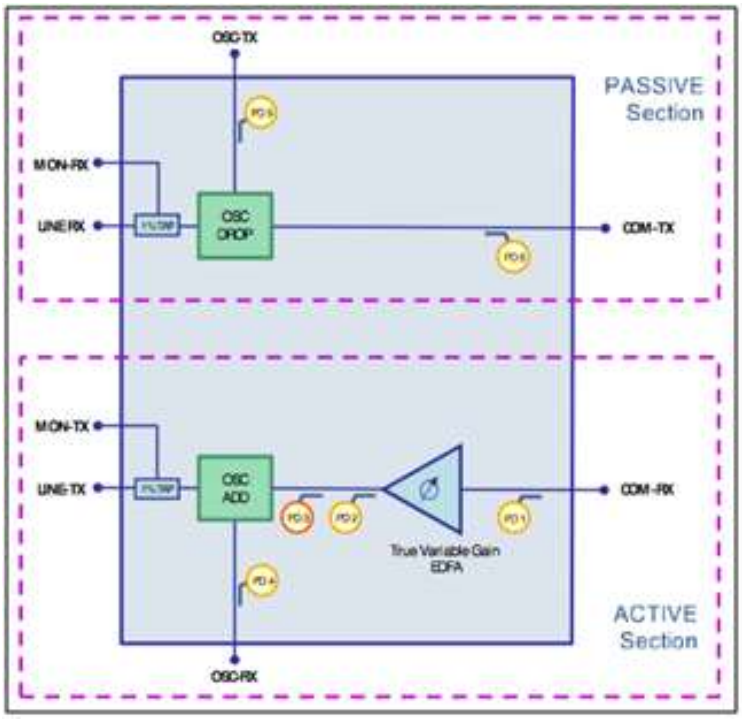
The Cisco True Variable Gain Booster Amplifiers, with maximum 17-dB and 24-dB gain, are high-power enhanced amplifiers suited for the needs of a next generation of optical networks. The coherent detection technology and a new modulation format, like the CP-DQPSK modulation scheme employed in 100Gb transponder units of the recent high-capacity optical networks, eliminate the need for dispersion compensation. The noise figure of these erbium-doped fiber amplifiers (EDFA) is thus optimized by having a single amplification stage with no need for a lossy midstage access to provision dispersion-compensating units.

The 17-dB and 24-dB amplifiers take advantage of the latest in amplifier technology, variable optical attenuators, photo diodes, and extensive software to facilitate a high degree of automation for simplified operations. They feature a low-noise-gain block for C-Band optical amplification requirements with an embedded gain-flattening filter. For flexibility of application support, the amplifiers support two modes of operation—constant gain and constant power—while also providing Amplified Spontaneous Emission (ASE) compensation in either modes. They also provide fast-transient suppression to respond quickly to network changes without adding impairments and degradation.

Both cards allow a programmable tilt and possess a non-distorting, low-frequency transfer function. Each card integrates software-controllable variable optical attenuators (VOA), along with extensive optical monitoring with photo diodes, to provide nodal- and network-based automatic power-level management. Extensive optical safety algorithms provide user safety when operating the network. The optical amplifier cards incorporate faceplate-mounted LEDs to provide a quick visual check of the operational status at the card. The cards are supported by the integrated CTC, a craft manager, which

provides the user access for OAM&P for the system.

The following figure depicts the functional block diagram that applies to both amplifiers.



NCS/NCS 2006/ONS MSTP EDFA 17- and 24-Amplifier Block Diagram

The table below describes the enhanced C-Band 96-channel low-cost amplifier cards with application cards.

Component	Deployment Application
Cisco True Variable Gain Booster Amplifier with maximum 17-dB gain (15454-OPT-EDFA-17)	Use this flexible amplifier as a preamplifier or as a booster amplifier, providing a total output power of 20-dBm and maximum gain of 17-dB. It integrates an optical service channel splitter or combiner to allow the optical supervisory channel (OSC) to be sent to the OSC signal from the OSC pluggable associated with the Transport Node Controller (TNC) card. Deployment locations include any site where high per-channel power is required to enter the fiber span.
Cisco True Variable Gain Booster Amplifier with maximum 24-dB gain (15454-OPT-EDFA-24)	Use this flexible amplifier as a preamplifier or as a booster amplifier, providing a total output power of 20-dBm and maximum gain of 24-dB. It integrates an optical service channel splitter or combiner to allow the OSC to be sent to and received from the OSCM card or the OSC signal. Deployment locations include any site where high per-channel power is required to hit the fiber span.

Transponders, Muxponders, and Xponders (Layer 1–2 cards)
The NCS/ONS 15454 MSTP consists of several different cards to convert and aggregate lower rate client signals into densely packed OTN wavelengths for transport across the DWDM network. The cards' density and supported rates are as follows:

- Full C-Band tunable 10G XFP – This is unique to Cisco; this XFP can tune to any of the 80 channels of the C-Band, and it has similar characteristics of the 10G transponder (further reach). It adds flexibility to wavelength assignment plans and helps with spare cost reduction.
- Diverse line of transponders and muxponder cards, including 10G transponders with higher tolerance to polarization-mode dispersion (PMD).
- MLSE 10Gbps full C-Band tunable transponders and muxponders (15454-10EX-L1-C and 15454-10MEX-L1-C) – It has 30ps PMD and 4000 ps CD tolerance, critical for 10G circuits between far locations or through high PMD fiber.
- 10Gbps full C-Band tunable transponders – 10G transponder with EFEC capability and full C-Band tunable, adds flexibility and low cost for spares.
- 2.5Gbps multi-rate transponders – Support for client rates from 50M to 2.5G.
- 2.5Gbps multi-rate transponders with splitter protection – Dual trunk card for 50M to 2.5G clients.
- 4 x OC48 full C-Band tunable muxponders – OC-48 to 10G muxponder.
- 2.5Gbps data muxponder – GE, ESCON, and FC multiplexer to 2.5G trunk.
- 2.5Gbps data muxponder with splitter protection – GE, ESCON, and FC multiplexer with dual 2.5G trunks.
- 10Gbps data muxponder – GE, 1GFC, 2GFC, and 4GFC multiplexer to 10G trunk.
- Xponder – Layer 2 over DWDM with GE and 10GE client interfaces.
- MSPPoB – OC-192 SONET multiplexer on a blade with OC-3/12/48/192/GE client support.
- 40G transponder – OC768/STM256/40GeWAN-PHY, OTU3 (OC768/STM256/40GeWAN-PHY).
- 40G muxponder – Multiplex of four 10G clients (8GFC, OC-192, 10GE, and OTU2).

AR-XP and AR-MXP (latest data center-centric card) supports:

- SONET/SDH:
  - STM-1/OC-3
  - STM-4/OC-12
  - STM-16/OC-48
- OTN:
  - OTU-1
  - OTU-2
- Ethernet:
  - Fast Ethernet (FE)
  - Gigabit Ethernet (GE)
- SAN:
  - Enterprise Systems Connection (ESCON)
  - 1 Gigabit Fibre Channel or fiber connectivity (FICON)
  - 2 Gigabit Fibre Channel or FICON
  - 4 Gigabit Fibre Channel or FICON
  - 8 Gigabit Fibre Channel or FICON
- Video:
  - SD-SDI (270 Mbps)
  - HD-SDI (1.485 Gbps)
  - Third-generation SDI (3G-SDI) (2.970 Gbps)
- OTU2 10G 4-port L1 Xponder (lates L1 10G card) supporting:
  - OC-192/STM-64 (9.95328 Gbps)
  - 10GE WAN PHY (9.95328 Gbps)
  - 10GE LAN PHY (10.3125 Gbps)
  - 10G FC (10.518 Gbps)
  - OTU-2
    - Standard G.709 (10.70923 Gbps)
    - G.709 overclocked to transport 10GE as defined by ITU-T G; Sup43 Clause 7.1 (11.0957 Gbps)
    - G.709 overclocked to transport 10GE as defined by ITU-T G; Sup43 Clause 7.2 (11.0491 Gbps)
    - G.709 proprietary overclocking mode to transport 10G FC (11.3168 Gbps)

- 100G trunk card and accompanying 2x40G ,10x10G, 2 x 100/40 CFP client cards supporting :
  - 100G trunk card : 100GE Lan Phy, OTU4
  - 100G daughter 10x10 card:
  - Latest release CPAK based 100G for hyper dense LR4 and SR10 client handoffs

CLIENT		MAPPING
Format	Rate (Gbps)	
10GE LAN-PHY	10.3125	CBR-BMP clause 17.2.4 (ex G sup43 7.1) + GMP ODU2e to OPU3e4
	10.3125	GFP-F clause 17.4.1 (ex G sup43 7.3) + GMP ODU2 to OPU3e4
OC-192 /STM-64	9.953	CBR-BMP clause 17.2.2 (Sync) + GMP ODU2 to OPU3e4
10G FC	10.518	513b transc + AMP GFP-F clause 17.8.2 + GMP ODU2e to OPU3e4
8G FC	8.500	CBR-BMP clause 17.9 (OduFlex) + GMP ODU2 to OPU3e4
OTU2	10.709	ODU transparent + GMP ODU2 to OPU3e4
OTU2e	11.096	ODU transparent + GMP ODU2 to OPU3e4

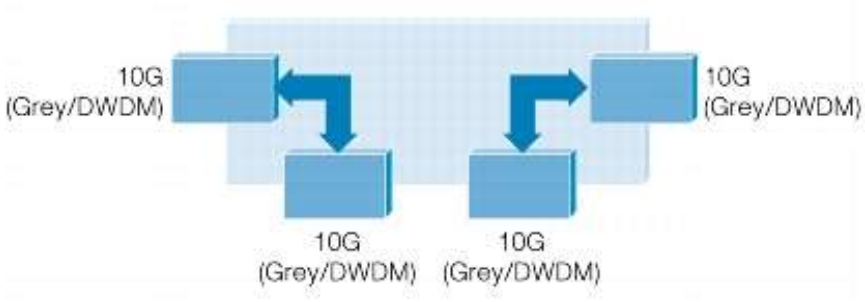
- 100G daughter card 2x100/40

CLIENT		MAPPING	TRUNK		
Format	Rate (Gbps)		Format	Rate with 7% GFEC or EFEC OH (Gbps)	Rate with 20% UFEC OH (Gbps)
100GE LAN-PHY	101.125	Bit transparent through standard G.709v3 mapping	OTU4	111.809	124.964
OTU4	111.809	Transparent G.709 standard			
40GE LAN-PHY	41.250	1024b/1027b transc + OPU4 GMP G709 Appendix VIII			
OTU3	43,018	Transparent G.709 standard			

Layer 1 10G OTU2 Xponder
The OTU2 Xponder consists of a 4-port, XFP-based 10G transponder that supports multiple bit rate signals over a 100GHz spaced, ITU-compliant wavelength:

- OC-192/STM-64 (9.95328 Gbps)
- 10GE WAN PHY (9.95328 Gbps)
- 10GE LAN PHY (10.3125 Gbps)
- 10G FC (10.518 Gbps)
- OTU-2

The OTU2 Xponder card is a plug-in module to the Cisco NCS/ONS 15454 MSTP, enabling a cost-effective architecture for delivering high-rate 10Gbps services. The OTU2 Xponder card architecture contains a single client interface that is mapped to a single line interface, without accessing the Cisco NCS/ONS 15454 shelf cross-connect fabric.



OTU2 Xponder

Commented [AM2]: Too burry?

Each of the four interfaces can be independently configured to support OTN wrapper. Combining the XFP and OTN configuration enables multiple configurations. For example, two grey XFPs with no OTN on two ports and two DWDM XFPs with OTN wrapper enabled allow this card to act as 2 x 10G transponder in a single board. Using amplification and dispersion compensation, the OTU2 Xponder card is capable of a 1000-km reach. When operated within the outlined specifications, each card will transport the 10-Gbps signal with a maximum bite error rate (BER) of 10E-15.

Operating Modes
Boards can be configured to operate in the following modes:

- 2 x 10G transponder
- 2 x 10G regenerator, FEC/EFEC equipping the four ports with DWDM XFP
- 1 x 10G regenerator, EFEC/EFEC equipping two ports with DWDM XFP
- Fiber-switched protected 10G transponder

100Gb Technology

100G Coherent Performance – Cisco's OIF standard single-carrier 100G coherent polarized-DQPSK offers best-in-class B2B optical signal-to-noise ratio (OSNR) (7.5dB), chromatic dispersion (CD) tolerance (80,000ps), and polarization mode dispersion (PMD) tolerance (180ps differential group delay [DGD]) allowing Denton ISD to deploy 96 wavelengths of 100G over the most challenging optical fibers.

100G Density – Cisco's 100G solution offers Denton ISD 100G transport capacity per RU, thanks to the integrated ADC/DSP ASIC design allowing Cisco's 100G coherent transceiver to be 7"x5"x0.75". At 100G/RU, Denton ISD requires less space, power, and shelves at terminal, ROADM, or regeneration sites, lowering TCO as the system scales.

As previously mentioned, Cisco's solution addresses total cost of ownership (TCO) through industry-leading density on the 100G transponder; a flexible system that grows with Denton ISD's future needs; ROADM technology that enables touchless optical provisioning for increased service velocity and lower operational costs; and scalability to provide up to 28.8 Tbps of capacity per fiber.

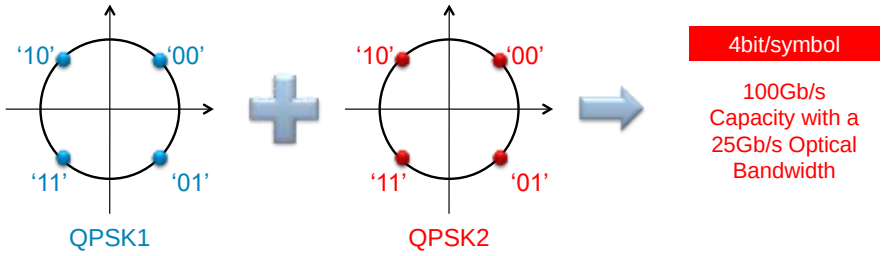
Key NCS/ONS 15454 Elements

100G Coherent Transmission

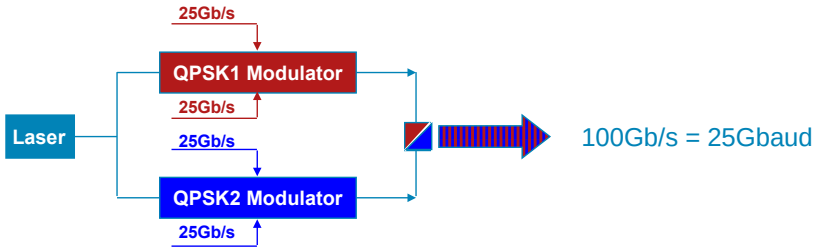
The Cisco NCS/ONS 15454-100 Gbps coherent DWDM trunk card features an advanced modulation scheme to provide optical performance significantly better than industry-standard 10-Gbps equivalent interfaces.

Cisco selected a CP-DQPSK modulation format to optimize 100-Gbps transmission in terms of OSNR, CD, and PMD robustness. Note that Cisco's solution complies with the OIF PM-QPSK standard for long-haul transmission.

The CP-DQPSK modulation scheme consists of multiplexing two DQPSK signals using two different orthogonal light polarizations, as shown in the figures below.

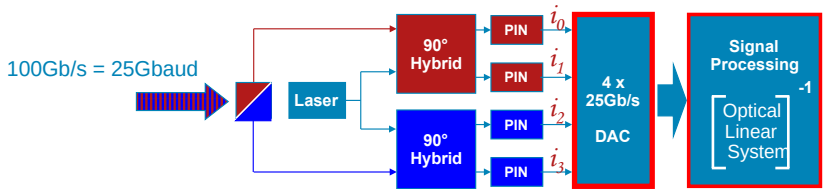


CP-DQPSK Logical Modulation Scheme



CP-DQPSK Logical Transmitter Scheme

The core of the 100-Gbps CP-DQPSK modulation scheme is the optical receiver, based on coherent optical detection, where a digital signal processor (DSP) calculates the inverse of the optical system matrix, allowing the receiver to recover the original transmitted signals.



CP-DQPSK Logical Receiver Scheme

The primary benefits of CP-DQPSK are:

- Strong optical signal-to-noise ratio (OSNR) performance
- Outstanding chromatic dispersion robustness, avoiding any additional cost related to optical chromatic dispersion (CD) compensation equipment
- Extended polarization mode dispersion (PMD) robustness (three times better than 10-Gbps units)
- High spectral efficiency, allowing 100-Gbps wavelengths to be transmitted across a large number of ROADMs with negligible penalty

The 100-Gbps channels feature a software-configurable baud rate between 27.952 Gbaud and 31.241 Gbaud, depending on forward error correction (FEC) selection, as well as a G.709v3 OTU-4 digital wrapper, long-reach and long-haul, ITU-compliant, 50 GHz-spaced optical interface using LC connectors. The DWDM output line interface is tunable to 96 wavelengths across the full optical C-Band, dramatically reducing inventories for spares. When operated within the outlined specifications, the trunk card can operate with a post-FEC bit error rate (BER) of better than 10^{E-15}.

Long-Haul 100G Network

- Transport at 100 Gbps over low-quality fiber with high PMD
- Support for up to 96 100-Gbps wavelengths (50-GHz channel spacing) with high tolerance to filtering penalties
- Improved overall system density for 100 Gbps per slot, five-times greater than the density achieved with 40-Gbps units
- Support for different configurations (transponder, muxponder, or regenerator) through software provisioning only

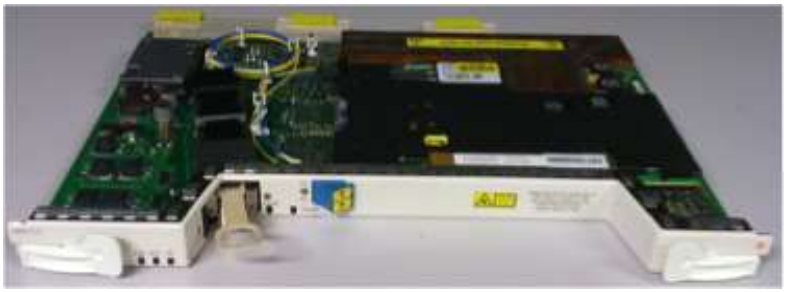
Key Performance Statistics

- Multiple FEC algorithm supported with 7% and 20% of OH:
  - 7% based on standard G.975 Reed-Solomon FEC
  - 7% based on third generation of EFEC targeting 4 x 10-3 BER (Pre-FEC)
  - 20% based on standard G.975.1 I.7 EFEC targeting 1 x 10-2 BER (Pre-FEC)
- Bit rate: 111.8Gb/s to 128 Gb/s
- 96 channels full C-Band 50GHz tunable DWDM trunk
- Back-to-back OSNR: 7.5 dB
- Tolerated DGD: 180 ps
- Tolerated CD +/- 80,000 ps/nm

100G Coherent Modules

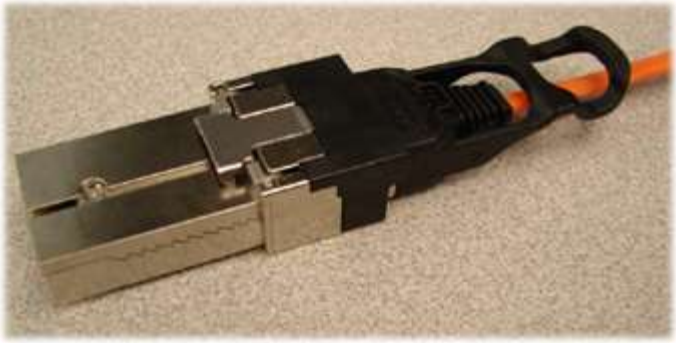
There are two types of 100G transponders that Cisco offers:

- 100G transponder with a CXP client
- 100G transponder with a CPAK client



100G Transponder

CXP and CPAK client provide for a high-level density of 100GE clients at minimum power consumption. The CXP provides 1EEE 100GE SR10 clients.

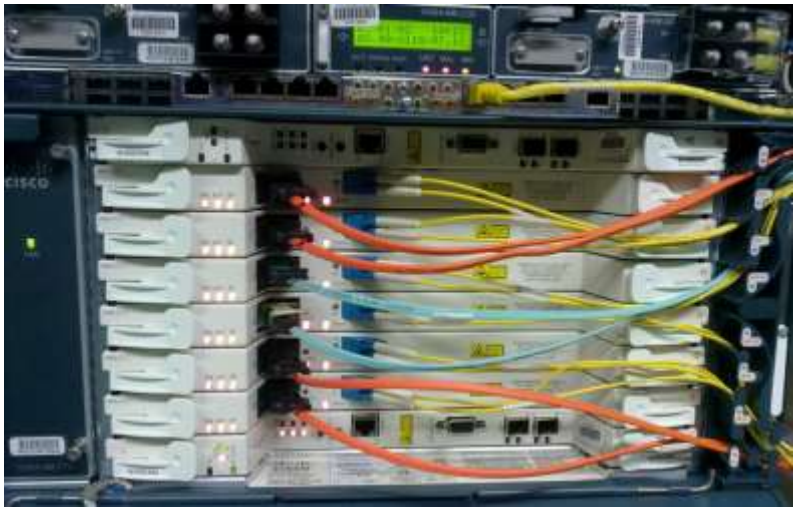


CXP Client

The CPAK provides for 1EEE 100GE LR4 clients.

CPAK Client

The CPAK consumes 30% of the power, requires half the heat sink size required by a CFP, and is 30% smaller than the CFP pluggable available today. This allows for high-density 100GE clients unprecedented in the industry. Six 100G transponders with clients per six RU NCS 2006/ONS 15454 M6 shelf and 42 100G transponders and clients in a single 42 RU rack.



Fully Populated 100G NCS 2006/ONS 15454 M6 Chassis: 600G/Shelf

10x10G Client Card

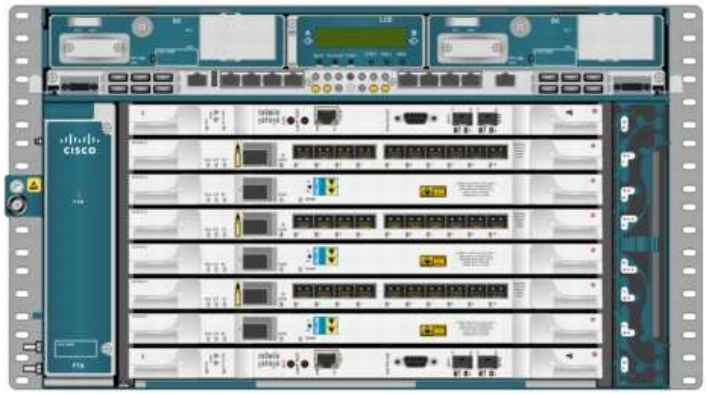
Front panel interfaces are:

- 10x SFP+ supporting 10GE, OTU2, OC-192, 10G, and 8G FC interfaces.
- 1 x 100G CXP for future fan-out applications

The same unit supports two working modes (SW configurable):

- 10-ports 10G multi-rate muxponder – coupled with 100G DWDM line card
- Able to support any combination of 10G signals (SONET/SDH, 10GE, 10G FC, and 8G FC)
- 5 x 10G transponder – Standalone configuration with DWDM SFP+, supporting FEC/EFEC (no CXP pluggable needed)

Used in conjunction with the 100G DWDM line card, this card provides 100G muxponder (MXP) functionality.



Typical NCS 2006/ONS 15454 M6 Node

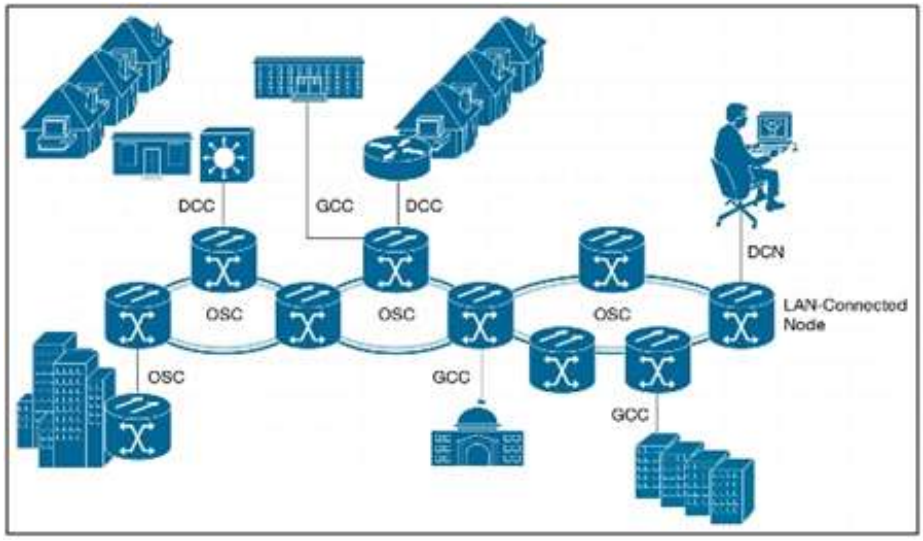
The objective is to provide a zero-touch photonics layer that offers complete flexibility in the hardware and, therefore, total control through software. This is achieved while providing high performance and scalability to 1Tbps and 400Gbps super channels.

Software Functionality
Network Automation
Cisco believes the ability to simplify network activation is a key revenue enabler for Denton ISD. To that end, Cisco's network automation features have been integrated into the NCS 2006/ONS MSTP solution from day one.

- **Auto-Discovery** – As a result of its unique discovery technology, Cisco NCS 2006/ONS MSTP networks are capable of auto-discovering nodes, links, and network resources within a defined Open Shortest Path First (OSPF) Protocol area.
- **Automatic Power Control** – The NCS 2006/ONS MSTP can auto-adjust the power of the amplifiers in the DWDM network to respond to network failures and degradation.
- **Auto-Provisioning** – The Cisco NCS 2006/ONS MSTP can automatically calculate the optical settings needed to perform a node auto-turn-up.

Network Topology Discovery

As a result of the unique discovery technology based on Layer 3 routing protocols implemented over the DWDM control channel, optical supervisory channel (OSC), generic communications channel (GCC), and data communications channel (DCC), Cisco NCS 2006/NCS 2006/ONS MSTP networks are capable of auto-discovery. Nodes, links, and network resources are automatically provided within a defined OSPF Protocol area. The immediate advantage is that the management system needs to know the IP address of one LAN-connected node only in a management network.



DWDM Network Topology Discovery

The management system, Cisco Transport Controller (CTC), Cisco Prime Optical, or even a Transaction Language 1 (TL1)-based operations support system (OSS) need the IP address of only one of the LAN-connected nodes—that is, one of the nodes connected to the data communications network (DCN). The other nodes have been automatically discovered by the OSPF Protocol running over the OSC, GCC, and DCC. The network topology discovery mechanism provides the management system with the set of nodes, links, and network resources.

If no OSC, GCC, or DCC connectivity exists among two nodes, the Cisco NCS 2006/ONS MSTP offers a variety of links that can be manually provisioned taking part to the mechanism for future discovery.

Network Craft Interface – Downloaded from the Node – No Installation Code

CTC is a revolutionary craft application GUI that provides broad control and full Fault, Configuration, Accounting, Performance, and Security (FCAPS) capabilities. In addition, no installation code is needed on the user workstation.

Cisco Transport Controller (CTC)

- Provides integrated craft GUI system
- Provides GUI available from node
- Auto-discovers systems and networks
- Manages sub-network (OSC and GCC based) and multiple sub-networks
- Provides auto-routed AZ circuit provisioning for DWDM and SONET/SDH
- Provides a task-oriented tool targeted at installation and turn-up, maintenance and troubleshooting, provisioning, and control of a sub-network

Automatic Power Control
The capability to adjust the power of the amplifiers in the DWDM network to respond to network failures and degradation is one of the most important topics in photonic systems.

The Cisco NCS 2006/NCS 2006/ONS MSTP can respond to network events in two ways:

- Automatic gain control
- Automatic power adjustment

Automatic gain control is the capabilities of the amplifiers to work in constant gain mode, to help ensure that added traffic in an optical add/drop multiplexer (OADM) survives to a fiber cut in the span before. The Cisco NCS 2006/ONS MSTP amplifiers provide fast transient suppression. They immediately react to any short-term variation in the input power, adjusting their output as a result of the given gain. This characteristic is useful to help ensure that traffic in DWDM networks survives.

However, during the life of the DWDM network, the aging of the fibers and components and changes in operating conditions may also impair the traffic capabilities. A constant gain system is not usually capable of reacting to these slow events. The Cisco NCS 2006/NCS 2006/ONS MSTP has a control plane that calculates and distributes new settings to the amplifiers across the network in such a way that slow variation of the network is easily compensated. The Cisco NCS 2006/NCS 2006/ONS MSTP is the only DWDM system that combines the behaviors of constant gain and constant power systems.

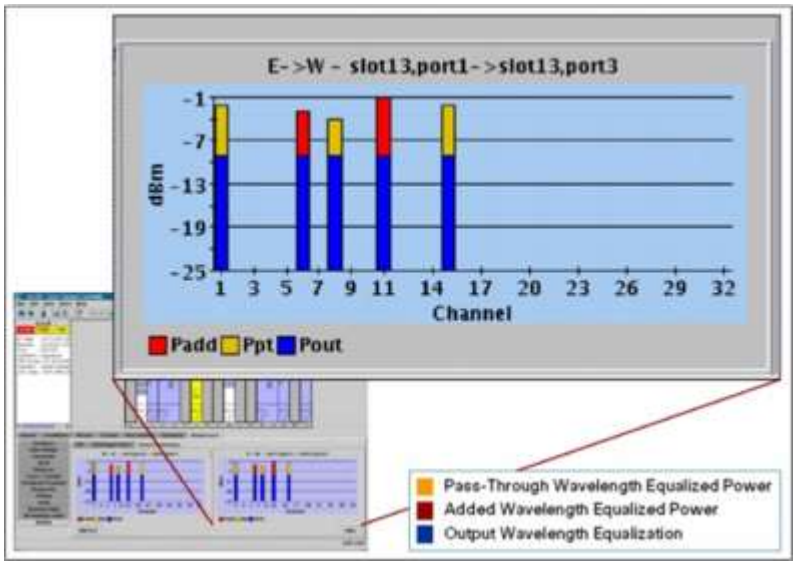
The major advantage of the automatic power control is that no field intervention is required during the life of the network; the network settings are adjusted automatically.

Automatic Turn-Up
The Cisco NCS 2006/NCS 2006/ONS MSTP can automatically calculate the optical settings needed to perform a node automatic turn-up. Using in-service span loss monitoring, the node can compute the settings for variable optical attenuators, amplifier gain, and expected power thresholds and apply them to correctly turn up the optical node. This capability reduces the work of the installation team, which only has to mount racks and shelves, plug in the cards, and connect the patch cords. Initial provisioning tasks are reduced to a minimum.

Alien Wavelength Management

Cisco NCS 2006/NCS 2006/ONS MSTP is designed to work with any stable ITU-T source. Whatever is the source, the Cisco NCS 2006/ONS MSTP can monitor it along the network, tracking the path and the power level at each ROADM node.

The alien wavelength is a special case of an optical trail, where the source is not part of the Cisco NCS 2006/NCS 2006/ONS MSTP management domain. The Cisco Transport Controller (CTC) and the Cisco NCS 2006/NCS 2006/ONS MSTP allow management of the alien wavelengths as optical trails and also provide the capability to monitor them at the intermediate nodes of the network.



Alien Wavelength Monitoring

Network-Level Alarm Correlation

One alarm per failure in the network—that is, the root cause of the problem spontaneously advertised to the management system and thus to the network operations center (NOC)—is the service provider's goal. It is usually attained with a sophisticated OSS capable of correlating failure notifications coming from all the nodes of the network, but this is far from an optimal method for suppressing irrelevant notifications and symptoms.

Alarm correlation at the OSS level is usually preferable across domains, but it cannot correctly perform the fault management function for the DWDM network. The Cisco NCS 2006/ONS MSTP solves the problem directly at the network level with a standard alarm correlation capability that works at both the node and network levels.

Each Cisco NCS 2006/ONS MSTP node has a rich set of monitoring points, from variable optical attenuators (VOAs) to photo detectors, going to the rich termination function of the transponders (SONET/SDH, G.709, and SAN) to detect each kind of failure. However, the system can demote all the derived alarms to simple conditions and notify the root cause only to each of the management interfaces. The correlation function works within the reference standards for time-stamping and set and unset alarm declaration and thus is interoperable with any standard OSS.

A node-level alarm correlation function, however, is not enough. In ROADM-based mesh networks, where intermediate optical path monitoring functions are implemented, a fault in a node or link may result in thousands of failure detections on nodes downstream. Some vendors reduce the number of monitoring points to prevent this alarm flooding, but this the wrong way to proceed. Real failures that occur at this point of the network will be actually detected at the termination points, making troubleshooting almost impossible.

As a result of its unique implementation of ITU-T G.798 Optical Transport Section (OTS) and Optical Multiplex Section (OMS) Payload Missing Indication (PMI) and OCH Forward Defect Indication (FDI) signaling, the Cisco NCS 2006/ONS MSTP DWDM can suppress alarms on downstream nodes in the network, presenting one alarm only for each unidirectional failure. Each time a failure at the OCH level is detected, an OCH FDI is signaled downstream, telling all the nodes to demote the related detected failures (usually loss of light or loss of signal payload). Whenever a failure at the OMS or OTS is detected, a PMI is signaled downstream, telling all the nodes to demote the related section alarms (usually loss of light).

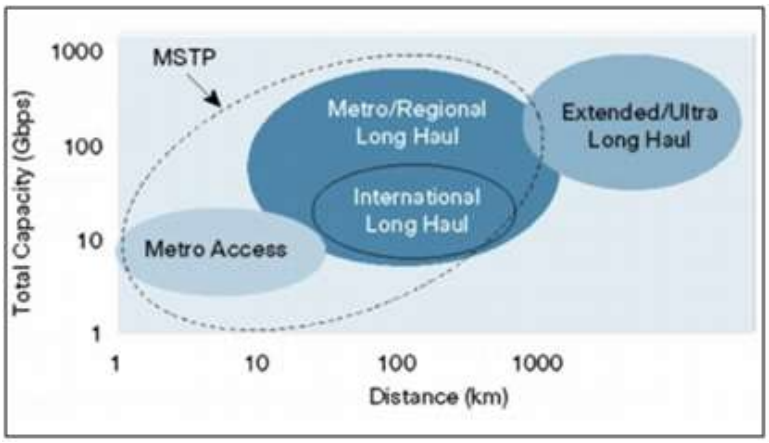
The result of the combined node and network alarm correlation is that the node detecting the actual failure sends one notification to the management interface, and all the other nodes are prevented from doing so and provide the alarm list on demand only.

Easy node and network setup, rapid troubleshooting, no need for service calls, and a sophisticated management function with new added-value services such as alien wavelength management make the Cisco NCS 2006/ONS MSTP superior to competing solutions. The Cisco NCS 2006/ONS MSTP is specifically designed to hide the DWDM complexity from the user, while providing a rich set of management functions.

Network Management

Cisco introduced the ONS MSTP in 2003, which has transformed metro and regional DWDM networks. Early deployments of metro and regional DWDM focused primarily on fiber relief and used long-haul DWDM technologies. However, long-haul DWDM products are expensive and operationally inefficient for metro networks. The adoption of DWDM by competitive local exchange carriers (CLECs) and multiple system operators (MSOs) advanced the technology to low-cost-per-bit solutions, but operational efficiency continued to be a problem, particularly with footprint, power, network setup, and optical power management. The emergence of higher-bandwidth services, such as Gigabit Ethernet and storage-area networks (SAN), led to the introduction of multiple “point products,” but for multiple service offerings these solutions continue to be inefficient.

The Cisco NCS 2006/ONS MSTP provides capital and operational efficiency by addressing the increasing demand for multiple services, greater transport capacity, networking flexibility, multiple distance options, and management simplicity in a single platform. With innovative technology, such as ROADM and wavelength management intelligence, the Cisco NCS 2006/ONS MSTP addresses the needs of both service providers and business customers.

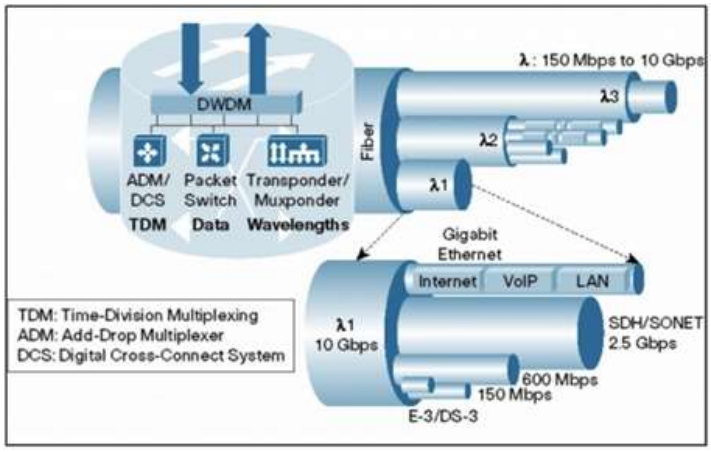


Transforming Metro and Regional Networks with the Cisco NCS 2006/ONS MSTP

Design Innovation

Traditional metro DWDM solutions have rigid network architectures and require considerable manual interaction to manage, particularly when new sites are added or network capacity is upgraded. Traditional solutions are optimized for low-cost-per-bit, fixed topologies that cannot efficiently address the operational constraints of metro and regional networks. Metro networks face unique challenges, such as the inherent difficulty in predicting demand for services such as TDM, data, SAN, and video, or service bandwidth at 1Gb, 2.5Gb, 10Gb, even 100Gb rates.

Furthermore, complexities arise when managing metro DWDM network architectures that are typically ring topologies—open ring, multi-hub ring, closed ring—because of dynamic add/drop traffic patterns. Traditional solutions cannot automatically manage DWDM “analog” variables, such as optical noise, dispersion, dynamics of adding and dropping wavelengths, and optical performance monitoring. The Cisco NCS 2006/ONS MSTP has been designed from the start to mitigate these challenges, and the use of ROADMs makes it easy to modify traffic patterns without affecting existing traffic. The Cisco NCS 2006/ONS MSTP can natively transport any service—TDM, data, or wavelengths—over a metro or regional network at a lower cost than traditional wavelength-only DWDM solutions. To summarize, multiservice capabilities simplify service planning, and software intelligence simplifies operations.



Cisco NCS/MSTP Architecture

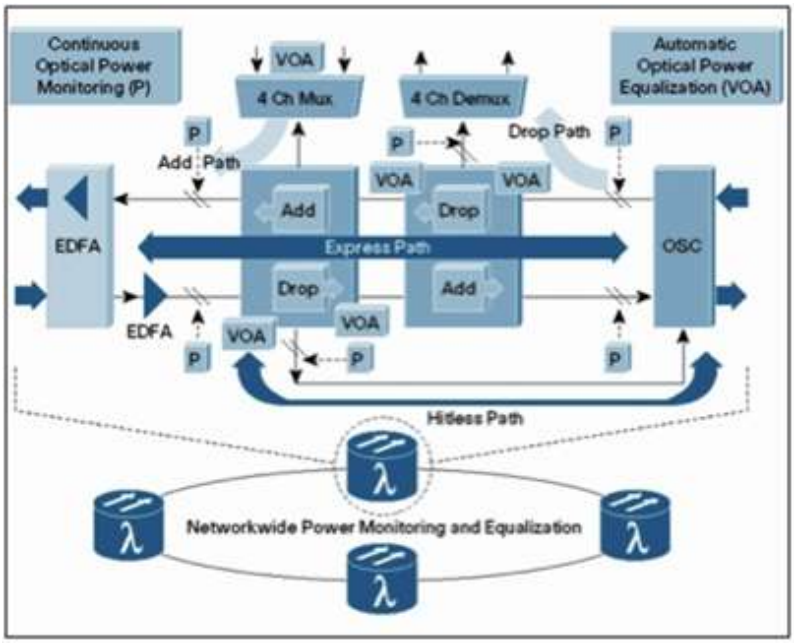
Technology Innovation

The Cisco NCS 2006/ONS MSTP uses advanced photonics technologies, combined with innovative engineering, to address the unique requirements for metro and regional networks:

- Industry-leading 1- to 40-channel ROADM granularity, supporting ROADMs reduced complexity in network planning and service forecasting
- Scalable, 1 to 96 wavelengths in a single network for superior cost-versus-growth trade-off
- Transport of 16Mb to 100Gb wavelength services, as well as aggregated TDM, data, and storage services for maximum service flexibility
- Transmission capability from tens to hundreds of kilometers (up to 4500 km) through the use of advanced amplification, dispersion compensation, and EFEC technologies
- Ready-to-deploy card architecture for complete flexibility in configuring DWDM network elements—terminal nodes, optical add/drop nodes, line amplifiers, and dispersion compensation—within amplified or unamplified networks
- High shelf density for high-bandwidth (40Gb/100Gb) wavelength services
- Integration of pre- and post-amplification
- Use of software-provisionable, Small Form-Factor Pluggable (SFP) and 10 Gigabit SFP XFP client connectors, and wavelength tunability31 for reduced inventory
- Multilevel service monitoring: SONET/SDH, G.709 digital wrapper, optical service channel for unparalleled service reliability

Automatic Optical Power Management

An important capability of the Cisco NCS 2006/ONS MSTP is automatic optical power management. Traditional DWDM solutions require considerable manual interaction to turn up, manage, and upgrade DWDM networks. Through strategic optical power monitoring and variable optical attenuation (VOA), Cisco NCS 2006/ONS MSTP software is able to dynamically monitor and control optical power, a critical operation in amplified DWDM networks. The Cisco NCS 2006/ONS MSTP software reconstructs a model of the provisioned DWDM network. Software algorithms then automatically provide network-wide optical power management by equalizing channels that are intrinsically unequal, adjusting for optical paths with different insertion losses (add, drop, express, and hitless paths) and maintaining constant power when wavelengths are added or dropped.

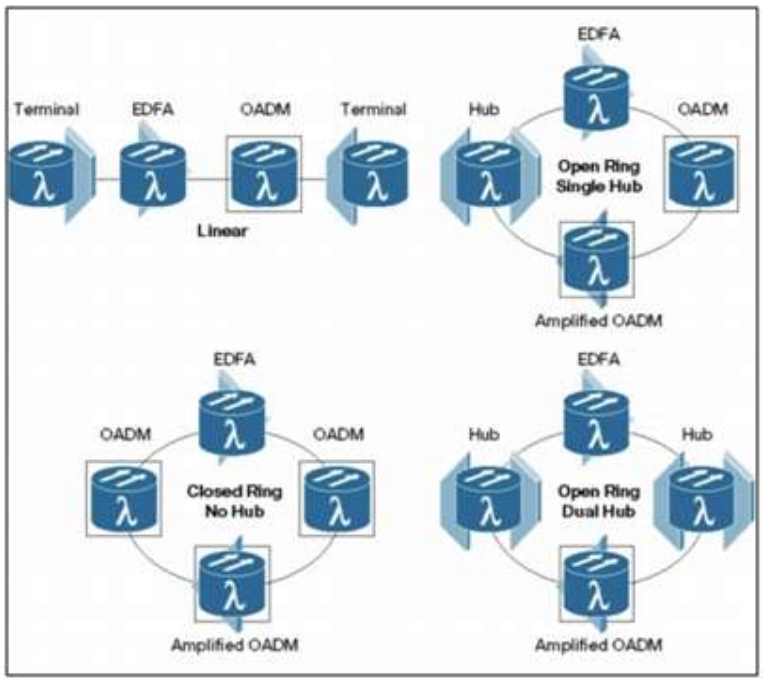


Network-wide Power Monitoring and Equalization

Commented [AM3]: Too blurry

Topology Flexibility

Traditional DWDM solutions were optimized for point-to-point transmission. Metro and regional DWDM networks require ring topologies with complex traffic patterns. The Cisco NCS 2006/ONS MSTP can be configured to support any metro or regional DWDM topology, as shown below.



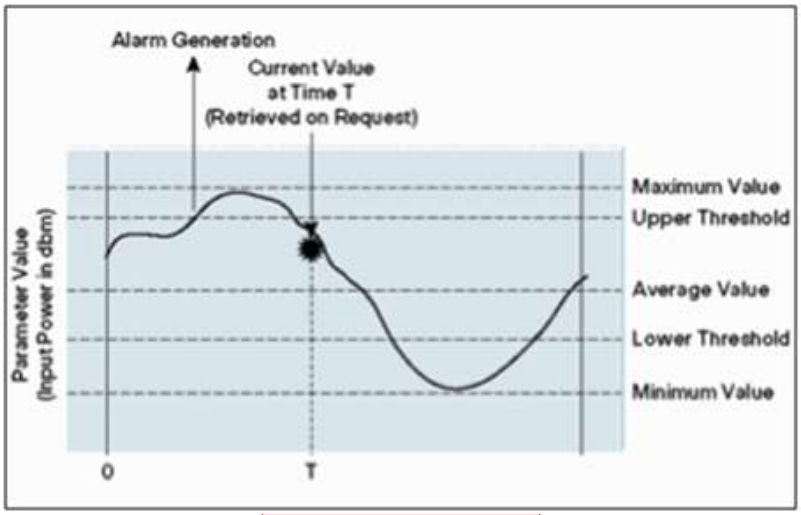
Flexible Networks with Cisco NCS 2006/ONS MSTP

Target networks include:

- **Access rings** – To collect traffic from multiple remote sites to a central hub. Capacity per ring is typically low (up to eight wavelengths).
- **Metro inter-office facility (IOF) rings** – To interconnect metro central offices. Ring capacity can be high and the traffic pattern distributed. One or all wavelengths may be dropped/added at intermediate sites using ROADMs.
- **Metro core** – The backbone of large metro networks. Ring capacity is typically high and ring circumferences are large. Wavelength add/drop flexibility is essential, and ROADMs play a critical role in this design.
- **Long regional spans** – IOF and core rings with long spans that do not have a requirement to add/drop wavelengths at intermediate sites.
- **Dedicated long-haul network alternative** – When traffic capacity is not high, it can be more cost effective to eliminate the long-haul network as a separate layer, and use the free capacity of the interconnected regional networks.

Simple Management and Monitoring

Cisco NCS 2006/ONS MSTP network management is based on easy-to-use GUIs. Optical service channels are used for communication in the network, similar to the data communications channel (DCC) in the MSPP. GUIs display a range of views from the network level to the port level for easy provisioning and monitoring. Cisco NCS 2006/ONS MSTP network management also monitors the DWDM "analog" components and generates SONET/SDH-like alarms. Below is a graphical representation showing the software generating an alarm when a provisioned threshold has been violated. Combined with the "digital-level" monitoring of SONET/SDH and G.709 digital wrapper, the Cisco NCS 2006/ONS MSTP provides unparalleled service reliability. Problems can be discovered and corrected before revenue-generating services are affected.



Power Monitoring and Reporting

Commented [AM4]: Too blurry

Metro and Regional Networks Transformed

With its multiservice capability, innovative optical technology, automatic optical power management, industry-leading ROADM, and MSPP-like ease of use, the Cisco NCS 2006/ONS MSTP transforms how metro and regional DWDM networks are built and managed. By combining multiple services and intelligent DWDM, the Cisco NCS 2006/ONS MSTP will significantly reduce both capital expenditures and operating expenses for today's service providers and business users.

Network Planning and Design

The Cisco Transport Planner (CTP) is a fully comprehensive DWDM network design and design-management tool (e.g., delta planning, rack layout definition, cabling procedure) that allows Cisco NCS 2006/ONS MSTP customers to concentrate on service definition and availability while radically simplifying the process of comparing alternative service-delivery and investment scenarios. CTP uses the latest in optical transport technologies from the Cisco Optical portfolio, featuring the Cisco NCS 2006/ONS MSTP with fully integrated multi-degree ROADM technology, to help engineer the optimal DWDM infrastructure capable of any-to-any service delivery for linear, ring, multi-ring, and mesh networks.

The output from CTP provides content beneficial to both the design and deployment phases, including system performance reporting, BOM generation, graphical layouts of racks and shelf configurations, optical connections between nodes, and downloadable provisioning and configuration settings for each optical node.

The benefits of designing with CTP extend beyond deployment to the in-service phase supported by MSTP features that significantly reduce the operating expenses (OpEx) traditionally associated with wavelength-division multiplexing (WDM) networks and optical add/drop multiplexers (OADM) by automating labor-intensive operations. The intelligent DWDM functionalities of the Cisco NCS 2006/ONS MSTP dynamically monitor and adjust wavelength power and signal conditions to help ensure optimal compliance with SLAs, giving providers proactive control over a customer's service experience.

Challenge
Designing DWDM networks has always been a complex task because of the intrinsic nature of optical transmission, which is based on analog technology despite the transport of digital signals. Many different parameters have to be accounted for because of linear and nonlinear effects. Linear effects include noise accumulation, optical power budget, and chromatic dispersion (CD) effects; nonlinear effects include cross-phase modulation, self-phase modulation, and four-wave mixing. Metro and metro-regional DWDM networks, which usually require many add/drop locations, have an additional layer of complexity because the same network supports different optical paths that must use the same common optical units (such as optical amplifiers and dispersion compensation units).

The design and optimization of a DWDM network is an interactive process that requires considering all the constraints of the system:

- Distance and insertion loss of the network spans
- Type and number of services required in each network location

Based on these constraints, a DWDM network design should optimize the hardware placement in the different network nodes to minimize the cost of the design. When fixed OADM units are used for capacity add/drop in the different sites of the network, the design needs to optimize the number and type of units used in each node to reduce overall network cost.

ROADM in DWDM networks is expected to provide complete flexibility in the traffic pattern. This flexibility needs to be accounted for and supported by the network design tool to verify and support the different optical paths existing in the network.

Solution
The Cisco NCS 2006/ONS MSTP offers a complete solution for designing, provisioning, and maintaining an optical DWDM network, including:

- **Cisco Transport Planner (CTP)** – This Java-based application helps users model and design DWDM networks based on the Cisco NCS 2006/ONS MSTP.
- **DWDM units** – A complete set of DWDM transport and aggregation units helps deliver simple, fast, and intelligent optical capabilities.
- **Intelligent optical transmission software** – Each network element can automatically support transport functionalities in the DWDM domain similar to those in the SONET, SDH, and data domain, defining what is now considered next-generation DWDM transport.
- **Cisco Transport Controller (CTC)** – This integrated tool can be used to support installation and provisioning at the network level.

These benefits surpass those that are available from a simple hardware-based solution. The Cisco NCS 2006/ONS MSTP solution helps users design, maintain, and optimize their DWDM networks to maximize network performance and save on operational costs.

The CTP tool supports the user from the design phase to the deployment phase of a DWDM network. This tool was originally developed to help create BOMs for customer-specific designs. The latest release of the tool (Release 10.5) has evolved significantly from the original version to support the new functionalities provided by the Cisco NCS 2006/ONS MSTP and NCS2K.

Key features and functionalities of CTP include:

- **GUI-based tool to optimize DWDM layer design** – Users normally have the availability of different locations in the network besides those where traffic add/drop is required. The CTP helps users determine the type and quantity of equipment to be used not only for the locations where add/drop is required but also for all the other locations. The tool accounts for the network topology, the fiber types and lengths, and current and future traffic demand.
- **Any-to-any, fully flexible network design** – Taking advantage of the availability of ROADM units in the Cisco NCS 2006/ONS MSTP, the CTP helps users design a DWDM network with complete flexibility in terms of both source-destination patterns and interfaces and services.
- **ROADM optimization** – Taking advantage of the availability of multiple ROADM solutions in the Cisco NCS 2006/ONS MSTP, CTP automatically optimizes the number of channels (e.g., 40 channels vs. 80 channels) and the configuration (e.g., degree-2 vs. multi-degree) of the ROADMs in the network. CTP can also manage the scalability requirements and enable an in-service upgrade to add new directions and new traffic patterns to an existing design.

CTP provides flexible design options by controlling which and how many of the nodes will be equipped with ROADM. In addition, users can determine which of the nodes in the network shall be equipped with multi-degree ROADM functions. Users can also select the traffic and connectivity types to be used to route traffic among the nodes, for any-to-any design, which can also be supported in multi-ring and mesh networks, giving users complete control to accommodate different network scenarios and minimize the overall cost of the design.

- **Complete set of DWDM interface options** – The Cisco NCS 2006/ONS MSTP is the transport

DWDM platform for all Cisco units and platforms equipped with a DWDM colored interface. CTP can support the design of networks where the optical signals are coming from any of the available Cisco devices. The user simply selects the client service type or forces the specific unit to be used for any given service. The flexibility of the platform and the CTP help users evaluate the cost of various options.

- **Custom-defined DWDM interfaces** – The Cisco NCS 2006/ONS MSTP manages direct interconnection of DWDM interfaces to help reduce capital expenditures (CapEx) associated with interfacing different equipment through gray optics. From the network design perspective, CTP can also accommodate third-party DWDM interfaces by allowing the user to input interface-specific parameters and then using this interface in the network design.
- **Support for network design changes** – One of the most useful services the CTP gives Cisco NCS 2006/ONS MSTP users is to assist them in the evaluation and definition of changes requested to scale and evolve an existing network (delta planning). Although this clearly helps when fixed OADM units are used for the design, delta planning allows the user to add and remove ROADM nodes from a design, add new services to the network, and change the flexibility associated with an existing or a planning design. Delta planning also gives the user a complete set of reporting features to help determine what needs to be changed and where, at the node and network level.
- **Detailed system performances results report** – For each of the services defined at the network level, the CTP provides the relevant optical parameters required to understand whether the traffic could be supported. The tool gives users a quick indication of the results based on color-coded icons, as well as the opportunity to view comprehensive reports. Reporting on overall latency for service types that may be affected by this parameter is available, as well.
- **Complete node and network BOM** – Overall cost is one of the most critical parameters to control when designing optical networks. CTP can synchronize the price of each item from the Cisco.com website and, based on this information, can generate a complete BOM for the network and for each node in the design. This information can be used to evaluate different scenarios, using multiple options and constraints for the network design. The latest release of the CTP (Release 10.5) also supports custom pricing lists that can be saved, exported, and exchanged among users.
- **Comprehensive support from design to installation** – CTP supports both the design and the commissioning phases of a DWDM network. The tool provides a graphical layout of the racks, shelves, and units of each network location, so this information can be available during the planning or installation of the network. In addition, CTP provides a complete list of the optical path cords that have to be installed between the different units to allow the proper signal flow at the node and network levels. CTP can also be used to support situations in the field when the fiber parameters may differ from those considered in the original design. In this case, it is possible to run the tool in "install mode," which validates the design against the new fiber data without changing the overall BOM.
- **Automatic data exchange between design and Cisco NCS 2006/ONS MSTP** – CTP can be used to accelerate the installation and commissioning phase of the Cisco NCS 2006/ONS MSTP in the field. The tool can generate provisioning files, which are then used to configure the relevant optical parameters at the node level. Starting with the latest release of CTP (Release 10.5), the same file can also be used to pre-provision the individual cards in the nodes of the network, allowing users to make sure the installation in the field has been properly done, even before the first DWDM wavelength is provisioned across the nodes of the network.

The direct data exchange between Cisco Transport Planner (CTP) and the Cisco NCS 2006/ONS MSTP is an important functionality, allowing a very simple approach to DWDM network design and deployment. All the relevant design parameters used by CTP to configure and validate the optical connections in the network can provide the Cisco NCS 2006/ONS MSTP with required reference levels. These references are then automatically used by each network node to support the following intelligent optical transmission features:

- **Automatic node setup** – This feature automatically sets and maintains all the optical paths available in a DWDM node. This automatic control is provided directly by the node controller unit and requires neither human intervention nor the use of management interfaces.
- **Automatic power control** – This feature operates at two different levels in the network so it can react to both catastrophic (fast) events and (slow) degrades. Catastrophic events are managed directly at the optical amplifiers level to help ensure the fastest reaction possible to a sudden change in the number of channels passing through the units. Degrades (such as additional fiber loss or aging) are managed at the network level as an additional automatic system reaction to changes in the network operating conditions. The DWDM nodes exchange power-levels data and can adjust amplifier gain if the measured optical power level differs too much from the expected value. This multilayered control mechanism helps assure that the optical network is always operating optimally, despite changes at the physical layer.
- **Wavelength path provisioning (WPP)** – This feature allows the Cisco NCS 2006/ONS MSTP to manage DWDM connections the same way SONET, SDH, and data circuits are managed by the Cisco ONS MSPP. The user can create Optical Channel Network Connections (OCHNCs) as well as Optical Channel Client Connections (OCHCCs) and then manage them as MSPP circuits. One of the primary advantages of WPP is that all ROADMs in the optical path are automatically set and maintained upon circuit creation, without ever requiring manual operation. OCHNCs are normally used to provision optical circuits when DWDM interfaces are not part of the Cisco NCS 2006/ONS MSTP. An example of this provisioning is when Layer 2 or Layer 3 line cards are directly interfaced with the Cisco NCS 2006/ONS MSTP. OCHCCs are normally used to provision optical circuits between the near- and the far-end client port of Cisco NCS 2006/ONS MSTP transponder or muxponder units. In this case, the user can manage every client service, even if the service is aggregated with other services and transported across the network as part of a higher-bit-rate optical channel trail (OCH-Trail).

With its multiservice capability, innovative optical technology, automatic optical power management, and MSPP-like ease of use, the Cisco NCS 2006/ONS MSTP transforms how DWDM networks are built and managed. Combining multiple services and intelligent DWDM, the Cisco NCS 2006/ONS MSTP significantly reduces both CapEx and OpEx for today's optical networks.

Emerging Development Focus
Cisco's Optical Transport products have seen a wealth of functional upgrades over the past two years. Operationally the solutions have become easier to operate and install. There have been significant improvements in service port density, which in turn has resulted in more efficient rack space utilization, as well as lower power requirements. All of which help our customers realize operational savings.

Cisco has led the industry with a number of exclusive items recently: Tunable XFPs with optical performance equal to a fixed transponder and ROADM on a single blade which shrinks the node footprint significantly and integrates amplification, while continuing to improve the ease of use and troubleshooting capabilities on the well-known CTC interface.

While the recent enhancements to the Cisco Optical product line are significant, any good manufacturer continues to develop their offering. The following excerpt will shed some light on Cisco's R&D focus over the next couple of years.

Carrier Packet Transport (CPT) Multiprotocol Label Switching – Transport Profile (MPLS-TP) Fully Integrated with DWDM
CPT unifies both packet and transport technologies in a single platform. It integrates DWDM, optical transport network (OTN), Ethernet, and MPLS-TP functionality, giving service providers a strong foundation for the next generation of transport.

The CPT system offers:

- A unique architecture with remote managed satellite units
- A compact, energy-efficient form factor
- Outstanding Gigabit Ethernet and 10 Gigabit Ethernet port density per rack unit
- Integrated A-to-Z management for packet and transport

Cisco is committed to optical development and convergence; below are highlights of key features and functionality. Cisco is also committed to Denton ISD's success and is willing to partner in further developing the future roadmap to meet the needs of this demanding space.

NCS2K WSON Control at DWDM Layer
The omni-directional, colorless, and contentionless ROADM nodes provide the necessary flexibility for the architecture of the network to be able to leverage an embedded optical control plane, which is aware of DWDM-specific properties and constraints. Wavelength switched optical network (WSON) is the standard-based architecture, which Cisco has selected as the foundation of the optical control plane.

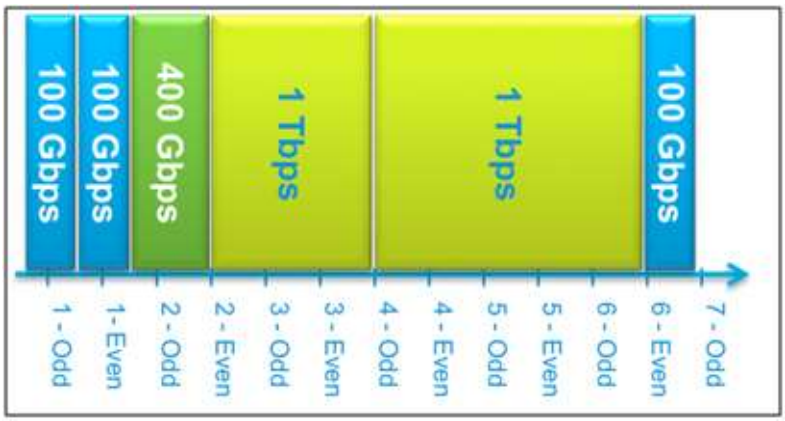
- WSON allows higher layer services to interact with the optical transport layer to provision new services or wavelengths, as well as provide protection and restoration capabilities efficiently compared to current modes of operation.
- Cisco's approach to WSON is to leverage a distributed architecture, so that the network has all the information required for the proper actions to be taken, as well as complete visibility, understanding, and management of both linear and non-linear effects related with the traffic that is running on a given span at any given moment.

A DWDM-aware Generalized Multiprotocol Label Switching (GMPLS) control plane enables:

- Automatic network discovery
- Automatic A-to-Z provisioning
- Impairment knowledge for lambda routing and re-routing
- Restoration

Flex Spectrum ROADM

While the Denton ISD network would not see a benefit from the emerging Flex Spectrum ROADM technology today, it can be evolved in the future to incorporate the technology where cost justified. Standard ROADM nodes support fixed grids, usually 50Ghz or 100Ghz spaced. The fixed grid is becoming a challenge as the data rates continue to increase. As we look into the future, flexible spectrum will be necessary to address 400Gb and higher rate signals. A flexible spectrum will remove restrictions from channel spacing and allow a mix of wavelengths on different bit rates within the same system. Cisco supports a 96-channel Flex Spectrum ROADM that is capable of being gridless, colorless, omni-directional, and contentionless.



Cisco Flex Spectrum ROADM

Switching Layer OTN to MPLS

Cisco has recently announced its NCS product line. This new platform will have multiple personalities depending on the service cards the operator chooses to utilize. With an agnostic fabric, the NCS product can provide OTN, TDM, and ultimately MPLS switching. These platforms make up core switching elements that allow providers to maximize their lambda utilization by efficiently grooming the underlying protocols onto fully packed lambdas between drop or transit locations. These solutions could work seamlessly from an end-to-end perspective and network management perspective with the ONS DWDM layer proposed for Denton ISD.

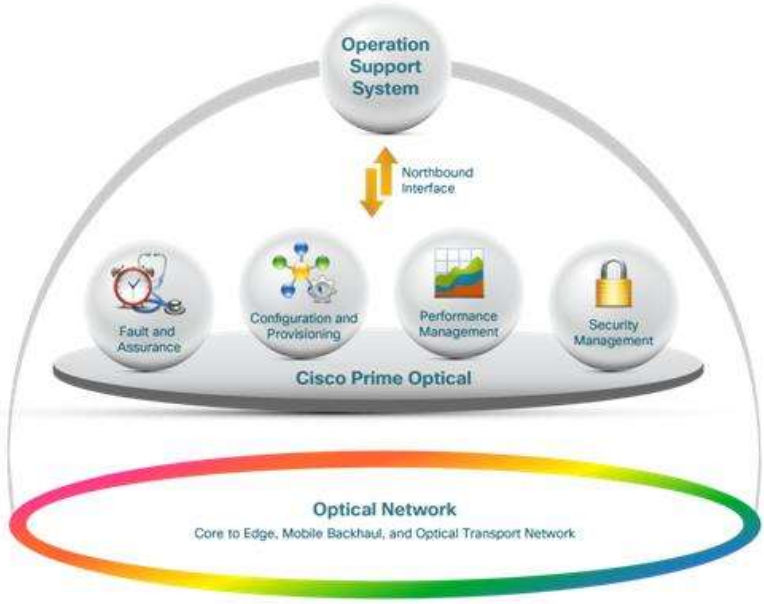
Cisco Prime Optical Network Management (Optional OSS System)
Cisco Prime Optical can be used by Denton ISD to manage the NCS 2006/ONS 15454 devices in the network. While the vast majority of daily OAM&P features needed to manage the ONS network directly can be accomplished with the robust embedded element manger CTC, Prime Optical extends that functionality to allow a client/server based holistic manager of managers' platform.

Cisco Prime Optical Overview
Service providers around the world are transitioning from time-division multiplexing (TDM)-based networks to all packet transport networks to meet the continuing surge in bandwidth requirements. With this transition, service providers face tough operational challenges in management of their optical networks as they continue to evolve and adapt to changing market requirements. To help ensure profitability, business agility, and quality of service (QoS), service providers need a management system equipped to efficiently handle converged technologies, as well as diverse equipment and applications that make up this complex, ever-evolving optical network.

Cisco Prime Optical is a simplified, yet complete, management solution that meets this requirement. It is a single software solution that manages the converged IP and optical network from access to core, supporting both legacy TDM and DWDM technologies for efficient delivery of high-quality next-generation services. Through automated and advanced mechanisms for configuration, provisioning, and troubleshooting, Cisco Prime Optical helps operators to efficiently execute end-to-end circuit creation and manage every point within the converged network with unprecedented accuracy and scale.

Benefits

- **Business agility** – Accelerates time to market of services through operational scale and efficiency in network discovery, configuration, provisioning, troubleshooting, and change management
- **Enhanced customer satisfaction** – Helps enable rapid resolution to network issues through advanced diagnostics and real-time service-level agreement (SLA) monitoring
- **Lower integration costs** – Reduces both capital expenditures (CapEx) and operating expenses (OpEx) through pre-integration with the Cisco Prime for IP Next-Generation Network (NGN) suite of management applications, as well as standards-based interfaces to third-party applications



Features

- GUI-based user interface with automated configuration and provisioning
- Support for TDM, Wavelength Switched Optical Networks (WSON), DWDM, and Synchronous Optical Networks Synchronous Digital Hierarchy (SONET/SDH)
- Detailed topology maps with drill-down navigation, displaying both optical and packet network devices
- Support for up to 5,000 optical network elements
- Redundant software and hardware support for high availability (HA), supporting Linux
- Standards-compliant (CORBA TMF 814 v.3) information model and northbound interface (NBI) for integration
- Support for Linux and Cisco Unified Computing System (UCS), with embedded Oracle options

Benefits – Target Customers

- Service providers who need an efficient and productive optical infrastructure with one view of the nationwide optical network supporting fault, configuration, performance, and security (FCAPS) management to constantly monitor the key performance indicators of the optical network
- Service providers or large enterprises using the optical transport network to transport vital information for their businesses, requiring monitoring the health of the network 24 hours a day, 7 days a week
- Service providers who want to integrate the management of their Cisco optical transport network in their operations support systems (OSSs) umbrella

- Service providers who need a carrier-class element manager software (EMS) solution that includes HA and scalability for their Cisco optical transport network

Competitive Differentiation

- Cisco Prime Optical facilitates the deployment of new packet transport networks and the management of legacy time-division multiplexing (TDM) technology. The following features enable the smooth transition to an integrated transport network.
  - Point-and-click provisioning of tunnels in the MPLS-TP domain
  - Ethernet Virtual Circuit (EVC) provisioning and assurance
  - Pseudowire provisioning and assurance
- With Layer 2 service alarm isolation, you can quickly locate which Layer 2 services are affected by an existing Layer 2 service alarm, reducing time to diagnose and repair.
- Cisco Prime Optical can be installed on Cisco UCS servers running Linux Red Hat Enterprise distribution which provides lower application TCO.
- Cisco Prime Optical is more flexible and less expensive to operate than most competitors' solutions. Cisco Prime Optical can reconfigure DWDM network paths remotely, without the intervention of field operators to adjust patch cable or power levels.
- An Oracle database is embedded in the application and installs seamlessly with Cisco Prime Optical at no additional cost to the customer. The result is lower CapEx and reduced OpEx.

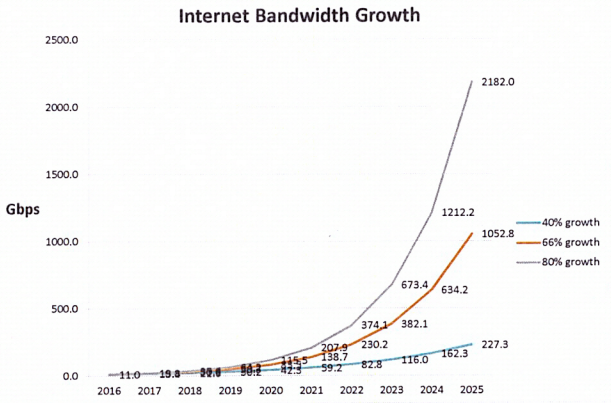
Denton ISD

Annual growth rate	40%	66% COSN STD	80%
Plot labels	40% growth	66% growth	80% growth
Starting value, Gbps	11.0	<-- Input Value - What Internet BW should be Today to Get to USAC Target in 2018	

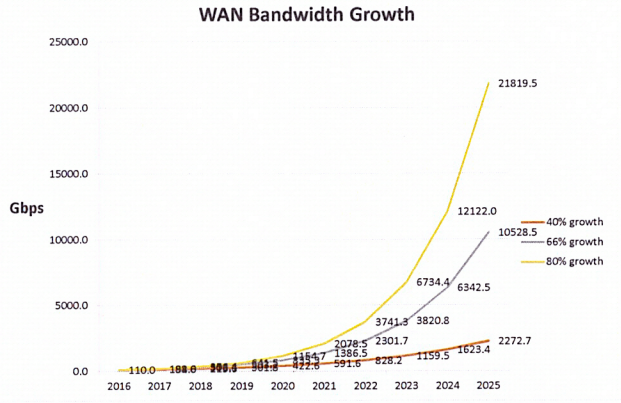
CoSN SEND Guidance: Plan to double your aggregate Internet capacity every 18 months (66% annualized growth rate)

Internet Access School Year	Gbps		
2016	11.0	11.0	11.0
2017	15.4	18.3	19.8
2018	21.6	30.3	35.6
2019	30.2	50.3	64.2
2020	42.3	83.5	115.5
2021	59.2	138.7	207.9
2022	82.8	230.2	374.1
2023	116.0	382.1	673.4
2024	162.3	634.2	1212.2
2025	227.3	1052.8	2182.0

Aggregate WAN School Year	Gbps		
2016	110.0	110.0	110.0
2017	154.0	182.6	198.0
2018	215.6	303.1	356.4
2019	301.8	503.2	641.5
2020	422.6	835.3	1154.7
2021	591.6	1386.5	2078.5
2022	828.2	2301.7	3741.3
2023	1159.5	3820.8	6734.4
2024	1623.4	6342.5	12122.0
2025	2272.7	10528.5	21819.5



FCC/E-Rate Modernization Order Maintains a 10 to 1 WAN to Internet Bandwidth threshold for School Districts



Quick WAN Calculation Tool for School Districts

#Students/Faculty/Staff	High	Middle/Acad.	Elem / Other	10/5/1	20/10/5	FCC WAN	FCC Internet
31,845	5	8	23	113	295	318.45	31.845
				Aggregate WAN BW in Gigabits			Gb

28,950 Enter Number of Students in District
2,895 Staff & Faculty Impact = 10% of Student Population

Historical Internet Bandwidth Analysis - Input Values in Red Below

	2011	2012	2013	2014	2015	2016	Bandwidth Growth % 5 Year Average
Bandwidth (Gbit/s)	1	2	2	2	2	10	
Growth Percentage		100.00%	0.00%	0.00%	0.00%	400.00%	100.00%

Bandwidth Needed per School in Gbps by 2016 based on 40% Annual Growth			Internet Bandwidth
11.00	4.13	0.96	11.00
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2016 based on 66% Annual Growth			Internet Bandwidth
11.00	4.13	0.96	11.00
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2016 based on 80% Annual Growth			Internet Bandwidth
11.00	4.13	0.96	11.00
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2017 based on 40% Annual Growth			Internet Bandwidth
15.40	5.78	1.34	15.40
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2017 based on 66% Annual Growth			Internet Bandwidth
18.26	6.85	1.59	18.26
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2017 based on 80% Annual Growth			Internet Bandwidth
19.80	7.43	1.72	19.80
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2018 based on 40% Annual Growth			Internet Bandwidth
21.56	8.09	1.87	21.56
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2018 based on 66% Annual Growth			Internet Bandwidth
30.31	11.37	2.64	30.31
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2018 based on 80% Annual Growth			Internet Bandwidth
35.64	13.37	3.10	35.64
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2019 based on 40% Annual Growth			Internet Bandwidth
30.18	11.32	2.62	30.18
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2019 based on 66% Annual Growth			Internet Bandwidth
50.32	18.87	4.38	50.32
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2019 based on 80% Annual Growth			Internet Bandwidth
64.15	24.06	5.58	64.15
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2020 based on 40% Annual Growth			Internet Bandwidth
42.26	15.85	3.67	42.26
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2021 based on 40% Annual Growth			Internet Bandwidth
59.16	22.19	5.14	59.16
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2022 based on 40% Annual Growth			Internet Bandwidth
82.82	31.06	7.20	82.82
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2023 based on 40% Annual Growth			Internet Bandwidth
115.95	43.48	10.08	115.95
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2024 based on 40% Annual Growth			Internet Bandwidth
162.34	60.88	14.12	162.34
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2020 based on 66% Annual Growth			Internet Bandwidth
83.53	31.32	7.26	83.53
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2021 based on 66% Annual Growth			Internet Bandwidth
138.65	52.00	12.06	138.65
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2022 based on 66% Annual Growth			Internet Bandwidth
230.17	86.31	20.01	230.17
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2023 based on 66% Annual Growth			Internet Bandwidth
382.08	143.28	33.22	382.08
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2024 based on 66% Annual Growth			Internet Bandwidth
634.25	237.84	55.15	634.25
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2020 based on 80% Annual Growth			Internet Bandwidth
115.47	43.30	10.04	115.47
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2021 based on 80% Annual Growth			Internet Bandwidth
207.85	77.94	18.07	207.85
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2022 based on 80% Annual Growth			Internet Bandwidth
374.13	140.30	32.53	374.13
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2023 based on 80% Annual Growth			Internet Bandwidth
673.44	252.54	58.56	673.44
High	Middle	Elem	

Bandwidth Needed per School in Gbps by 2024 based on 80% Annual Growth			Internet Bandwidth
1212.20	454.57	105.41	1212.20
High	Middle	Elem	