Enabling Transport Network Resiliency with Unified Access Transport

A Technical Paper prepared for SCTE by

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1. Introduction

This paper introduces the concept of Unified Access Transport (UAT), a common access optical transport network for Residential, Business and Wireless services at Rogers Communications. The paper not only presents UAT but also puts forth recommendations for its effective deployment.

Unified Access Transport is a key enabler to Rogers Communications' network modernization and expansion programs. UAT enables core consolidation, Hybrid Fiber-coaxial (HFC) and 5G modernization, as well as Wireless and Wireline service expansions into underserved areas.

Within the subsequent sections of this paper, design considerations for urban and rural deployments are explored with a primary emphasis on bolstering network resiliency and scalability. Network enhancements such as automated optical protection switching to minimize customer impact, and automated Optical Time Domain Reflectometer (OTDR) to reduce Mean Time-to-Repair (MTTR) are examined. Network deployment accelerators such as Reconfigurable Optical Add-Drop Multiplexer (ROADM) over existing passive multiplexers and optical disaggregation are also discussed.

This paper provides insight into lessons learned from deployments to date and previews what's next for UAT.

2. What is Unified Access Transport?

UAT is a common access optical transport network that transports aggregated traffic from homes, businesses and wireless cell sites to the core network. It connects network elements in the field – Remote PHY Device (RPD), Passive Optical Network (PON) Optical Line Terminals (OLT), Enterprise Network Interface Devices (NID) and Radio Base Stations (RBS) – to core locations via common optical multiplexers and Points of Presence (POPs) as outlined in Figure 1.

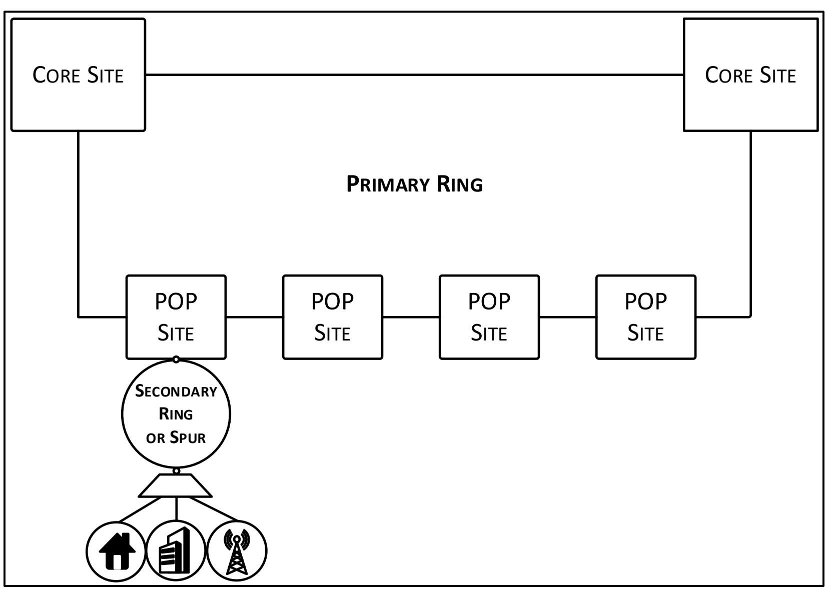

Figure 1 – Unified Access Transport Network

UAT is composed of primary collector rings connecting POP sites to Core sites and secondary rings or spurs connecting devices in the field to the POP. Optical transport for the primary collector rings uses

ROADM line systems or dual-fiber Dense Wavelength Division Multiplexing (DWDM) couplers. Secondary access rings of UAT are comprised of single-fiber DWDM multiplexers in the field and POPs. POP site optical switches and field splitter/couplers are used to protect the DWDM multiplexer trunks.

At Rogers Communications, UAT complements Unified Fiber Plan (UFP), a holistic methodology for planning, designing and building fiber links that optimizes fiber routing and dimensioning to connect all sites of interest. It optimizes the fiber use in the network. UFP is outside of the scope of this paper.

3. UAT Drivers

The following sub-sections discuss four key drivers for the UAT rollout.

3.1. Network Simplification and Resiliency

The first driver is network simplification and resiliency. Figure 2 illustrates the network before and after the UAT transformation.

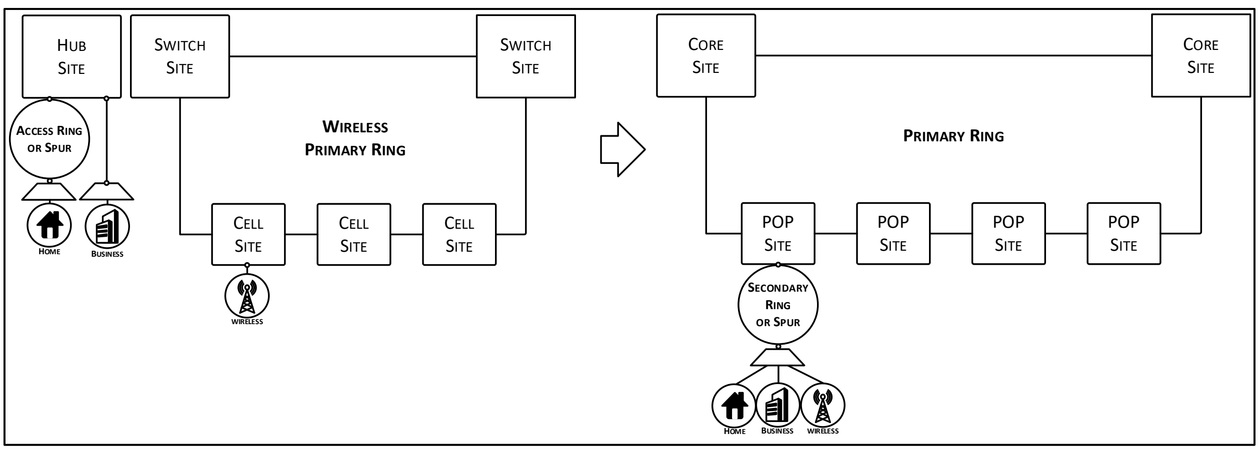

Figure 2 – Network Topology Before and After UAT Transformation

Prior to UAT introduction, Rogers Wireline, Enterprise and Wireless access networks used different topologies, did not share fiber and often did not share the core facilities. Although both Wireline and Enterprise access networks were based on a hub-and-spoke topology where a device in the field has a dedicated optical link to the core node located at the hub site, services did not share fiber. Wireline RPD and 10 Gigabit Symmetrical PON (XGS-PON) traffic traversed single-fiber DWDM multiplexers while Enterprise IP network and Layer 1 wave services traversed dual-fiber Coarse Wavelength Division Multiplexing (CWDM) multiplexers. Note that all wireline and enterprise services from the large geographical area terminated at the same centralized core locations and as such were exposed to catastrophic facility failure.

Rogers Wireless IP Radio Access Network (IPRAN) mobile transport network topology is much more distributed. It is based on a set of collector aggregation rings connecting IPRAN cell sites deeper in the access plant to two geographically diverse wireless switch sites. As such, wireless service, connected via compliant topology, is not exposed to catastrophic failure at the switch site facility. Wireless aggregation routers at IPRAN cell sites are connected via dedicated dual-fiber CWDM multiplexers in urban areas or legacy Fixed Optical Add-Drop Multiplexer (FOADM) based networks in more rural areas. As facilities housing IPRAN core routers are often not collocated with wireline primary hubs, wireless CWDM multiplexers and ROADM optical networks were rarely shared with other services. Furthermore, traffic from most of the wireless sites connects to wireless aggregation routers at the IPRAN cell sites via pair of dedicated linear fiber strands making for the inefficient use of fiber resources.

To effectively utilize fiber resources, UAT first had to align different network topologies so that all services shared common add and drop locations. Aligning on a common set of UAT POPs and core sites, facilitates the use of common passive and active optical systems which improves fiber utilization. Adopting a distributed topology where traffic is aggregated closer to the edge of the network further improves fiber utilization and enhances network resiliency against the fiber cuts and core facility outages. The concept is illustrated in Figure 3 where a recent headend relocation and HFC modernization project uplifted approximately 100,000 homes passed (HP) area to the UAT architecture. The project deployed a UAT primary ring with four UAT POPs that aggregate traffic deep in the access plant, eliminating fiber segments greater than 2,000 linearly fed customers. Wireless locations were leveraged for UAT POPs drastically reducing cost and implementation time. Rather than establishing a new hub site location, Converged Cable Access Platform (CCAP) and Broadband Network Gateway (BNG) devices were split between the existing two hub site locations connected to the UAT ring allowing for significant Capex and Opex savings. As such, UAT provides the opportunity to reduce the Rogers fiber diversity threshold to less than 2,000 customers, instead of fiber architecture augmentation alone.

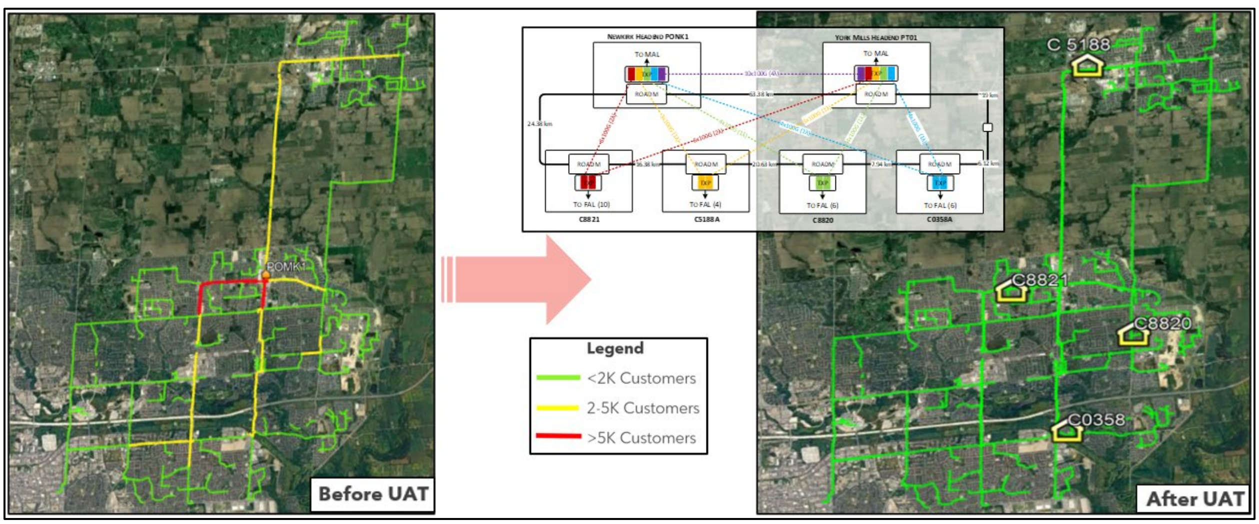

Figure 3 – Network Resiliency Before and After UAT Transformation

3.2. Wireline Network Modernization and Uplift

The second driver is wireline network modernization and uplift of HFC networks to support Data Over Cable Service Interface Specification (DOCSIS) 4.0 and Fiber to the Home (FTTH) uplift in select parts of the wireline network. An essential part of the HFC modernization is migration to Distributed Access Architecture (DAA) where analog optical nodes are replaced with digital optical RPD nodes. Rogers Communication IP Wireline Access Network (IPWAN) enables wireline service aggregation at the UAT POPs further improving fiber utilization and enhances network resiliency by enabling RPD and OLT connectivity to core devices at geographically diverse locations. Longer distances associated with digital optics on RPDs are further extended with active optical transport at UAT POPs. Together with virtual CMTS and DAA, UAT enables core node consolidation by up to 50%, that results in a favorable estimated 10-year total cost of ownership.

3.3. Wireless Network Modernization and Uplift

The third driver is modernization of the wireless access network, which introduces new Base Band Units (BBU), Remote Radio Units (RRU) and antennas that support multiple frequency bands, higher order carrier aggregation combinations and Multiple Input Multiple Output (MIMO) technologies. This along with the rollout of newer wireless terminal devices significantly increases demand per customer. Higher traffic demand is further amplified by the introduction of the new 5G frequency bands under the wireless uplift program. Wider channels and even higher order MIMO antennas in mid and millimeter frequency bands further increase traffic demand and put a strain on mobile transport network.

To meet the increased demand, UAT enables metro and regional collector ring upgrades from 10 Gigabit per Second (Gbps) to 100 Gbps. Capacity per site and latency improvements are particularly noticeable in urban areas where wireless traffic terminates at the UAT POPs with ROADM based optical transport.

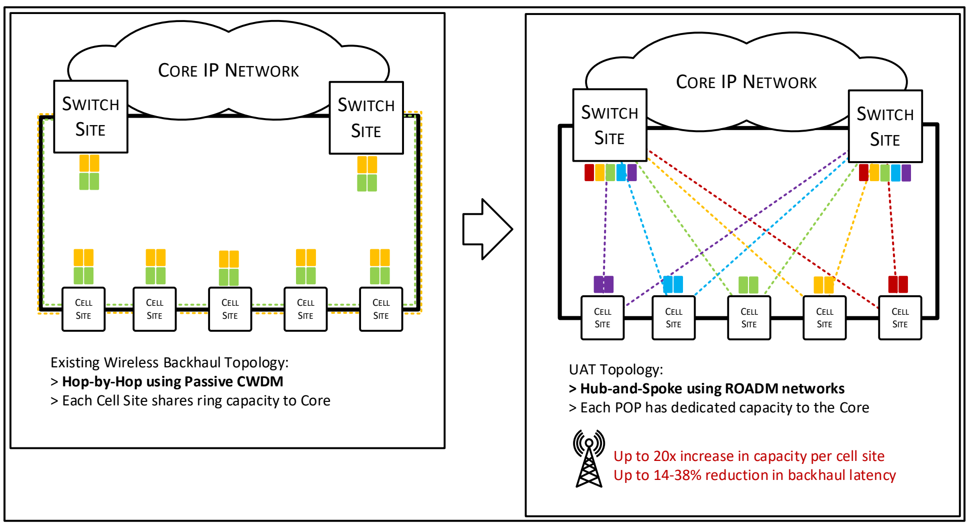

Figure 4 – Mobile Transport Capacity Uplift and Latency Improvement

To meet the increased customer demand in urban areas and improve coverage in the areas where macro towers are not permitted, Rogers Communications is densifying networks by deploying small cells where RRUs mounted on street furniture are connected to BBU hotels at macro sites via passive DWDM multiplexers.

3.4. Service Expansion

The fourth driver is fiber network expansion to out of footprint greenfield and brownfield underserved communities. Expanding wireline XGS-PON and Fixed Wireless Access (FWA) services to rural underserved areas outside of traditional cable footprint requires active optical transport to backhaul services to the existing core locations. Meeting aggressive occupancy timelines from government subsidy programs is critical. Uplifting legacy 10 Gbps FOADM-based optical transport networks used to backhaul mobile traffic in rural areas to high-capacity ROADM based coherent systems enables faster service turnup across wide areas of opportunity. The concept is illustrated in Figure 3 where uplifting existing optical systems used to backhaul IPRAN reduced new fiber construction to less than 10% of the total fiber distance used for the primary rings.

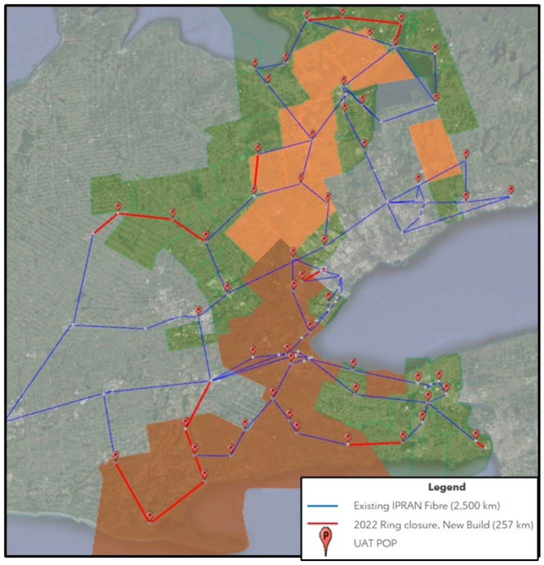

Figure 5 – Legacy FOADM to ROADM UAT Uplift in Service Expansion Areas

Uplifting legacy optical systems to UAT, provides backhaul capacity not only for the newly connected XGS-PON and FWA customers but also uplifts the transport to meet the customer demand for newly added 5G bands in rural areas. Furthermore, in the absence of cable headend locations in rural areas, uplifting existing wireless shelters to UAT POPs that house XGS-PON OLTs and IPWAN aggregation routers, proved to be more cost effective and less time-consuming than setting up standalone wireline facilities and connecting them to optical rings.

4. Engineering Design Considerations for UAT

The following sections review engineering design standards taken into consideration when building the UAT network.

4.1. Topology Options

The physical topology of a UAT ring is characterized as a classical ring. POP sites are daisy-chained together by fiber plant to form a primary ring. The fiber plant must be diverse, so a single fault cannot interrupt multiple spans and isolate POP sites. The primary ring terminates at two geographically diverse core sites. To close the ring, the core sites are connected via a backbone fiber system as shown in Figure 6. The backbone and primary ring must also be fiber diverse. A single backbone can support multiple primary rings so long as the fiber diversity criteria is met.

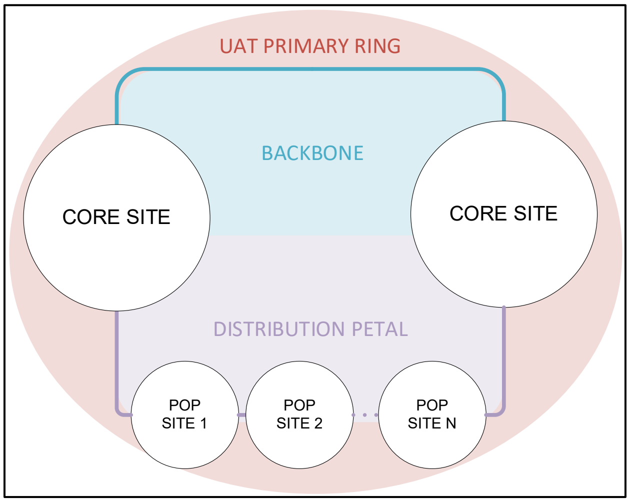

Figure 6 – UAT Ring Physical Topology

After a new primary ring is physically established, an IP system planner has two options to connect each POP site to the two core sites:

1) Hub-and-Spoke Topology
2) Hop-by-Hop Topology

Hub-and-Spoke topology in Figure 7 connects each POP site with dedicated capacity to the core sites. This is commonly achieved with dedicated wavelength circuits over a ROADM line system. Hub-and-spoke topology provides scalable high capacity to each POP site. It is best suited for high to medium density metro deployments and/or high growth deployments.

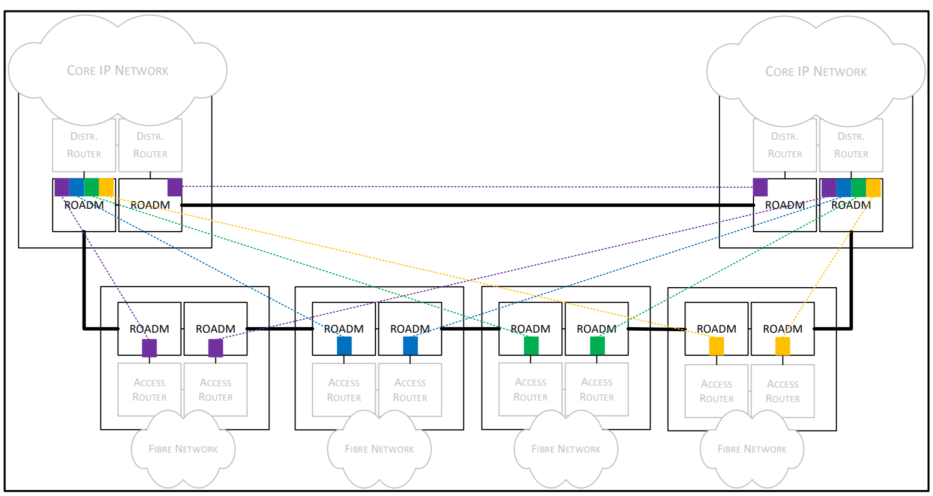

Figure 7 – Hub-and-Spoke Topology

Hop-by-Hop topology in Figure 8 connects each POP site with shared capacity to the core sites. The capacity is shared amongst all POP sites in the primary ring. Fiber span distance is the primary determining factor on whether to deploy Hop-by-Hop using active or passive transport; more on this in the following section. Hop-by-Hop topology is best suited as a cost-effective alternative for low density, low growth deployments.

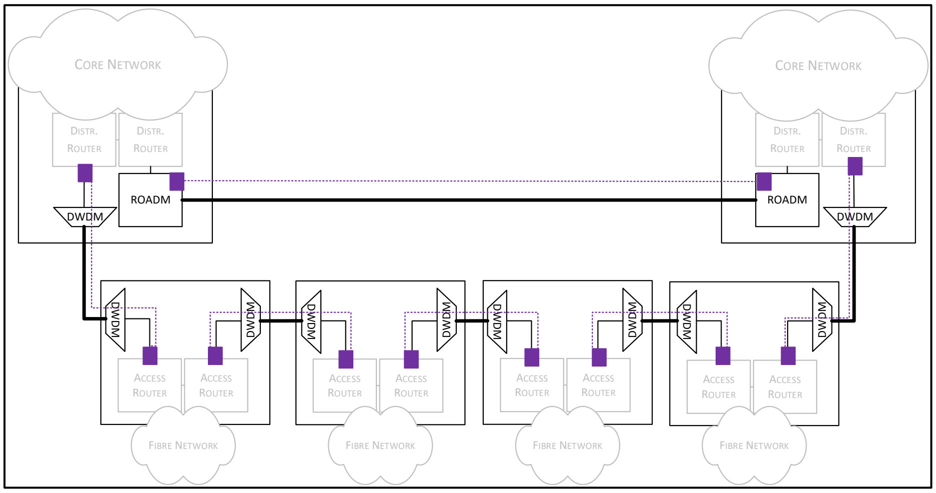

Figure 8 – Hop-by-Hop Topology

4.2. Active Optical Transport

For high-capacity metro UAT applications or distances that exceed the optical budget of a passive design, an active DWDM system is required to provide transport support between UAT POPs and core locations. The active system should be optimized, in features and in cost, for access applications.

While long-haul DWDM systems are designed to maximize utilization of scarce inter-city fiber resources, metro DWDM systems should be designed to minimize equipment cost as fiber is usually more readily available. Such cost optimization is achieved by using hardware specialized for the metro-regional applications, while maintaining the resilience and operational features deployed in long haul systems.

Transponders used for the long-haul applications are usually based on proprietary fixed lasers and optoelectronics, tailored for maximum capacity and reach performance. Conversely, metro-regional transponders typically use more cost-effective pluggable line side DWDM optics that offer adequate performance for the application while allowing operators to benefit from continuous cost and performance improvements in the pluggable coherent transceivers.

Flexible grid support in long-haul DWDM systems is required to ensure compatibility of the DWDM photonic layer with the future generation of transponders, that will use higher baud rate optics allowing capacity per wavelength exceeding 1.2 Terabits per second (Tbps). The ROADMs are usually equipped with expensive optoelectronics including Route and Select (R&S) twin Wavelength Selective Switch (WSS) cards with larger number of ports (20-32), Erbium-Doped Fiber Amplifier (EDFA) arrays, and MxN multicast switches/WSS.

ROADMs for the access use flexible grid Broadcast and Select (B&S) WSS cards, with a lower number of ports (4-9) and passive 100 Gigahertz (GHz) flat top filters that support DWDM wavelengths up to 400 Gbps, at a much lower price point. This architecture allows the deployment of a mix of 10 Gbps non-coherent DWDM wavelengths for low-capacity application, with coherent 100, 200 and 400 Gbps wavelengths for higher capacity applications. Long-haul DWDM systems typically only support coherent wavelengths.

Due to their lower complexity, the photonic and transponder cards for access applications consume less power and are fitted in a more compact form factor. This is an important consideration for UAT POPs where space and power are sometimes restricted.

The ROADMs should support full hardware redundancy at shelf and card level to maximize traffic resiliency in case of hardware failure or during equipment software upgrades.

OTDR support, implemented on long-haul corridors to quickly detect and locate the fiber breaks, is based on dedicated hardware per span. Long-haul tailored hardware has a large dynamic range to accommodate fiber spans in excess of 100 km. In metro networks, where the spans are usually much shorter (15-20 km), the same hardware can be leveraged across multiple spans by bypassing the wavelength used by the OTDR between neighbor spans as illustrated in Figure 9. This implementation preserves the OTDR functionality at a lower cost than long-haul OTDR implementations.

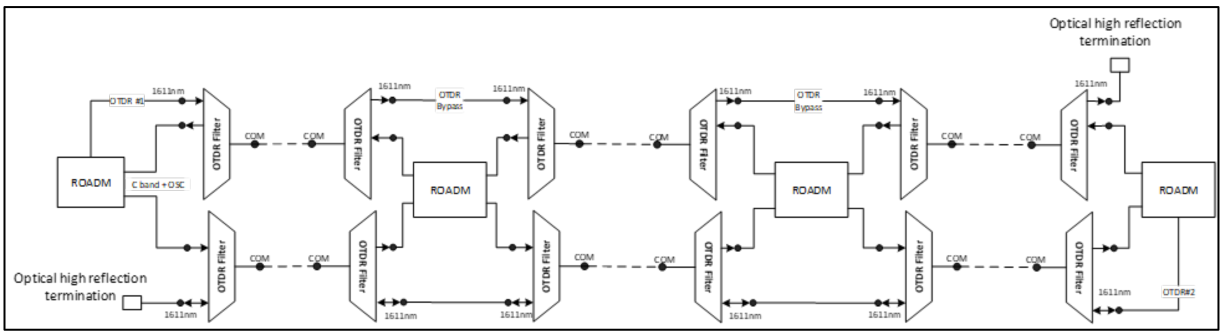

Figure 9 – OTDR Implementation on a Metro-Regional Optical Systems

Metro-regional DWDM systems are also more suitable for the foreign wavelength applications. The large OSNR margin of the coherent wavelengths can accommodate the penalty introduced by the third-party open line systems. Foreign wavelengths enable lower cost IP-over-ROADM solutions where transponders are eliminated and pluggable DWDM coherent optics are connected directly in the routers. More on this in Section 4.4.2.

Table 1 highlights the main differences between the metro-regional and long-haul DWDM active optical systems.

Table 1 – Metro versus Long-Haul ROADM Line System Comparison

Feature	Metro DWDM	Long-Haul DWDM
Transponders	Pluggable Optics $$	Proprietary Optics $$$
Flexible Grid Support	Yes	Yes
ROADM WSS Type	1x4 B&S/1x9 R&S $	1x20/1x32 R&S $$$
Low Space and Power Consumption	Yes	No
Hardware Diversity (Cards and Shelf)	Yes	Yes
OTDR Support	Multiple Spans $	Single Span $$$
CDC ROADM	No	Yes
Layer 0 Control Plane	No	Yes
800 Gbps+ Wavelength Support	No	Yes
Native 10 Gbps Wavelength Support	Yes	No

Feature	Metro DWDM	Long-Haul DWDM
Mix of 10 Gbps and 100/200/400 Gbps DWDM on Same Photonic Layer	Yes	No
Mix of Different ROADM Types on Same Photonic Layer	Yes	No
Transponder Direct Access to WSS for Low Cost/Low-Capacity drop	Yes	No
Foreign Wavelength Support	Yes	Optional

4.3. Passive Optical Transport

Passive optical transport networks play a prominent role in the UAT and are used in both primary and secondary UAT rings and optical spurs – see Figure 1.

4.3.1. Passive DWDM Multiplexers in Secondary UAT Rings and Optical Spurs

Single-fiber bi-directional 40 channel passive DWDM multiplexers are used in UAT secondary rings and spurs to connect up to 20 devices in the field – RPD, XGS-PON OLT, Cell Site Routers (CSR), Enterprise NIDs – to aggregation routers at UAT POPs or hub sites. Figure 9 shows a protected configuration where an optical switch at the UAT POP is used to protect against fiber cuts that would impact more than 5,000 wireline or 10,000 wireless subscribers.

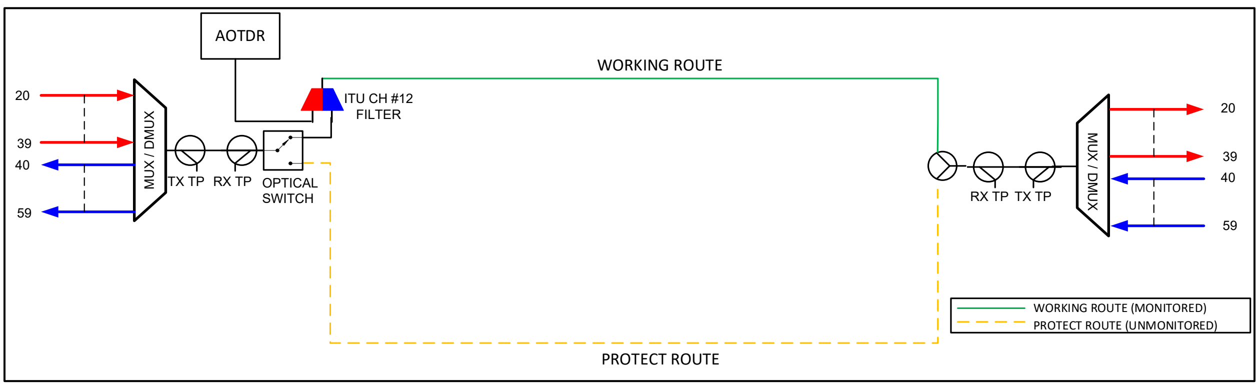

Figure 9 – Protected Bi-Directional Single-Fiber System

If the fiber cut impact is less than 5,000 wireline and 10,000 wireless subscribers, an unprotected configuration – as shown in Figure 10 – can be used to connect devices in the field to an appropriate aggregation router in the UAT POP.

Figure 10 – Unprotected Bi-Directional Single-Fiber System

The section between the DWDM multiplexer in the field and the UAT POP, which on average accounts for approximately 80% of the access fiber distance to the field device, is monitored with automated OTDR instrument. Automated OTDRs reduce MTTR of the fiber cut by approximately 2 hours when compared to unmonitored fiber. Shortening MTTR is the result of improved fault detection, notification, and localization.

Single-fiber bi-directional DWDM multiplexers are also used to connect wireless small cell RRUs mounted on the street furniture and BBUs at wireless macro sites. Two configurations illustrated in Figures 11 and 12 are used to connect up to six small cell locations to a BBU hotel at the macro site. Each small cell location has an 8-channel DWDM multiplexer that connects to a 48-channel DWDM multiplexer at the macro site allowing for up to 6 small cell locations per single fiber strand. Configuration selection is based on the fiber availability and layout of the fiber cables in the specific deployment area.

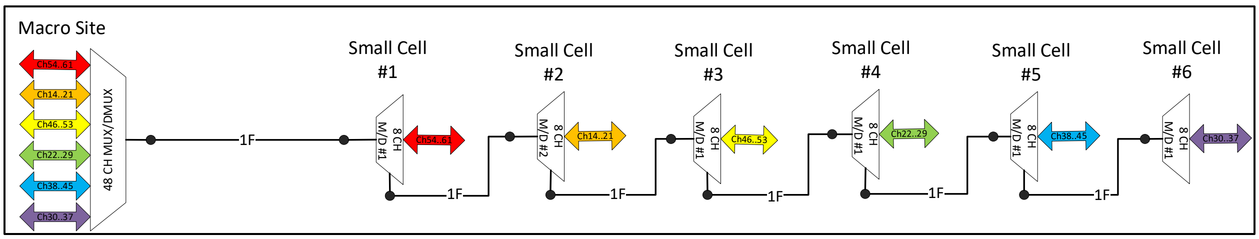

Figure 11 – Cascaded Bi-Directional Single-Fiber Configuration

The cascaded topology in Figure 11 is recommended for areas with scarce fiber and small cells installed along the architectural fiber cable. Fronthaul for small cells deployed along the major boulevards usually leverages cascaded topology.

Hub-and-spoke configuration in Figure 12 connects up to 6 small cell locations to a BBU hotel at the macro site via intermediate 6-band single-fiber DWDM multiplexer. This configuration is often used to connect small cells deployed in residential neighborhoods to architectural fiber where the band coupler is installed at the neighborhood entrance.

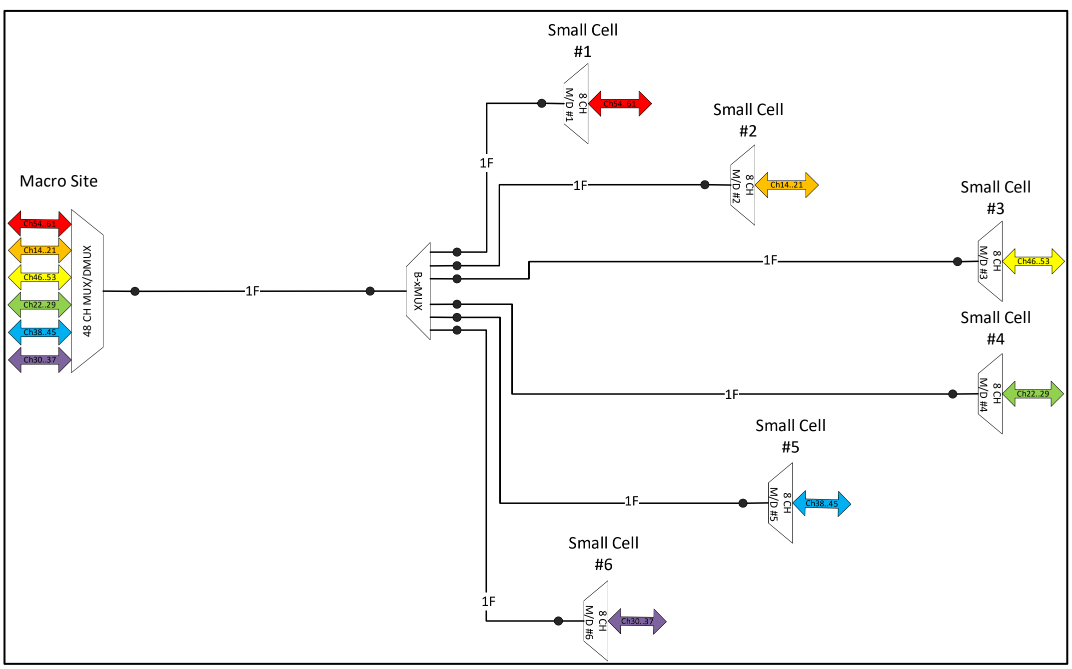

Figure 12 – Hub-and-Spoke Bi-Directional Single-Fiber Configuration

Maximum fiber distance between the BBUs at the macro site and RRUs at the small cell locations is dependent on the optical specifications of the end transceivers, optical impairments of the transmission medium (optical loss, chromatic dispersion, etc.) and latency limitation imposed by the Common Public Radio Interface (CPRI) protocol. Although detailed fiber distance calculations are outside of the scope of this paper, practical deployments have shown that 10 Gbps fronthaul link distance is limited to 15 kilometers (km) by the (e)CPRI protocol while 25 Gbps fronthaul link distance is limited by chromatic dispersion (CD) to 13-15 km. Interestingly, fronthaul configuration and number of passive DWDM multiplexers between the BBU and RRU are often not the limiting factor.

4.3.2. Passive DWDM Multiplexers in Primary UAT Collector Rings

Passive DWDM multiplexers are not only used in the UAT secondary rings and spurs to connect devices in the field to the UAT POPs. Many of the UAT collector rings in urban areas, where distances between the POPs are shorter, are also built using passive DWDM and CWDM multiplexers. Channel allocation plan for the three passive multiplexers commonly used for the UAT primary collector rings is illustrated in Figure 13.

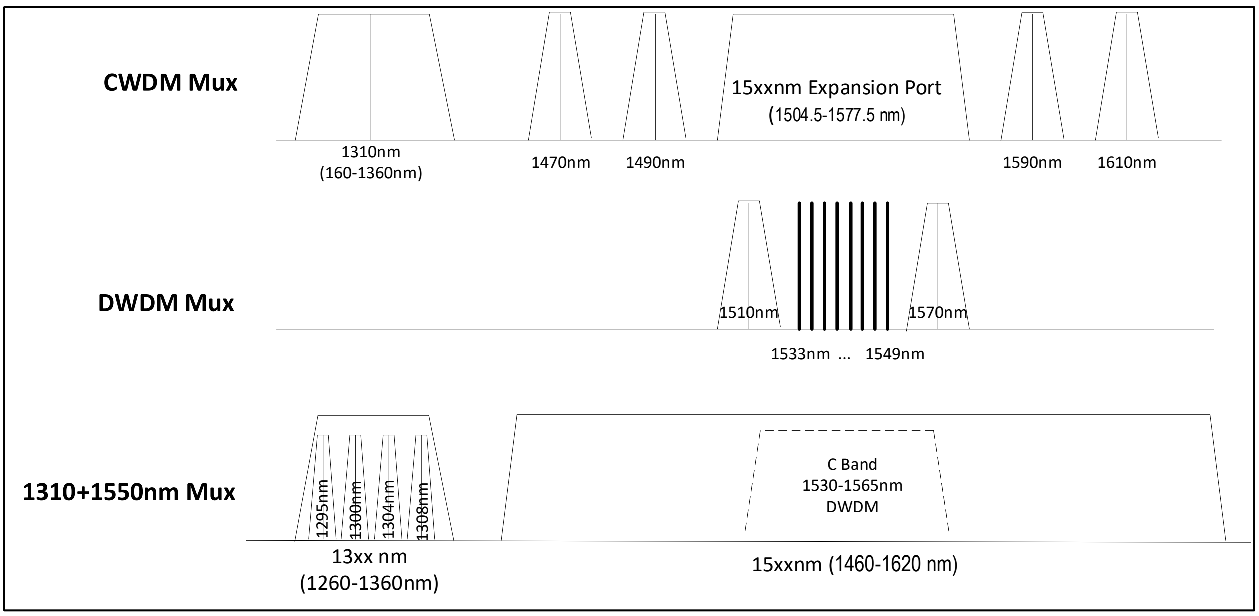

Figure 13 – Channel Allocation for Passive Multiplexers Used in the UAT Collector Rings

Figure 14 illustrates a greenfield deployment scenario where aggregation routers at the UAT POPs are connected to the 1310 nm port of the 1310+1550 passive coupler. The 1310 nm port fits four channels used by the 100 Gbps ER4 and ZR4 optics thus enabling connectivity between the routers with QSFP28 interfaces often deployed in the service provider access aggregation networks. The 1550 nm port of the coupler spans the full Conventional (C)-band which allows future system scalability. Cascading the DWDM multiplexer to the 1550 nm expansion port facilitates access to eight DWDM channels with 112.5 GHz passband that support line rates up to 800 Gbps. As per Figure 13, the 1550 nm expansion port also includes the 1510 nm channel used for the Optical Supervisory Channel (OSC) or OTDR monitoring of transport network elements, and the 1570 nm channel used for Optical Transfer Channel (OTC), required to build a high-precision timing network.

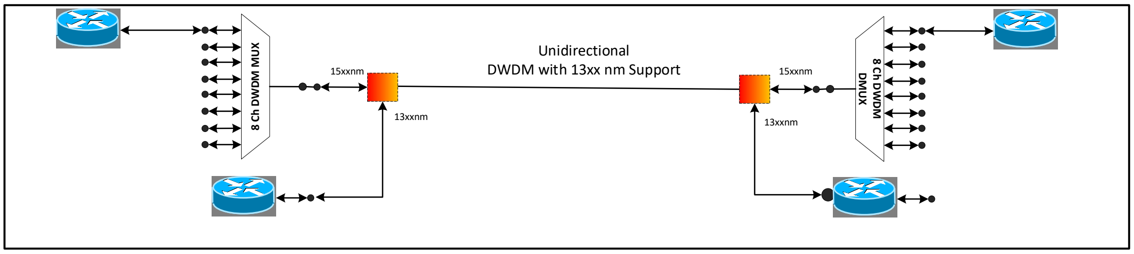

Figure 14 – Greenfield Deployment with 1310+1550 nm Passive Coupler

Dual-fiber unidirectional CWDM multiplexers are used extensively to interconnect cell sites in urban areas. The procedure to insert new high capacity DWDM systems into the 1550 nm expansion port of existing passive CWDM systems enables easier and more cost-effective rollout of UAT networks with all the benefits outlined in the Section 3.1.

Figure 15 shows a typical brownfield span connecting two IPRAN cell sites on an urban passive CWDM system. The CWDM multiplexer deployed in IPRAN has 1310 nm, 1550 nm and four CWDM ports - 1470, 1490, 1590 and 1610 nm. 1310 nm port is used for legacy Synchronous Optical Networking (SONET) traffic while one or more of the CWDM ports are used for 10 Gbps IPRAN links. Similar to 1310+1550 nm coupler, the 1550 nm expansion port of the CWDM multiplexer covers the full C-band. The addition of the DWDM multiplexer, as shown in Figure 15, allows for an easy addition of high capacity 100-400 Gbps DWDM channels used by newer QSFP-DD and CFP2 based aggregation routers and UAT active optical transport equipment without disruption to legacy SONET and 10 Gbps IPRAN channels. DWDM multiplexer also allows for access to 1510 nm OSC/OTDR channel and 1570 nm OTC channel.

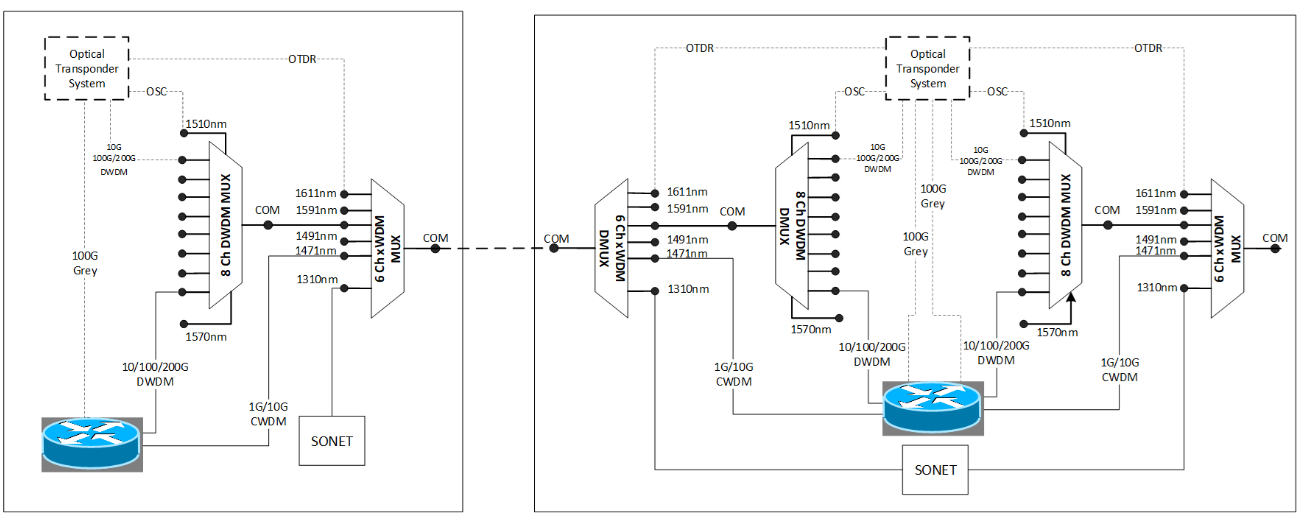

Figure 15 – Brownfield DWDM-over-CWDM Upgrade

Solutions outlined in Figures 14 and 15 are intended to be used for the hop-by-hop systems described in Section 4.1 where topology is static and optical passthrough of intermediate sites is not required. If optical passthrough capability through a single POP is required, the system designer would first consider using the higher power transceivers to overcome the cumulative optical loss from cascaded passive multiplexers. The designer can also reduce optical loss by eliminating standalone DWDM multiplexers and connecting the DWDM transceivers directly to the 1550 nm express port of the 1310+1550 nm coupler or CWDM multiplexer. The downside with this approach is a lack of future system scalability. If expressing wavelengths through multiple intermediate sites is required, coupling amplified ROADM system to the

1550 nm express port of the CWDM multiplexer or 1310+1550 nm coupler shown in Figure 16 is required. With this approach, the designer can build hub-and-spoke topology described in Section 4.1 over brownfield CWDM passive optical system.

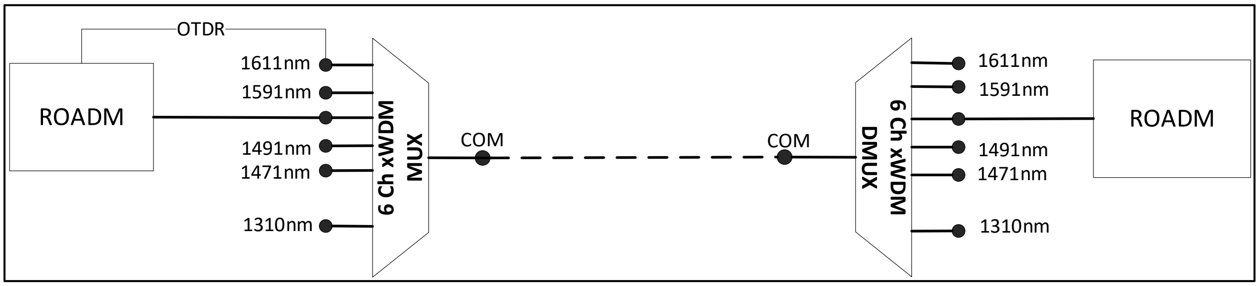

Figure 16 – Brownfield ROADM-over-cWDM Upgrade

4.4. Optical Transceivers in UAT

Optical transceivers play a prominent role in the UAT network. The following sections discuss optical transceiver requirements for the primary and secondary UAT rings.

4.4.1. Optical Transceivers in Secondary UAT Rings and Optical Spurs

Optical transceivers in the UAT secondary rings and spurs should be optimized for low cost, high volumes and simple turnup and commissioning. Pluggable optics with simple direct detect receivers that rely on a non-return-to-zero (NRZ) modulation to provide 1-25 Gbps line rates over non-amplified DWDM passive systems are tailored for such an environment. To simplify the commissioning process and minimize sparing by having a single module type that spans the full C-band, tunable DWDM transceivers have become the norm. As outlined in Table 2, some of the client devices in the access plant are not able to tune the transceiver wavelength. For such devices, external tuning devices are used to configure the channel for the tunable optics. Alternatively, a new class of tunable transceivers that automatically tunes to the channel determined by the DWDM filter, without the host equipment or external devices involvement, has recently been introduced. Although auto-tunable optics hold significant promise, current implementations of the tuning mechanism complicate optical power measurements along the optical path using conventional power meters making them impractical for the large-scale deployment. Potential solutions that address some of the limitations of existing auto-tunable modules are discussed in Section 5.

Table 2 – Optical Transceivers in Secondary UAT Rings and Optical Spurs

	Client Devices					
	RPD Node	**OLT Node**	**Enterprise NID**	**IPRAN Router**	**Baseband Unit**	**Remote Radio Unit**
Line Rate (Gbps)	10	10	1 and 10	10	10 and 25	10 and 25
Reach (km)	80	80	80	80	15	15
Host Device Tuning	No	Yes	Yes	Yes	No	No
Frequency Grid (GHz)	100	100	100	100	100	100
I-Temp Support	Yes	Yes	No	No	No	Yes
Form Factor	SFP+	SFP+	SFP+	SFP+	SFP+; SFP28	SFP+; SFP28
Power Consumption (W)	<2	<2	<2	<2	<2.5	<2.5

For 10 Gbps line rates typically encountered in the secondary UAT rings or optical spurs, optical power loss induced by the fiber transmission path – fiber, passive multiplexers and couplers, connectors, splices – is the dominant limiting factor. As the line rates in the access plant increase to 25 Gbps or above, optical reach of the NRZ direct detect optics is chromatic dispersion (CD) limited to 15 km. To leverage the existing passive single-fiber DWDM network and overcome the CD distance limitation, a new type of direct detect transceiver based on Pulse Amplitude Modulation 4-level (PAM4) modulation is required. To support even higher 100 Gbps line rates, more complex and costly coherent transceivers are required. Coherent module types considered for the access part of the UAT and their impact on the currently deployed single-fiber DWDM passive multiplexers are briefly discussed in Section 5.

4.4.2. Optical Transceivers in Primary UAT Collector Rings

Standard line rates for UAT primary rings range between 100 Gbps for the aggregation routers directly connected to the passive multiplexers and 200-400 Gbps for the transponder-based ROADM systems.

For the passive hop-by-hop primary rings, aggregation routers are connected directly to the optical multiplexer. To leverage existing QSFP28-based routers in the brownfield networks, 100 Gbps QSFP28 ER4 or ZR4 optics are directly connected to the 1310 nm port of the WDM couplers described in Section 4.3.2. 100 Gbps ER4 and ZR4 transceivers multiplex signals from four 25 Gbps NRZ direct detection optics operating in the 1310 nm range. As CD impact in 1310 nm band is minimal, 100 Gbps ER4 and ZR4 modules provide optical reach between 40 and 80 km not including loss from the WDM coupler which is sufficient for most of the primary collector rings.

If the 1310 nm port of the passive multiplexer is unavailable in the brownfield network applications or additional channels are required for scalability, operators have two options: (1) uplift the aggregation router to support CFP2 or QSFP-DD transceivers that can operate in the C-band, or (2) install active optical transport system to "convert" the grey 1310 nm QSFP28 interface to DWDM. As both options are costly and intrusive, the QSFP28-based coherent transceiver examined in Section 5 is urgently needed.

For collector rings with longer distances between sites or high-capacity metro applications where hub-and-spoke topology is required, active optical ROADM-based systems are recommended. As ROADMs typically require high input power of at least 0 decibel milliwatts (dBm), existing aggregation routers are connected to the optical line systems through a transponder card with grey 100 Gbps FR QSFP28 client ports and high power 200-400 Gbps CFP2 lines. Until recently, 0 dBm transmit power was achievable only with larger CFP2 modules that have enough space to house micro EDFAs and dissipate heat produced by the transceiver. Larger form factor and higher power consumption of CFP2 necessitates bigger and more expensive routers, making the IP-over-ROADM model with coherent CFP2 transceiver cost unattractive.

With the recent introduction of smaller form factor 0 dBm QSFP-DD ZR+ transceivers that can be hosted in smaller and less costly aggregation routers than CFP2, the IP-over-ROADM model has finally become more cost attractive than the traditional transponder-based model. In addition to reducing capital expenditure, eliminating the transponder in the IP-over-ROADM model reduces space and power requirements leading to operational savings. Eliminating the transponder also means fewer elements to plan, install and maintain, leading to quicker deployment times and more resilient overall transport system. As high power QSFP-DD ZR+ transceivers become more common and router vendors endorse pay-as-you-grow model for the 400 Gbps ZR+ transceivers, IP-over-ROADM costs are expected to become even more attractive.

Introduction of the 0 dBm 100G QSFP28 ZR transceivers mentioned in Section 5 is expected to have similar benefits as the high power QSFP-DD ZR+ modules. Figure 17 compares the IP-over-ROADM and IP-over-passive DWDM cost per port with the traditional transponder-based model.

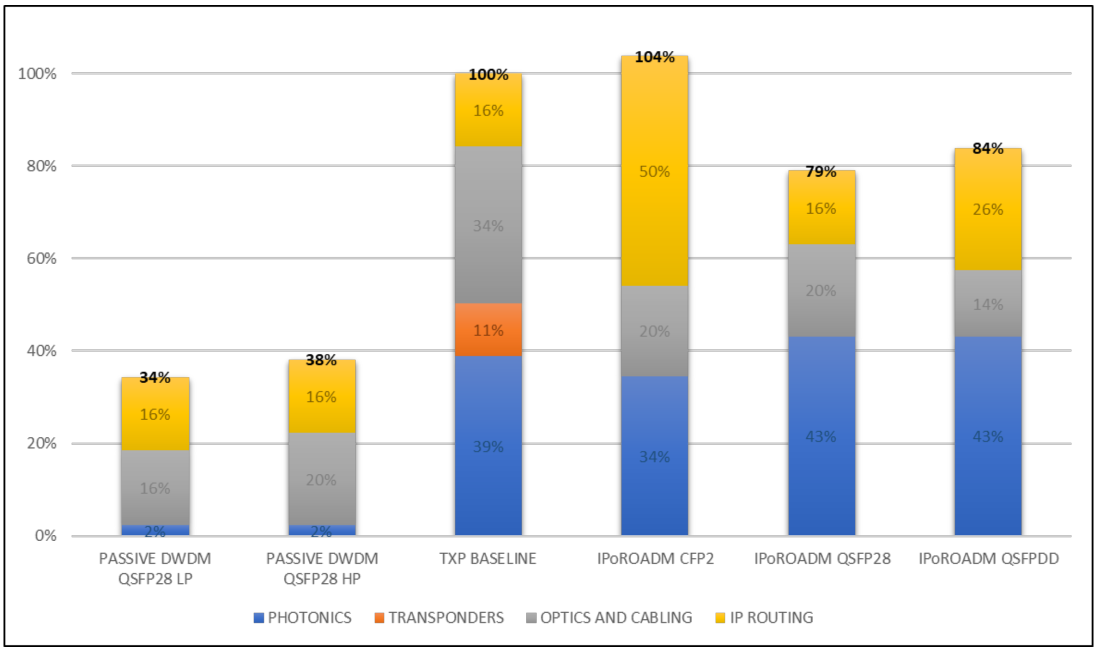

Figure 17 – Relative Cost per Port Comparison for the Primary UAT Rings

5. What's Next for UAT?

The following section previews the Plan of Record (POR) activities for the UAT. The focus of the activities is continued evolution of UAT to meet growing traffic demand while reducing costs and time-to-market without sacrificing network reliability.

Figure 18 shows directional POR for the UAT activities.

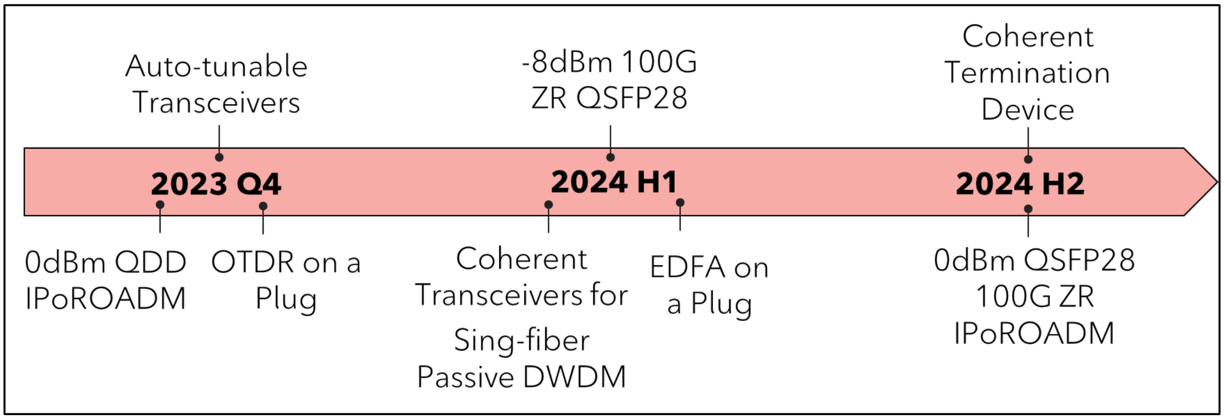

Figure 18 – UAT Plan of Record

Auto-tunable Transceivers. As discussed in Section 4.4.1, auto-tunable transceivers eliminate the need for the host equipment or an external tuning device to configure the transceiver's operating wavelength. This is particularly important for the access plant where host equipment is simpler and usually not able to change the transceiver's wavelength. Two main challenges exist with the current generation of auto-tunable transceivers: (1) the tunning mechanism engages shortly after receiver detects loss of signal which complicates troubleshooting procedures with conventional power meters that operate at a fixed wavelength, and (2) the tuning-mechanism lasts between 3.5 and 7 minutes prolonging the commissioning time. The first challenge can be resolved by having a troubleshooting mode that disables the scanning mechanism by fixing the wavelength with the external tuning box. Rogers Communications is working with equipment and transceiver vendors to certify this solution. The second challenge is addressed with the recent introduction of narrow-band auto-tunable transceivers that reduce the tuning mechanism duration to 1-1.5 minutes by covering a smaller set of adjacent channels. In addition to faster tuning, narrow band tunable transceivers are simpler and lower cost than full-band auto-tunable transceivers. The downside of the narrow-band tunable modules is that multiple part numbers are required to cover the full C-band, thus complicating sparing.

High Power QSFP-DD and Optical Disaggregation. Although introduction of 0 dBm QSFP-DD ZR+ transceivers and Open Line Systems enable optical disaggregation, improved automation and management tools are required before the IPoROADM model is rolled out in production networks. Rogers Communications engineering and Operations and Support Systems (OSS) teams are working collaboratively to introduce a vendor agnostic hierarchical multidomain controller that communicates with individual IP and Optical domain controllers to provide real time topology and service visibility, network analytics and service assurance through a common user interface. In addition to being able to provision and manage services end-to-end, the hierarchical controller provides a multilayer view of the network enabling easier correlation between optical and IP layer events.

OTDR on a Plug. Sections 4.2 and 4.3.1 outline the benefits of OTDR monitoring for the secondary rings and active optical systems used in UAT primary rings. To provide low cost OTDR monitoring for optical links on the passive collector rings, Rogers is working with routing and optics vendors to integrate a micro-OTDR transceiver directly into the aggregation router. Upon the loss of signal detected by the receiver, the transmitter switches into the OTDR mode and sends optical pulses down the impacted fiber link. The router then extracts the distance to the fiber fault from the OTDR transceiver and sends an SNMP message to the element management system as shown in Figure 19. The Micro-OTDR SFP transceiver is a CWDM transceiver that can operate in 1470, 1490, 1510, 1570, 1590 and 1610 nm channels and is thus perfectly suited for the passive CWDM and DWDM multiplexers on the UAT primary rings.

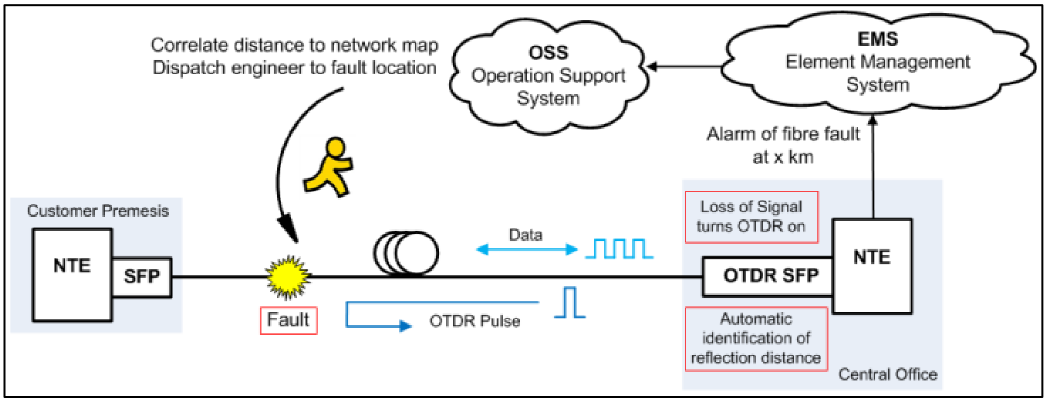

Figure 19 – OTDR on a Plug [1]

100 Gbps QSFP28 ZR. Figure 17 in Section 4.4.2 illustrates the benefit of using 100 Gbps ZR QSFP28 optics for the 100 Gbps DWDM primary rings. In addition to offering lowest cost per port for the greenfield deployment, 100 Gbps ZR transceivers allow for easy and cost-effective upgrade of the brownfield primary rings with widely deployed aggregation routers. While -8 dBm 100 Gbps QSFP28 ZR will be used for the passive primary rings, a high power 0 dBm version of the transceiver is predominantly expected to enable IPoROADM deployments. A critical challenge for transceiver vendors is to design 0 dBm optics that fit into the QSFP28 power budget supported by older routers. As primary rings evolve to higher speed line rates with the mass use of high power 400 Gbps QSFP-DD optics, 100 Gbps QSFP28 ZR will proliferate in the access part of the UAT and is expected to be one of the key enablers for the wider adoption of the Coherent Termination Device (CTD) discussed later in this section.

Coherent Transceivers for Single-fiber Passive DWDM. Conventional coherent transceivers use the same wavelength in both transmit and receive directions. Therefore, standard coherent modules require dual-fiber unidirectional passive multiplexers shown in Figure 20a. As discussed in Section 4.3.2, these multiplexers are deployed in the UAT primary rings. To enable the use of CTD over single-fiber bi-directional DWDM multiplexers used in the UAT secondary rings and spurs, a new approach is required. Figures 20b and 20c show two potential solutions for single-fiber unidirectional DWDM multiplexers: (1) coherent transceiver with two separate lasers operating at different wavelengths and (2) conventional single-laser coherent transceiver connected to a single fiber common line via optical circulators connected at both ends of the link. Table 4 shows high level pros vs cons of options illustrated in Figure 20. A more in-depth study is planned for the first half of 2024.

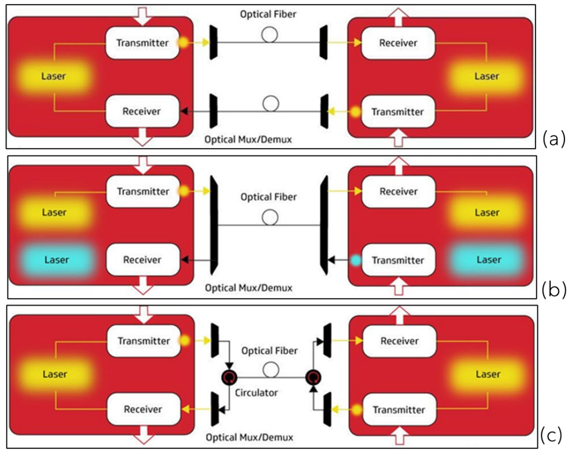

Figure 20 – Coherent Transceivers in UAT [2]

Table 4 – Coherent Transcievers over Passive DWDM Multiplexers

	Advantages	Disadvantages
Dual-Fiber Unidirectional DWDM Multiplexer	1. Works with conventional single laser transceiver that fits in a cost effective QSFP28 form factor. 2. Small form factor allows for lower cost host device.	1. Fiber inefficient.
Single-Fiber Bidirectional DWDM Multiplexer	1. Fiber efficient.	1. Requires large form factor costly CFP2 module to fit two lasers for the Bi-Di transceiver. 2. CFP2 form factor drives up the host device cost.
Single-Fiber Bidirectional DWDM Multiplexer with Circulator	1. Fiber efficient. 2. Works with conventional single laser transceiver that fits in a cost effective QSFP28 form factor. 3. Small form factor allows for lower cost host device.	1. Transmission performance is highly dependent on the quality of the fiber. Low reflection splices and connectors required.

EDFA on a Plug. Optical amplification is usually required for the longer spans connecting UAT POPs in rural primary rings. In this scenario active ROADM-based optical systems with WSS for expressing wavelengths and amplifier module are present. Amplification might also be required for urban primary rings to overcome losses from multiple cascaded passive multiplexers. This is applicable to brownfield DWDM-over-CWDM scenarios where optical signal from aggregation routers is patched through several POPs as shown in Figure 21. If space and power at the UAT POPs are constrained for standalone amplifier transport shelf, one option being considered is to connect a pluggable EDFA amplifier module directly to the aggregation router. While several routing vendors offer native EDFA-on-a-plug in the QSFP-DD form factor, integration of pluggable amplifiers in the SFP form factor is still very uncommon. An EDFA amplifier can be used as a booster, pre-amplifier or in-line-amplifier. A more in-depth study of pros and cons of integrating SFP EDFAs with existing brownfield routers is planned for the first half of

2024.

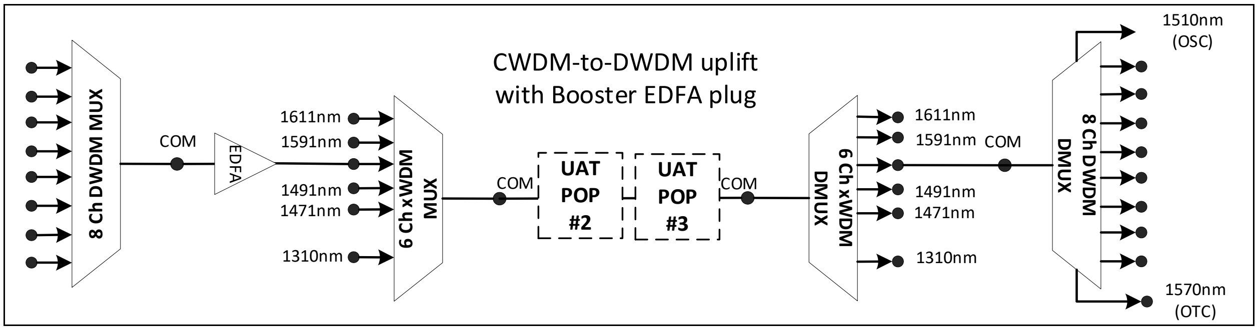

Figure 21 – EDFA on a Plug

Coherent Termination Device. The goal of the Coherent Termination Device (CTD) is to aggregate client devices on an outside plant router installed deeper into the access plant. As illustrated in Figure 22, CTD uses coherent transceivers to connect to aggregation routers located at the UAT POPs and direct-detect 10 or 25 Gbps transceivers to feed client end devices – RPD, OLT, Enterprise NIDs or CSRs. To keep the CTD costs and power consumption down, trunk coherent links should use the QSFP28 transceivers; this would also minimize upgrades of existing QSFP28-based aggregation routers at the UAT POPs. In fiber rich areas, CTD QSFP28 trunk ports would connect to aggregation router over dual-fiber unidirectional multiplexers. To avoid upgrading currently used single fiber bidirectional DWDM multiplexers, CTD QSFP28 trunk would connect through the optical circulator.

One of the advantages of aggregating traffic from client devices deeper in the plant via a CTD device instead of a passive DWDM multiplexer is that costly tunable 10 and 25 Gbps DWDM transceivers can be replaced with significantly lower cost grey optics. Additionally, unlike the topology in Figure 9 where client devices are connected to a single POP location, the CTD enables diverse coherent feeds to two geographically diverse UAT POPs. The topology shown in Figure 22 reduces the failure domain by eliminating a UAT POP site failure as a service affecting incident.

Despite the previously outlined advantages, the CTD adds another active point of failure in the plant that was not present with the passive multiplexer solution in Figure 2. A more in-depth study of the CTD's role in the access network is planned for the second half of 2024.

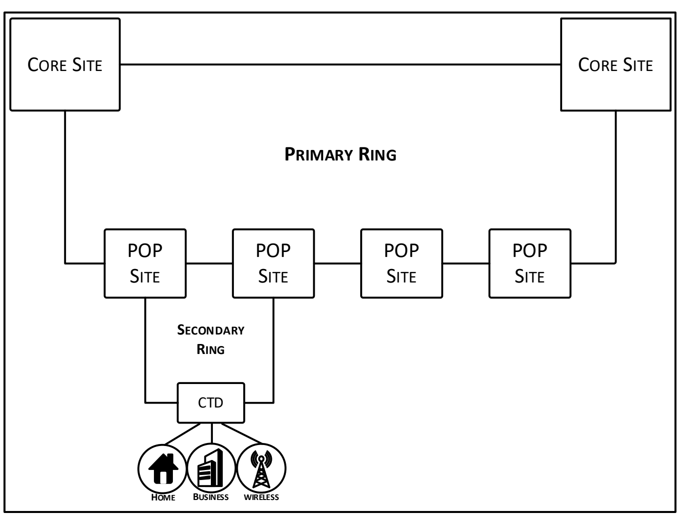

Figure 22 – Coherent Termination Device

6. Conclusion

This paper takes a closer look at Unified Access Transport, a common access optical transport network for all services at Rogers Communications. It explains the major drivers for the UAT – Network Simplification and Resiliency Improvements, Wireline and Wireless Modernization and Uplift, and Service Expansion – and presents how UAT enables them. After examining UAT topology options used in the urban and rural deployments, this paper explores specific requirements for the active optical solutions suitable for the metro-regional systems before investigating passive DWDM solutions for primary and secondary rings. Innovative network designs that minimize customer impact, such as optical switching between DWDM multiplexers in the plant and at the UAT POP, and monitoring solutions that reduce MTTR, such as OTDR, are also examined. In addition, transceiver options used in the UAT, both direct detect transceivers typically used in the secondary rings and coherent transceivers predominantly used in the primary collector rings are investigated. The analysis concludes that recent introduction of the 0 dBm 400 Gbps QSFP-DD ZR+ is a key enabler for the wider adoption of IPoROADM solutions in the primary collector rings. The paper concludes by reviewing near to medium term POR which indicates that transceiver advancements play a prominent role in the UAT evolution.

Abbreviations

BBU	baseband unit
BNG	broadband network gateway
B&S	broadcast and select
CCAP	converged cable access platform
CPRI	common public radio interface
CSR	cell site router
CTD	coherent termination device
CWDM	coarse wavelength division multiplexing
DOCSIS	data over cable service interface specification
DWDM	dense wavelength division multiplexing
DAA	distributed access architecture
dBm	decibel milliwatts
EDFA	erbium-doped fiber amplifier
FOADM	fixed optical add-drop multiplexer
FTTH	fiber to the home
FWA	fixed wireless access
Gbps	gigabit per second
GHz	gigahertz
HP	homes passed
HFC	hybrid fiber coaxial
IP	internet protocol
IPRAN	ip radio access network
IPWAN	IP Wireline Access Network
km	kilometer
MTTR	mean time-to-repair
MIMO	multiple input multiple output
NID	network interface device
OLT	optical line terminal
OSNR	optical signal to noise ratio

OTDR	optical time domain reflectometer
PON	passive optical network
POP	point of presence
RBS	radio base station
ROADM	reconfigurable optical add-drop multiplexer
R&S	route and select
RPD	remote phy device
RRU	remote radio unit
SONET	synchronous optical networking
Tbps	terabit per second
UAT	Unified Access Transport
UFP	Unified Fiber Plan
VCCAP	virtual converged cable access platform
WSS	wavelength selective switch
XGS-PON	10 gigabit per second symmetrical passive optical network

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[2] *Doubling up on Fiber Capacity: A Winning Strategy for Full Duplex Coherent Optics*; Steve Jia; https://www.cablelabs.com/blog/doubling-fiber-capacity-winning-strategy-full-duplex-coherent-optics

