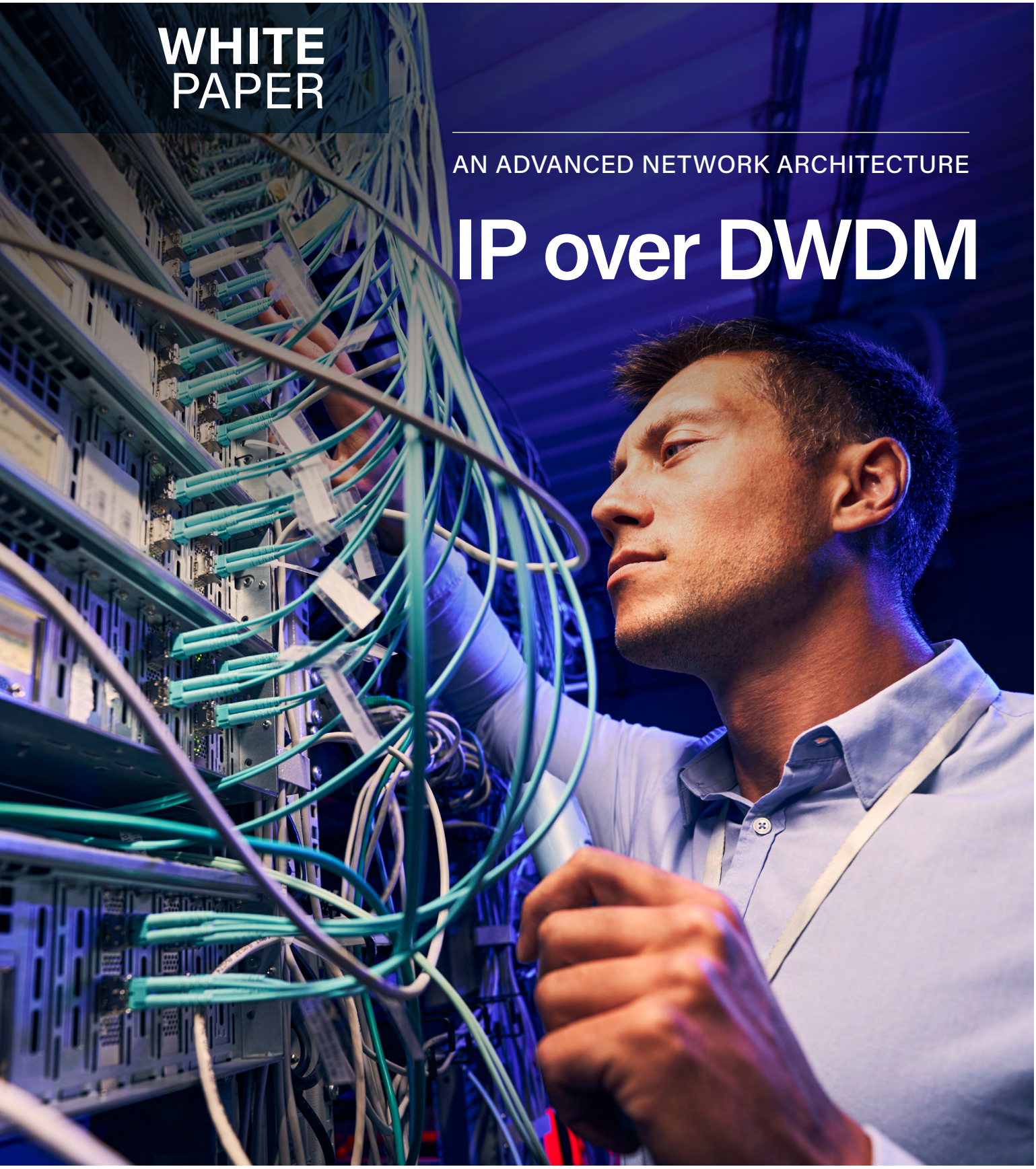
WHITE PAPER

AN ADVANCED NETWORK ARCHITECTURE

IP over DWDM



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INTRODUCTION

The demand for high-speed, reliable, and cost-effective data transmission continues to grow as internet usage and communication technologies become integral to everyday life. To address this demand, telecommunication service providers and data center interconnect (DCI) operators are increasingly turning to Internet Protocol over Dense Wavelength Division Multiplexing (IP over DWDM or IPoDWDM) as an effective solution. Dell'Oro Group states, "IPoDWDM will displace a portion of the WDM market. We believe this displacement started in 2023 and will continue for the foreseeable future. As a result, WDM Metro revenue is forecast to grow at a five-year CAGR of 2% rather than the historical rate of 5% to 9%. Most of this reduction is expected to occur in direct purchases of WDM Metro equipment for DCI."

This white paper explores the networking challenges faced by telecom service providers and DCI operators, highlights the limitations of traditional optical transport networks, and examines the value and advantages of IPoDWDM technologies. Furthermore, it provides design use cases and best practices for unified solutions leveraging IPoDWDM in DCIs, metro networks, and beyond.

CHALLENGES IN MODERN NETWORKS

Network operators across various domains, including DCIs, metro networks, and wireless fronthaul, are encountering significant challenges:

1. **Increasing Bandwidth Pressure:**
   Rapidly growing data traffic is straining existing infrastructure, necessitating scalable solutions to meet demand.

2. **Costly and Lengthy Fiber Deployment:**
   Deploying outside plant fiber is prohibitively expensive and time-consuming, often making it impractical.

3. **Complexity of Traditional Optical Transport Networks:**
   For use cases with distances under 80 km, traditional optical transport network (OTN) solutions are excessively costly and overly complex.

4. **Lack of Unified Solutions:**
   Many operators lack access to simple, cost-effective, and unified solutions for diverse scenarios. Unified solutions, comprising transceivers and passive DWDM multiplexer/demultiplexer (mux/demux) filters, remain elusive.

5. **Limited Scalability:**
   Traditional OTN solutions often require major upgrades to accommodate growth, limiting their scalability.

6. **Closed Architectures:**
   Proprietary systems and lack of openness hinder interoperability and innovation.

Traditional OTN technologies are expensive, complex, and ill-suited for applications within 80km. They lack scalability, flexibility, and openness, making them suboptimal for modern DCI and metro network deployments.

ADVANTAGES AND CONSIDERATIONS

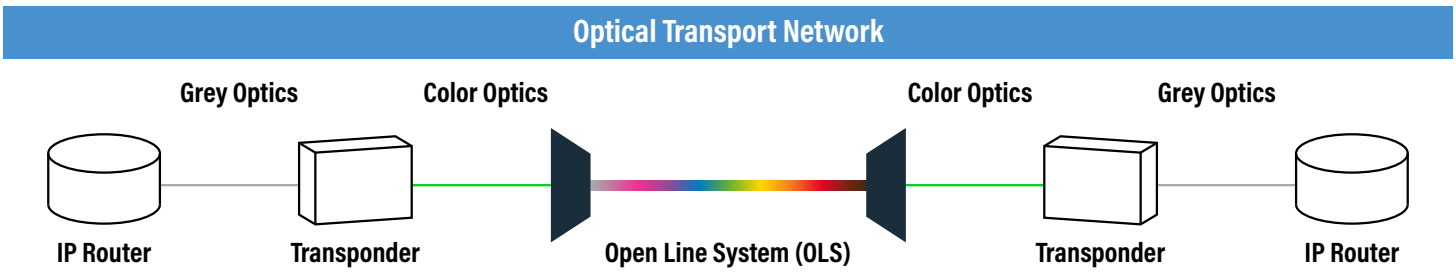
Integrating IP routers and switches into OTNs has become increasingly important as the demand for higher bandwidth capacity and more efficient data transmission continues to grow. Tunable DWDM pluggable transceivers and passive DWDM filters offer a unified solution to these challenges.

Tunable DWDM pluggable transceivers are versatile devices that can be easily tuned to different wavelengths, allowing for dynamic adjustments and optimal use of the optical spectrum. These transceivers also support high data rates, making them ideal for long-distance data transmission. Their compatibility with various IP routers and switches allows them to seamlessly integrate into existing networks without causing disruptions.

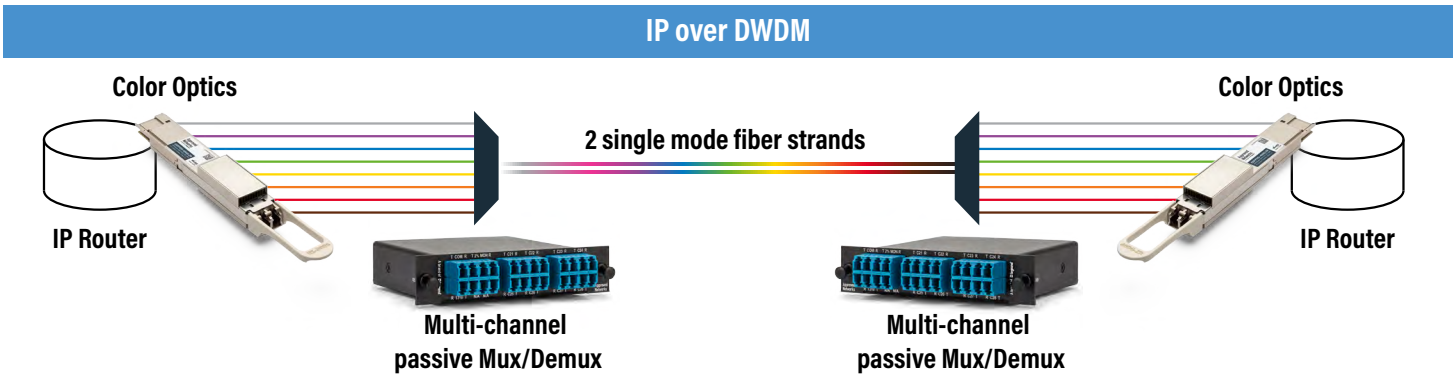
Passive DWDM filters, on the other hand, play a crucial role in increasing the data-carrying capacity of optical fibers. By multiplexing multiple wavelengths onto a single fiber pair and demultiplexing them at the receiving end, these filters significantly increase the fiber's bandwidth capacity. Unlike active devices, passive DWDM filters do not require external power making them highly reliable. Additionally, these filters are cost-effective and make efficient use of existing fiber infrastructure, making them an integral part of unified solutions for data transmission.

The integration of tunable DWDM pluggable transceivers and passive DWDM filters offer numerous benefits such as simplified network configurations, scalability, and bandwidth expansion capabilities that are a cost-effective option for meeting diverse network demands. These solutions help preserve existing fiber infrastructure, avoiding the need for new installations and construction projects. Tunable DWDM pluggable transceivers and passive DWDM filters provide flexibility, high capacity, compatibility, and cost-savings.

NETWORK ARCHITECTURE



Traditionally, for data to be transmitted over the OTN, it had to go through multiple layers of equipment, including transponders and muxponders, which convert signals from one format to another using light/colors. The network (or line) ports are connected to a multichannel wavelength-division multiplexing (WDM) network. They are also called color interfaces, as they are available in or can be tuned to multiple WDM colors. Client ports typically connect to subtended equipment such as routers or switches which act as clients of the OTN. These ports are termed grey interfaces if they only support a single channel per fiber (as opposed to color interfaces, which can be wavelength multiplexed onto the same fiber). These additional layers not only added complexity to the network architecture but also management and maintenance costs.



IP over DWDM integrates IP routers and switches in data centers directly into OTN using pluggable DWDM transceiver modules. This approach eliminates the need for intermediary transponders and grey interfaces, resulting in simplified, streamlined networks. By utilizing advanced pluggable transceivers such as 400G ZR/ZR+ or 100G ZR digital coherent optics (DCO), IPoDWDM delivers high performance while addressing diverse applications.

This architecture is especially well-suited for distances up to 80 km, where cost efficiency and simplicity are paramount. While IPoDWDM is not a new concept, the advent of 400G ZR/ZR+ and 100G ZR DCO technologies brings renewed viability, expanded use cases, and more cost-effective choices for network operators.

The simplified IPoDWDM network architecture offers the following benefits:

1. **Cost Savings:**
   - Eliminates the need for transponders equipment
   - Reduces power consumption and footprint
   - Lowers capital expenditures (CapEx) and operating expenditures (OpEx) by up to 75% compared to leading OEM muxponder solutions

2. **Scalability:**
   - Adapts to growing network demands, enabling future-proof deployments
   - Simplified network management

3. **Network Optimization:**
   - Simplifies architecture and reduces points of failure
   - Enhances reliability, operational efficiency, and higher bandwidth data transmission

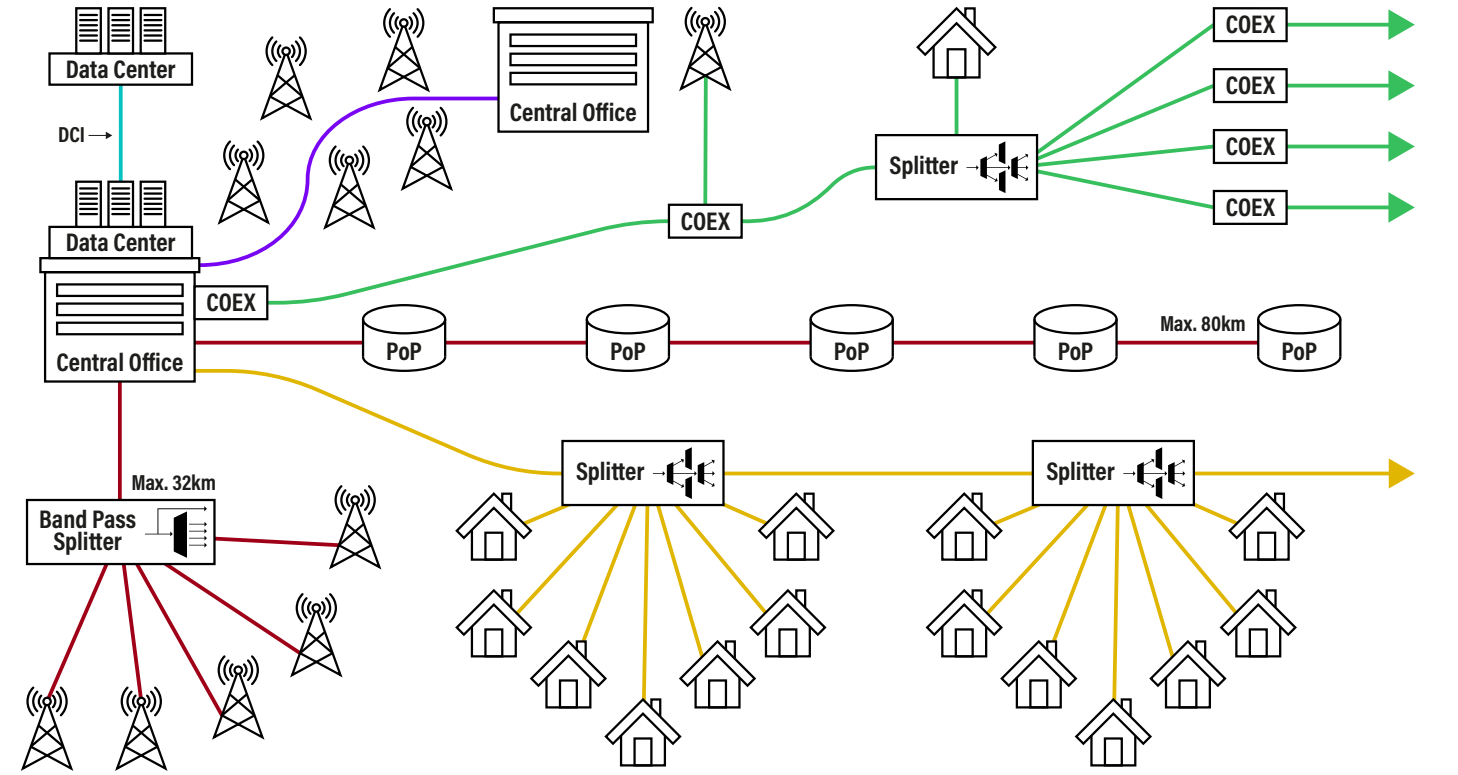
4. **Openness:**
   - Utilizes standards-based pluggable transceivers and passive mux/demux filters
   - Encourages interoperability and vendor flexibility

Advanced technologies like high-speed coherent transceivers and DWDM passive filters have made it possible to transmit data across vast geographical locations without the need for additional equipment. For organizations with large network footprints, this allows for a more cost-effective and efficient way of managing data transmission over longer distances.

IP OVER DWDM USE CASES

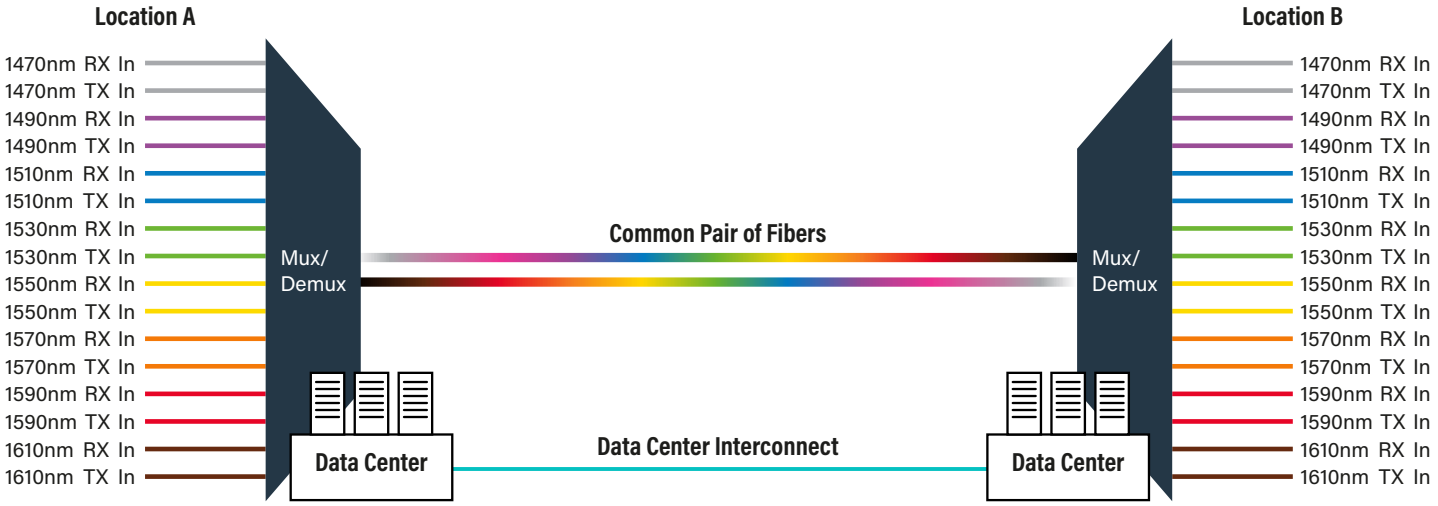
There are many ways to deploy IPoDWDM to fit your current fiber infrastructure and the way your endpoints are laid out geographically. In these next paragraphs we'll define how to apply IPoDWDM to different geographical locations.

Metro Network Diagram



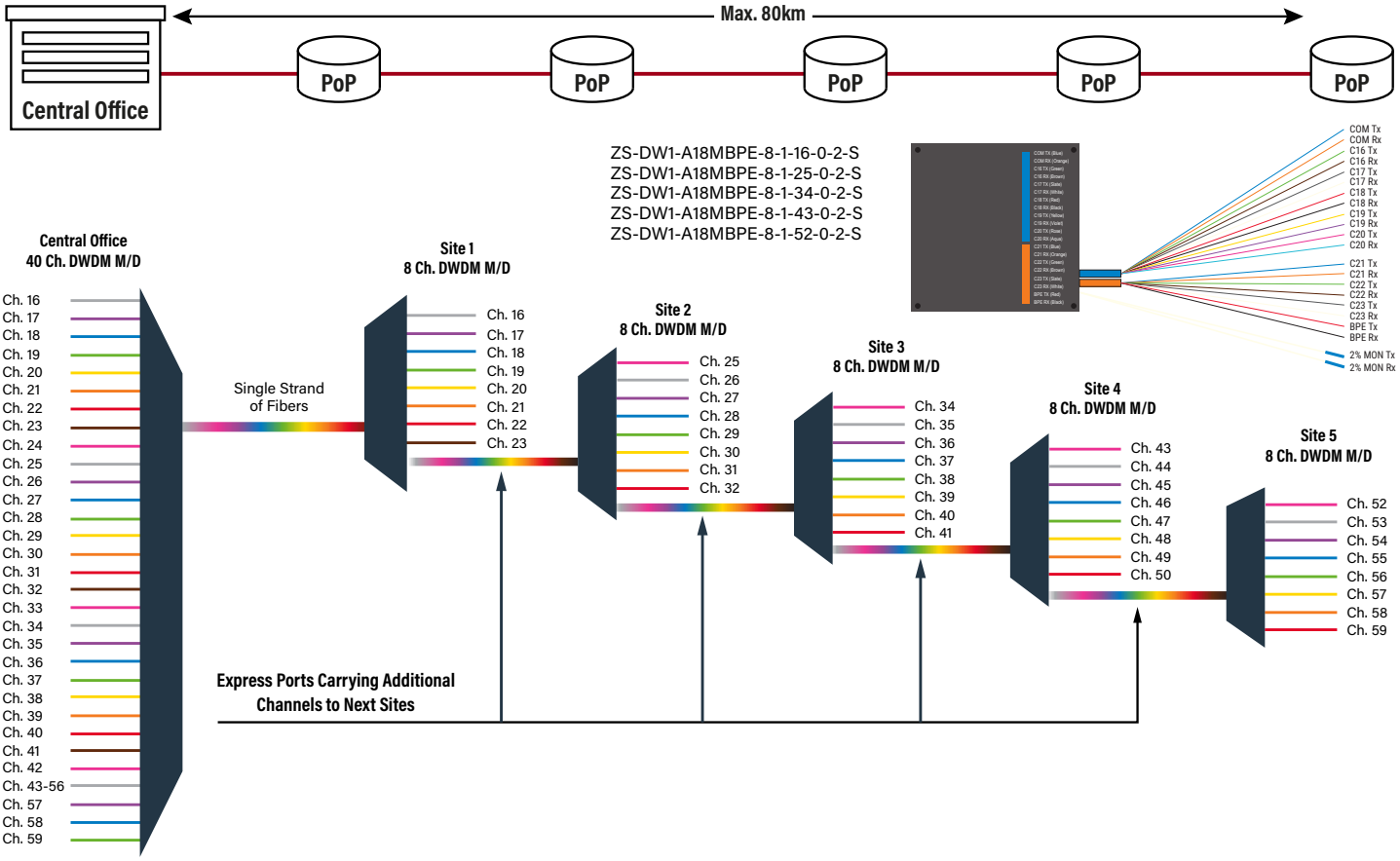
NETWORK DESIGN: POINT TO POINT

The easiest way to deploy mux/demux is through a point-to-point connection, where one passive mux/demux is installed in two locations that are directly linked by a single pair of fibers. This design can accommodate any number of channels and configurations. The below illustration is a pair of 8-channel CWDM mux/demuxes.



NETWORK DESIGN: DROP AND CONTINUE

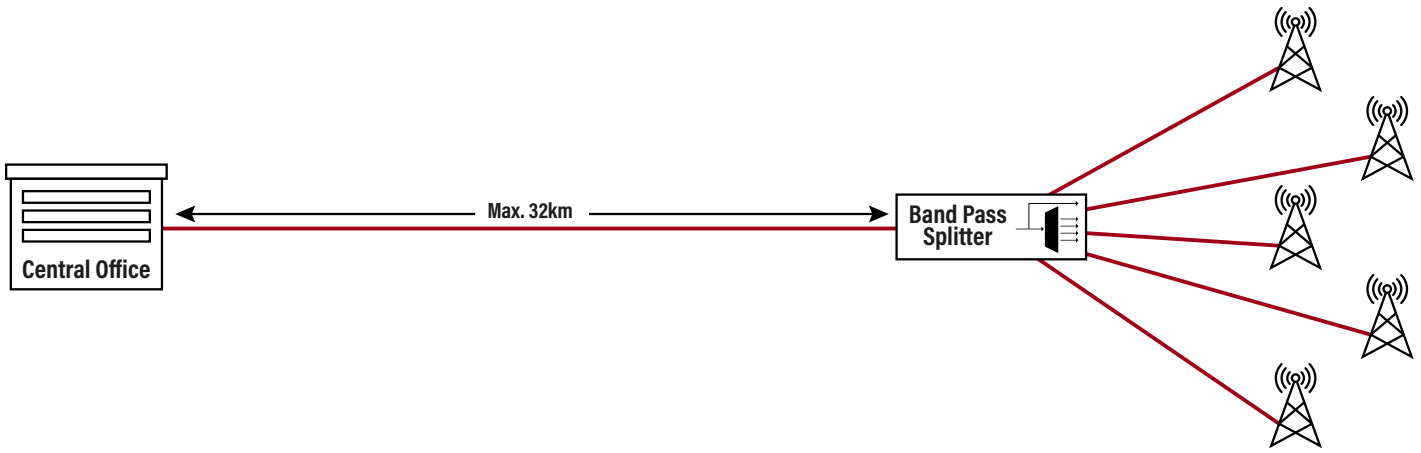
The drop-and-continue network topology, also referred to as Linear Chain or Passive Cascade, is a widely used point-to-multipoint topology for fiber optic networks. This type of topology involves connecting multiple endpoints in a network using a single fiber optic cable in a linear line design.

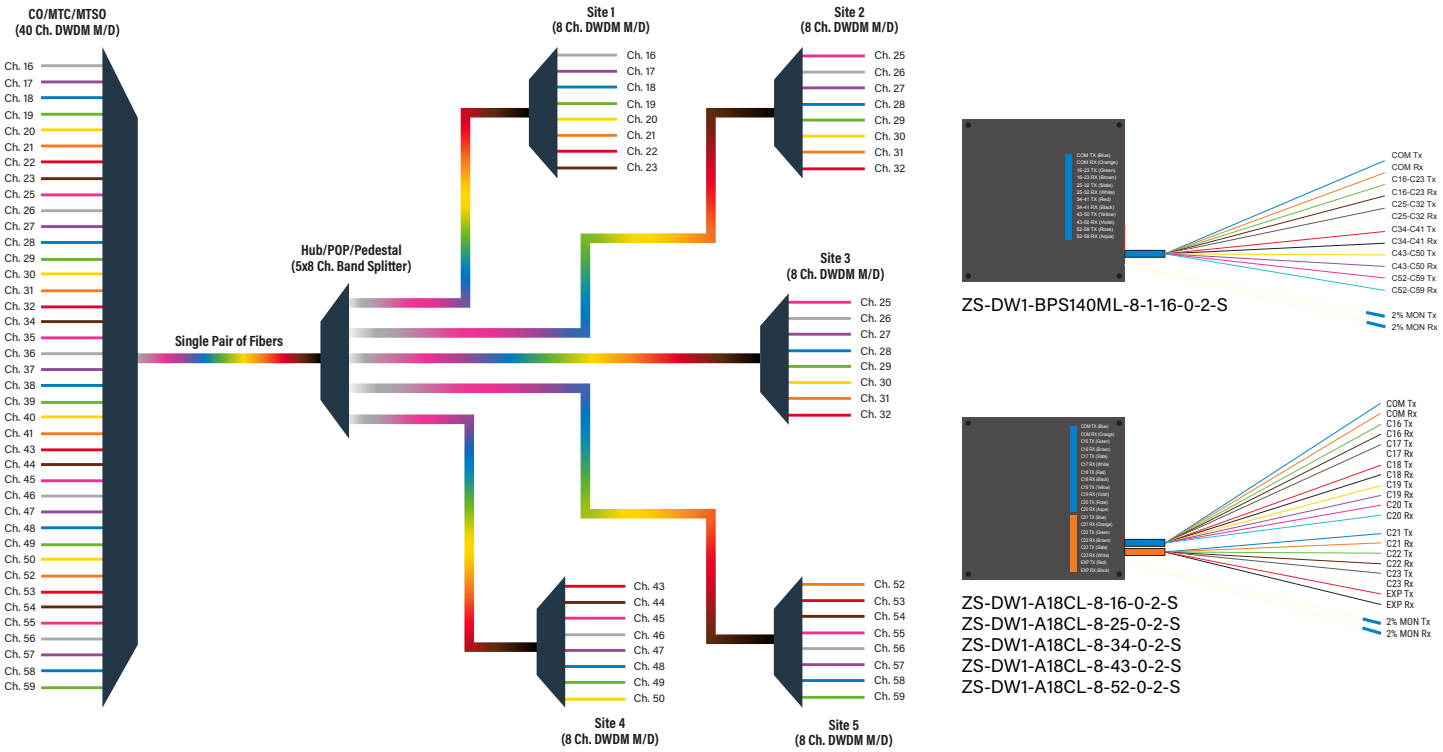


*Part numbers are for example only.

NETWORK DESIGN: HUB AND SPOKE

Hub and spoke topology is designed for remote distribution without the need for a Point of Presence (PoP) with powered transport gear. The main mux/demux is often a 40-channel unit that goes to a bandpass mux/demux in a pedestal or splice enclosure. From the Band Pass, it splits into five fiber cables that have eight channels each to remote endpoints.





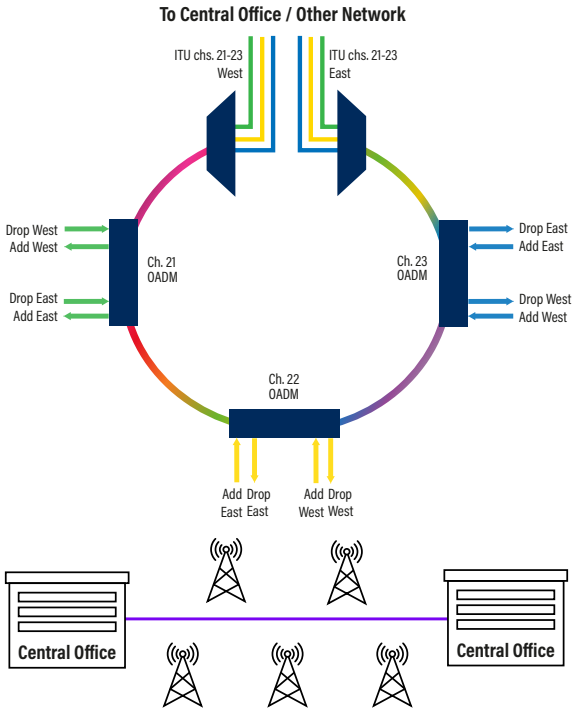
*Part numbers are for example only.

NETWORK DESIGN: OPTICAL ADD-DROP MULTIPLEXER (OADM) NETWORK RING/ARC

In an OADM network topology, OADM devices are strategically placed along a closed loop (ring) or a partially closed loop (arc). This setup enables the addition or removal of specific wavelengths of light at each node, while the other wavelengths continue to circulate throughout the network. This design offers flexible connectivity options between various locations within the ring or arc configuration.

- **Ring topology:**
  In a ring network, data can travel in both directions, providing redundancy in case of a fiber failure as traffic can reroute through the opposite direction. You must have at least one open node, this means you have two mux and demux that do not connect. Therefore, if you have latency spikes or protocol errors on the network, when it goes around, it does not get amplified. The open node breaks/terminates the interference.

- **Arc topology:**
  An arc is similar to a ring but features two specific hub locations at each end, with the mux/demux located in separate buildings. This enables more controlled traffic management between different network segments.

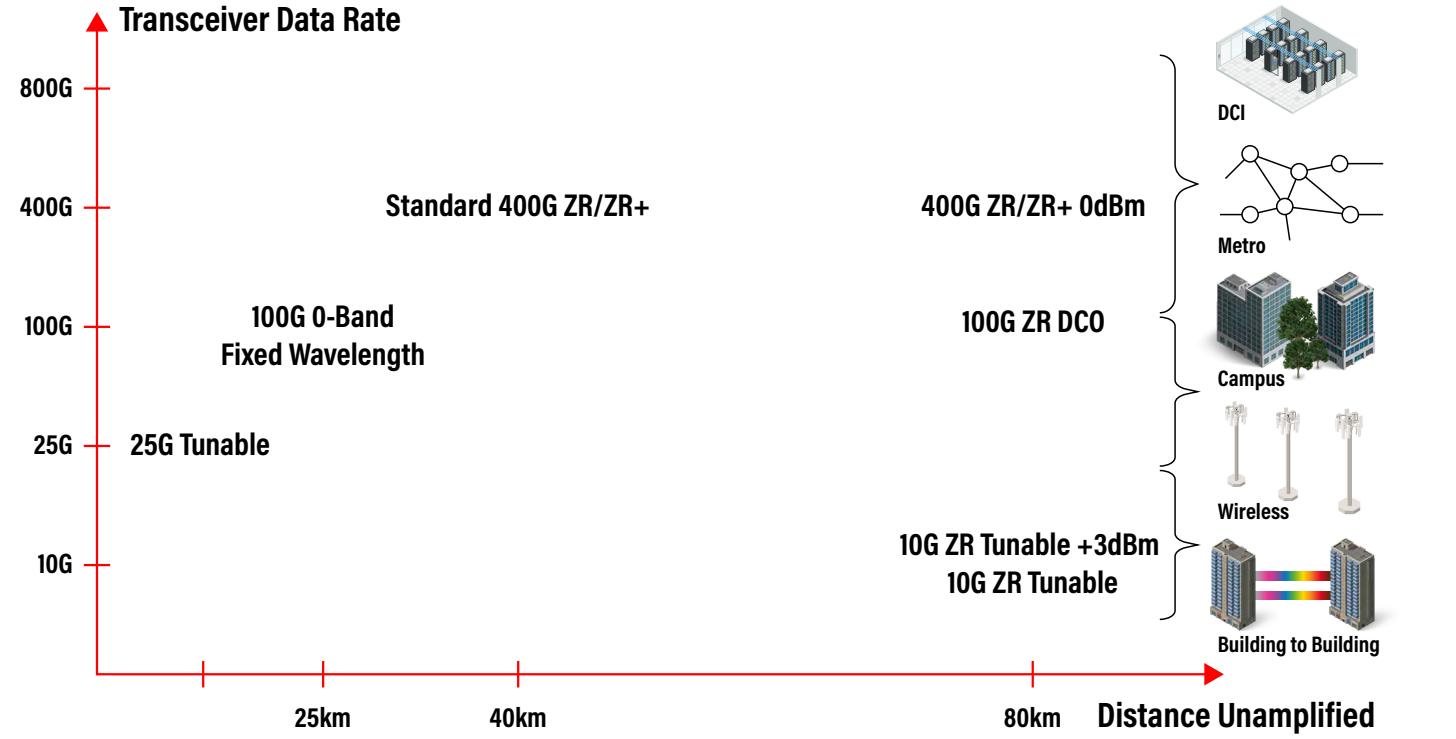


UNIFIED SOLUTIONS FOR IP OVER DWDM

Unified solutions combine high-speed coherent optical transceivers with passive DWDM multiplexers and demultiplexers (mux/demux) to create cost-effective and efficient network architectures. These solutions are particularly well-suited for DCI and metro network applications.

Approved Networks offers comprehensive solutions for telecommunication service providers and DCIs. Our unified solutions for IPoDWDM applications consist of a range of tunable DWDM pluggable transceivers, including 1G, 10G, 25G, 100G ZR Coherent, and 400G ZR/ZR+ Coherent, as well as passive DWDM filters. This integrated approach allows for the convergence of IP routers and switches into OTNs, covering distances of up to 80 km without amplification or dispersion compensation.

Approved Networks' Optical Unified Solutions (Transceivers, Passives) for IP over DWDM



By incorporating Approved Networks unified solutions, you can experience significant cost savings in both CapEx and OpEx, as well as simplified network configurations. These benefits are made possible by eliminating the need for an additional layer of OTN equipment that requires costly training of operations personnel consisting of Maintenance Technicians, Network Operations Center Technicians, and Network Provisioners for new services. This reduces equipment expenses, equipment infrastructure such as racks, and heat dissipation requiring less HVAC environmental capacity, resulting in further cost savings by lowering power consumption.

Approved Networks IPoDWDM unified solutions also provide the ability to effortlessly multiply bandwidth capacity without the need for lengthy and expensive new fiber installation. This is made possible by utilizing passive DWDM filters as part of our unified solutions. From 1G to 400G ZR/ZR+ Coherent, our solutions provide the flexibility to meet future growth and helps preserve existing outside plant fiber infrastructure, while significantly increasing bandwidth capacity.

CONCLUSION

IPoDWDM unified solutions offer a more cost-effective, streamlined, and high-capacity option compared to traditional OTNs. By utilizing the full capacity of the existing fiber infrastructure, businesses can save on the expense of laying new fiber, maintenance, and upgrades. Additionally, IPoDWDM eliminates the need for traditional OTN equipment, further reducing costs and simplifying network management.

IPoDWDM also boasts increased efficiency and scalability with the ability to carry multiple IP-based services along a single wavelength, minimize network complexity, and eliminate the need for separate equipment for each service. This leads to streamlined network management and increased capacity, allowing businesses to efficiently handle the growing demand for data transmission.

Approved Networks specialized DWDM engineers work closely with our customers to design solutions that meet their specific network requirements, ensuring a smooth and hassle-free implementation process. To learn more about how our IPoDWDM solutions can benefit your business and take your network to the next level, contact an Approved Networks representative for more information https://approvednetworks.com/contact-us/.

APPENDIX

Transceivers for Unified Solutions for IP over DWDM		
Data Rate	**Part Number**	**Description**
400G	AN-QSFPDD-400G-ZR	400G QSFP-DD ZR Coherent, DWDM Tunable, Duplex LC, C-temp, MSA Compatible
400G	AN-QSFPDD-400G-ZRP	400G QSFP-DD ZR+ Coherent, DWDM Tunable, Duplex LC, C-temp, MSA Compatible
400G	AN-QSFPDD-400G-ZR-0D	400G QSFP-DD ZR Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, MSA Compatible
400G	AN-QSFPDD-400G-ZRP-0D	400G QSFP-DD ZR+ Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, MSA Compatible
400G	QDD-400G-ZR-A	400G QSFP-DD ZR Coherent, DWDM Tunable, Duplex LC, C-temp, Arista compatible
400G	QDD-400G-ZRP-A	400G QSFP-DD ZR+ Coherent, DWDM Tunable, Duplex LC, C-temp, Arista compatible
400G	QDD-400G-ZR-0D-A	400G QSFP-DD ZR Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, Arista compatible
400G	QDD-400G-ZRP-0D-A	400G QSFP-DD ZR+ Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, Arista compatible
400G	QDD-400G-ZR-S-A	400G QSFP-DD ZR Coherent, DWDM Tunable, Duplex LC, C-temp, Cisco compatible
400G	Cisco QDD-400G-ZRP-S-A	400G QSFP-DD ZR+ Coherent, DWDM Tunable, Duplex LC, C-temp, Cisco compatible
400G	QDD-400G-ZR-S-0D-A	400G QSFP-DD ZR Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, Cisco compatible
400G	QDD-400G-ZR-0D-S-A	400G QSFP-DD ZR+ Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, Cisco compatible
400G	JNP-QDD-400G-ZR-A	400G QSFP-DD ZR Coherent, DWDM Tunable, Duplex LC, C-temp, Juniper compatible
400G	QDD-400G-ZR-M-A	400G QSFP-DD ZR+ Coherent, DWDM Tunable, Duplex LC, C-temp, Juniper compatible
400G	JNP-QDD-400G-ZR-0D-A	400G QSFP-DD ZR Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, Juniper compatible
400G	QDD-400G-ZR-M-0D-A	400G QSFP-DD ZR+ Coherent, 0dBm Tx Power, DWDM Tunable, Duplex LC, C-temp, Juniper compatible
100G	AN-QSFP28-ZR1R-DCO	100G QSFP28 ZR Coherent, DWDM Tunable, Duplex LC, C-temp, MSA Compatible
100G	AN-QSFP28-ZR1R-DCO-I	100G QSFP28 ZR Coherent, DWDM Tunable, Duplex LC, I-temp, MSA Compatible
100G	AN-QSFP28-WDM-Oxxxx	100G QSFP28 25km, DWDM O-Band Fixed Wavelength, Duplex LC, C-temp, MSA Compatible
25G	25GTS28DWDM15	25G SFP28 15km, DWDM Tunable, Duplex LC, I-temp, MSA Compatible
25G	AN-SFP28-TUNE-15-I	25G SFP28 15km, DWDM Tunable, Duplex LC, I-temp, MSA Compatible
25G	OP-SFP28-TUNE-15-I	25G SFP28 15km, DWDM Tunable, Duplex LC, I-temp, OnePort Programmable
10G	10GTSFP+MC80	10G SFP+ ZR, DWDM Tunable, Duplex LC, C-temp, MSA Compatible
10G	10GTSFP+MC80-H	10G SFP+ ZR, DWDM Tunable, Duplex LC, I-temp, MSA Compatible

Transceivers for Unified Solutions for IP over DWDM		
Data Rate	**Part Number**	**Description**
10G	OP-SFPP-TUNE-80-I	10G SFP+ ZR, DWDM Tunable, Duplex LC, I-temp, OnePort Programmable
1G	AN-DWDM-SFP-80-I-5494	1G SFP ZR, DWDM Fixed Wavelength, Duplex LC, I-temp, MSA Compatible

Note: Ask your Approved Networks representatives for the OEM compatibility information, and more products and variations are available.

Passive Filters for Unified Solutions for IP over DWDM	
Part Number	**Description**
1/2/4ch Dual Fiber	
ZS-DWDM-ADM-100-1-L-N-N-XX-L	1Ch, DWDM, OADM, Ch XX start, E/W, LC, No Skip, 2% MON, LGX
ZS-DW1-A11E0-N-0-XX-0-2	1Ch, DWDM, Mux/Demux, Ch XX start, 250um, Express, NO Mon, 2M fibers, Module only
ZS-DW1-ED1200-NN-XX-00-2	2Ch, DWDM, OADM, TFF, Ch XX Start, No Connector
ZS-DW1-E12M0-0000-NNXX-0000-1	2Ch, DWDM, OADM, Ch XX Start, West and East, 900um LC Mon,70x70x8mm, 250um,1M
ZS-DW1-BPS14E0-40XX-2	4Ch, DWDM, BPS, Ch XX start, 4 skip 0, MON, 2M fibers, Module only
ZS-DW1-ED1400-NN-XX-00-2	4Ch, DWDM, OADM, TFF, Ch XX Start, No Connector
8ch Dual Fiber	
ZS-DWDM-M/D-100-8-L-8-1-XX-L	8Ch, DWDM, Mux/Demux, TFF, Ch XX Start, Skip 1, LC/UPC, Standard Express, MON 2%, LGX
ZS-DWDM-MDB-100-8-L-8-1-XX-L	8Ch, DWDM Mux/Demux, Ch. XX-XX+7, 2% MON and BPS Express, LC, LGX
ZS-DW1-A18MBPE-8-1-XX-0-2-S	8Ch, DWDM, Mux/Demux, Ch XX START, 8 Skip 1, LC, MON ONLY, BPS, MOD ONLY,2M Fiber, Submersible
ZS-DWDM-MDAO-100-8-L-8-1-XX-R	8Ch, DWDM, Mux/Demux AMP ports 1625 OTDR, ChXX start, 8 skip 1, LC/UPC, 2% MON, Express
ZS-DWDM-MD3E-100-8-L-8-0-XX-LL	8Ch, DWDM, Mux/Demux, Ch XX start, 1310PB, Expressress port, LC, No Skip, Mon, LGX Mount 1W
40/44ch Dual Fiber	
ZS-DWDM-BPS-100-40-L-8-1-16-L-H	40Ch, DWDM Mux/Demux, 8 Skip 1, 5 Band, Band Pass Splitter, LC, LGX, I-Temp
ZS-DW1-BPS140ML-8-1-16-0-2-S	40Ch, DWDM BPS, Ch 16 start, 8 Skip 1, MON, 3M Fibers, LC/UPC 900um on Mon only, Module only, Submersible
ZS-DWDM-MDFO-100-44-L-8-0-16-R	44Ch, DWDM Mux/Demux Flat Top, Ch 16 start, OTDR, 8 skip 0, LC, 2% Mon, 1RU
ZS-DWDM-M/D-100-40-L-8-1-16-R	40Ch, DWDM Mux/Demux, C16-C59, 8 skip 1, 2% MON, LC, 1RU
ZS-DWDM-M/D-100-40-L-8-0-21-R	40Ch, DWDM Mux/Demux Ch 21 Start, No Skips, 2% MON, 1310PB, LC, 1RU
****For Amplification**	
ZS-DWDM-MDAO-100-8-L-8-1-XX-R	8Ch, DWDM, Mux/Demux AMP ports 1625 OTDR, ChXX start, 8 skip 1, LC/UPC, 2% MON, Express

Note: Customization is available for additional port and channel configurations.

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