FTTH Distance and Density Considerations

Rural Broadband

A technical paper prepared for presentation at SCTE TechExpo24

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1. Introduction

Cox Communications, like many other operators, is pursuing a share of the $42 Billion in Broadband Equity Access and Development (BEAD) Program funding to support rural expansion efforts, which is in addition to what has already been awarded via Rural Digital Opportunity Fund (RDOF) and a variety of local state, county and city grant opportunities. While these government funds have certainly stimulated growth like we've never seen before, it has introduced a host of network challenges for operators to solve. Furthermore, the size and density of each underserved community can vary greatly, from small 100 home clusters to towns with populations greater than 10,000 homes passed.

At Cox, our default solution for new build is Fiber-to-the-Home (FTTH), but there are many options to solve the distance and density challenges. Transport from the headend to Optical Line Terminal (OLT) has led us to consider optical amplification solutions traditionally reserved for long-haul backbone links. The OLT deployment methodology also needs to be considered; obviously size/density is the primary driver, but distance also factors into the equation. For the distribution network downstream of the OLT, despite the low density of a rural community, we still want to optimize OLT port consumption. In this paper, we explore the various architectural challenges, the tools that we put in our toolbox and ultimately a distance and density-based decision-tree that assists our estimating teams with network planning.

1.1. Background

Our first deployments of Passive Optical Networks (PON) were Broadband PON (BPON) in 2004, which were deployed to a very limited extent for commercial applications. As the PON technology matured, Cox began deploying GPON in 2008, again exclusively for commercial applications. Fast forward to 2014, we repurposed the GPON platform and offered a gigabit symmetrical product to our residential customers, deploying GPON in both brownfield and greenfield applications. In 2020, Cox enabled all of our products (Video, Telephony and Data) with All IP over the PON network.

The PON portion of the FTTH network also went through a series of evolutions in the 2014 to 2020 timeframe. Initial deployments of GPON OLTs were rack-mounted in large environmentally controlled cabinets feeding a 1:32 split ratio. While we still deploy large OLT cabinets to a limited extent today, we primarily deploy hardened passively cooled Remote-OLTs (R-OLT) for smaller targeted areas. The transport architecture used to deploy most of our GPON R-OLTs was a routed (layer 3) multi-hop ring solution, allowing up to 8 R-OLTs per ring. In 2020 it was decided to leverage synergies from our Distributed Access Architecture (DAA) solution used for Remote-Phy Device (RPD) node deployments and migrate OLT transport across a homegrown Dense Wave Division Multiplexing (DWDM) solution called the Optical Communication Module Link extender (OCML). Furthermore, in an effort to position ourselves to support the ever-growing bandwidth demands, we launched 10 gigabit symmetrical PON (XGS-PON) OLT's, capable of supporting 8G symmetrical products for our customers.

The GPON distribution network architecture started at a 1:32 split ratio and increased to a fixed 1:64 split ratio later on to optimize OLT port consumption efficiencies. In an effort to further optimize fiber and labor efficiencies, we introduced a distributed optical tap system, using a combination of unbalanced and balanced couplers to control optical insertion loss in a more efficient manner (see Figure 1).

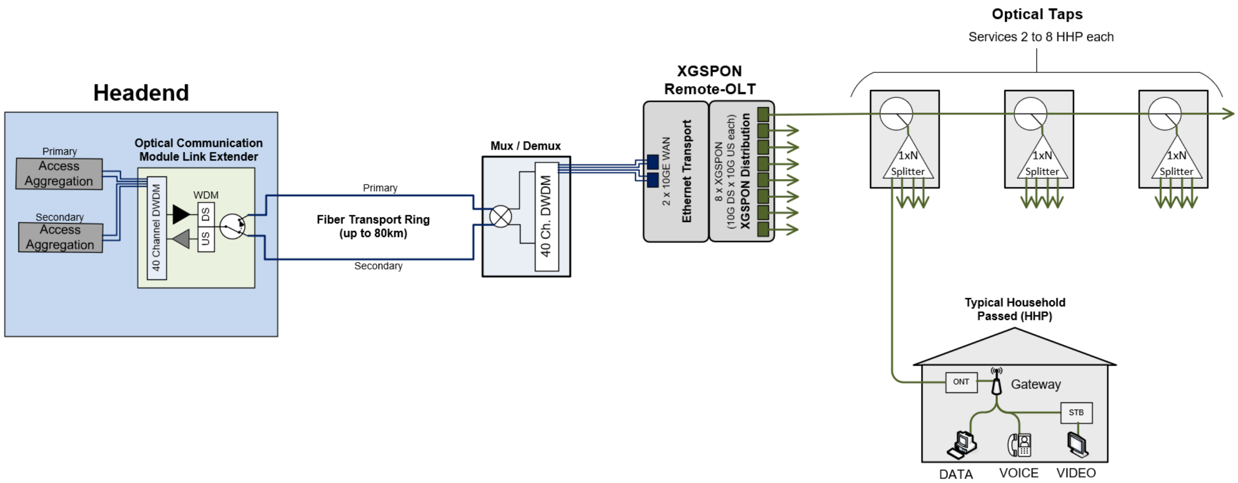

Figure 1 – Cox Communications Standard FTTx Architecture

1.2. Rural Communities

In addition to government funding from programs such as BEAD and RDOF, Cox also decided to proactively self-fund construction to adjacent communities. Regardless of the driver, many of these communities are well outside of our existing footprint. The size of each targeted census block group (CBG) varies from less than 100 households passed (HHP) to upwards of 10,000+ HHP. The vast majority of the passings are Single Family Units (SFU), however the density of them is also highly variable.

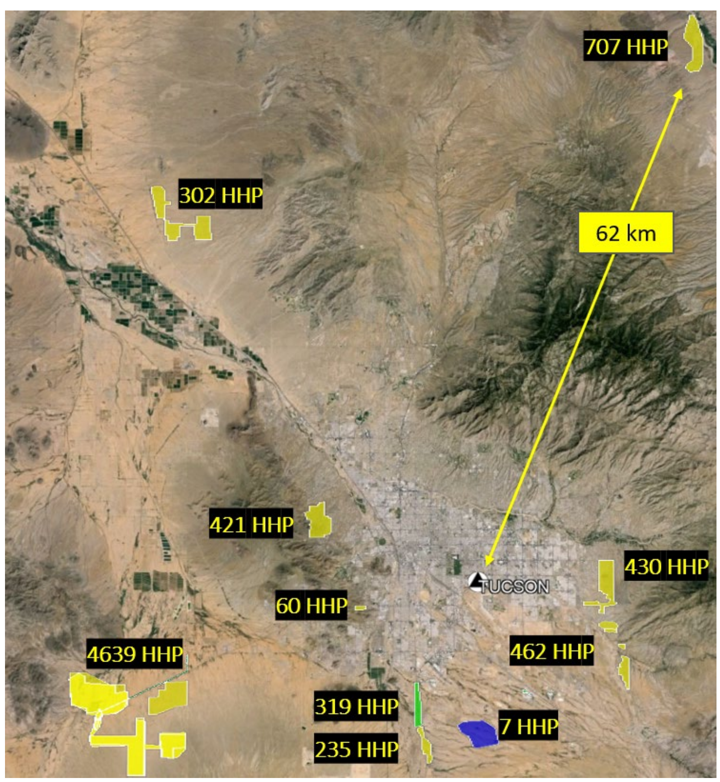

Figure 2 – Example of Rural Opportunities

Those familiar with Outside Plant (OSP) construction probably already know that the typical density of a metropolitan area is about 100 HHP / Plant Mile. The densities observed in the rural areas are typically much lower. Of the roughly 45,000 HHP in our nationwide study group, the average is 34 HHP / plant mile, ranging as low as 5 HHP / plant mile. The example below shows the effective densities in HHP / plant mile of prospective census block groups. For sake of comparison, our existing network in Central Florida averages 93 HHP / plant mile.

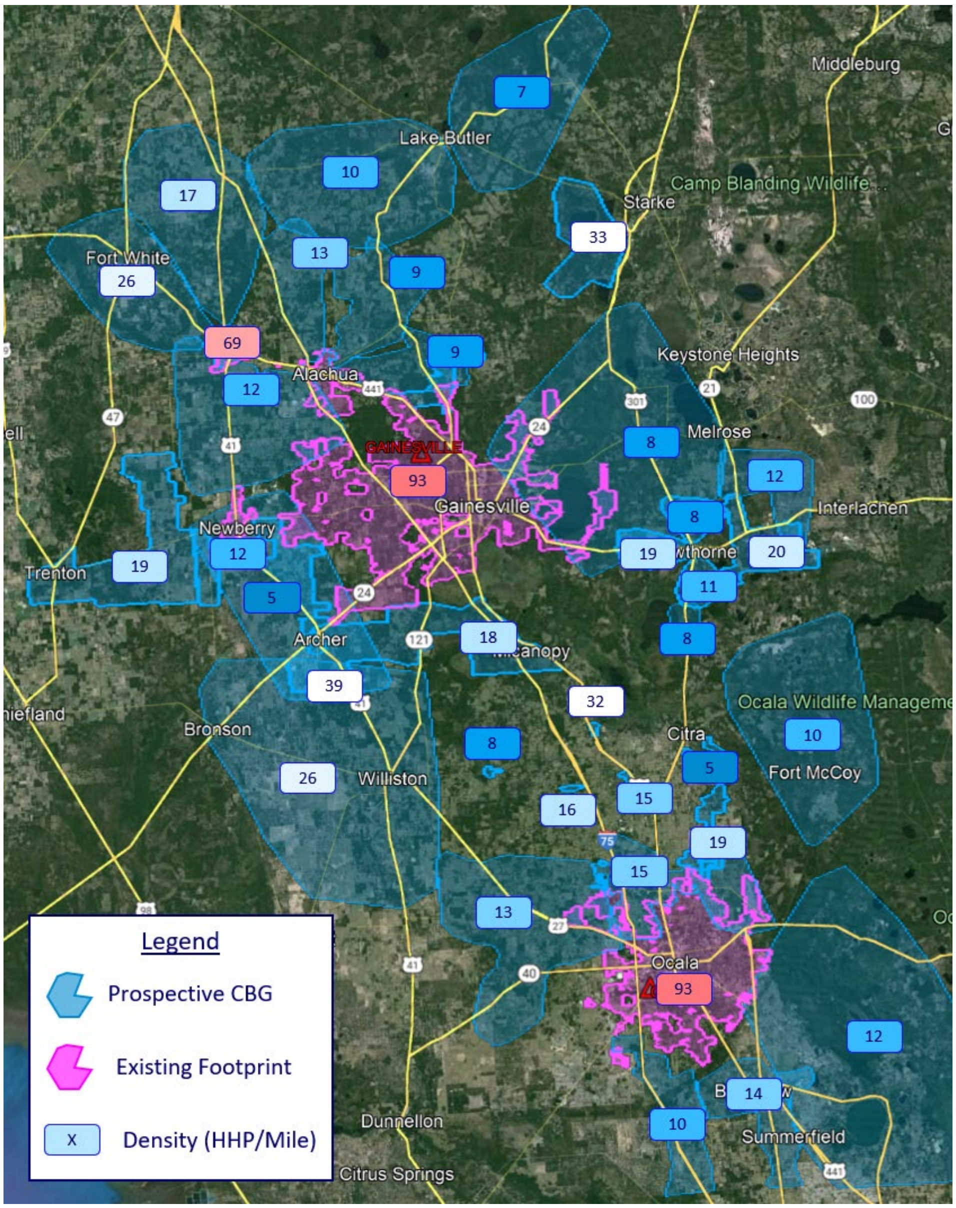

Figure 3 – Example of Rural Opportunities

1.3. Distance Concepts

When assessing new territories outside of your existing network, it's important to have a good sense of distance, understanding the relationship between these three distance concepts can be valuable:

Distance Concepts:

Linear: Distance 'the crow flies' between two points on a map

Route: Street-level path length on a map

Optical: True fiber length the signal travels from transmitter to receiver.

The linear distance to the edge of our existing footprint is typically 20-25 km from an existing headend, but based on a study that we conducted, the optical distance is a little more than twice that. The chart below contains a sample size of 9,257 RPD Nodes in our West region, where the optical distance to linear distance ratio worked out to an average of 2.3 to 1.

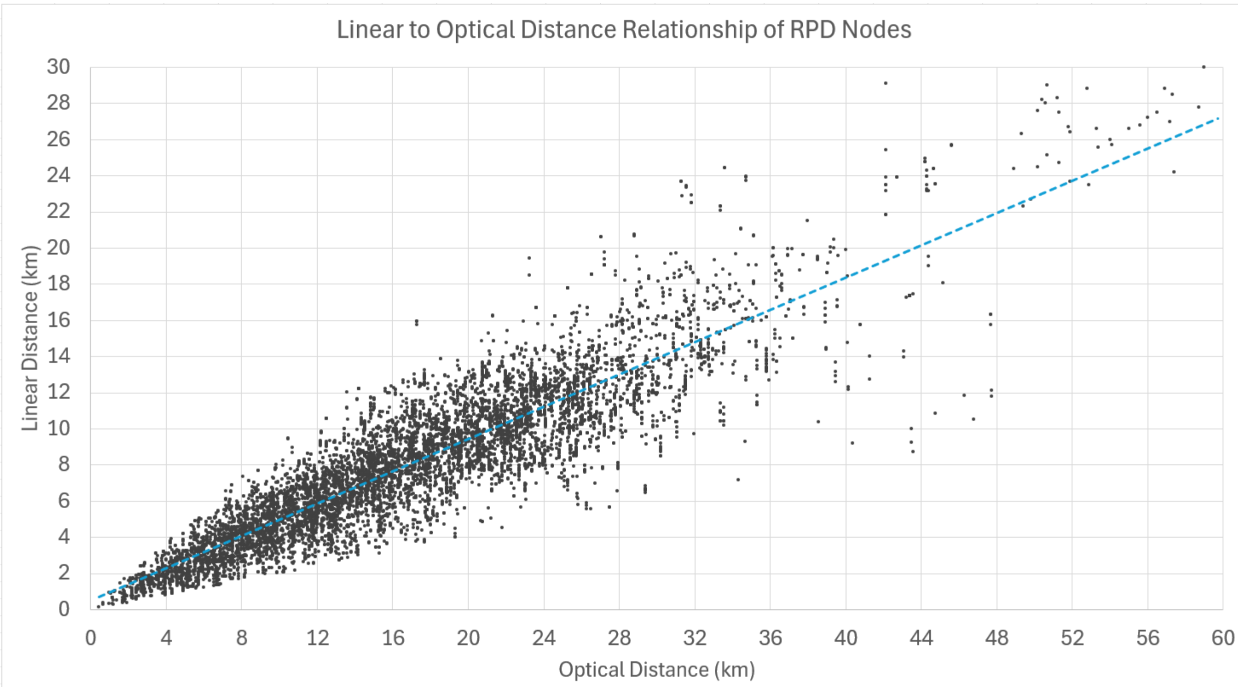

Figure 4 – Relationship of Linear to Optical Distance Study

If you were to draw a 35 km radius circle centered around a central headend in just about any metropolitan area and you'll quickly see that it easily covers millions of homes passed and almost everything is within optical reach. It's not a perfect science, but this ratio can come in handy to get a rough sense of technology types that may be needed for transport to a rural area. For example, typical ZR optics are rated to 80km of optical reach, which is effectively 34.8 km (21.6 miles) of linear distance, anything outside of that likely will require amplification or longer reach optics.

For more precision, a street level route can be established using the driving directions feature of a GIS mapping tool. When thinking about a fiber cable that runs along that route there's a lot of hidden distance. Factors such as slack loops, fiber twist, risers and cable sag will add 20 – 25% of distance. For sake of our estimates, we assume an additional 25% on top of the route length for optical distance.

2. Optical Transport Network

When deploying OLTs in the field, Cox implements three backhaul strategies; Direct Fiber, OCML, and Reconfigurable Optical Add Drop Multiplexers (ROADM). Cox's preferred backhaul solution is to use an inhouse Dense Wave Division Multiplexing (DWDM) technology called OCML. While it uses standard 10Gbs 80km tunable DWDM transceivers, OCML has a few unique features as compared to other DWDM solutions such as ROADM.

Cox has developed an extensive automation system to activate and manage the lifecycle of OLTs. The OLTs are activated using Zero Touch Provisioning (ZTP). With the automation system, if an OLT dies, it can be replaced, and the new unit retrieves its configuration with little manual intervention. The system also allows for the OLT hardware to be upgraded as new hardware becomes available.

2.1. Direct Fiber Backhaul

Direct Fiber backhaul is the simplest solution to deploy. Just like it sounds, this solution uses gray optics to connect an OLT in the field to the Access Aggregation Routers (AAR) in a facility. This solution is limited to ~100km and requires 4 fibers. The uplink standard for all Cox OLT deployments incorporates aggregation diversity, meaning each OLT terminates on a pair of AARs. To accomplish this, port 1 on the OLT terminates on AAR1 and port 2 on the OLT terminates on AAR2. The majority of the OLTs we deploy are small with 8-16 ports and most deployments require multiple OLTs. This transport solution does not scale well, but there are cases where it is the best choice.

2.2. OCML Backhaul

A few of the features that makes OCML unique are:

- All the active components are deployed in a Cox facility.
- It uses a single fiber for the primary and secondary (protect) paths.
- It uses a single DWDM filter in the field for Mux/DeMux (MDM).

The OCML is a half slot module that is installed in a 1RU (1.75") chassis; each chassis supports two modules. The main components of each model are a 40 channel (100GHz) DWDM filter, pre and post Erbium Doped Fiber Amplifiers (EDFA), and an optical switch for line protection in the field. Mixing upstream and downstream wavelengths on the same fiber (bi-directional) in essence decreases the system to 20 channel pairs, each upstream/downstream connection consumes 1 channel pair. The OCML systems have a very simple and easily repeatable deployment model that moves the OLT closer to the customer, reducing the number of fibers needed for backhaul, while greatly extending the reach of PON.

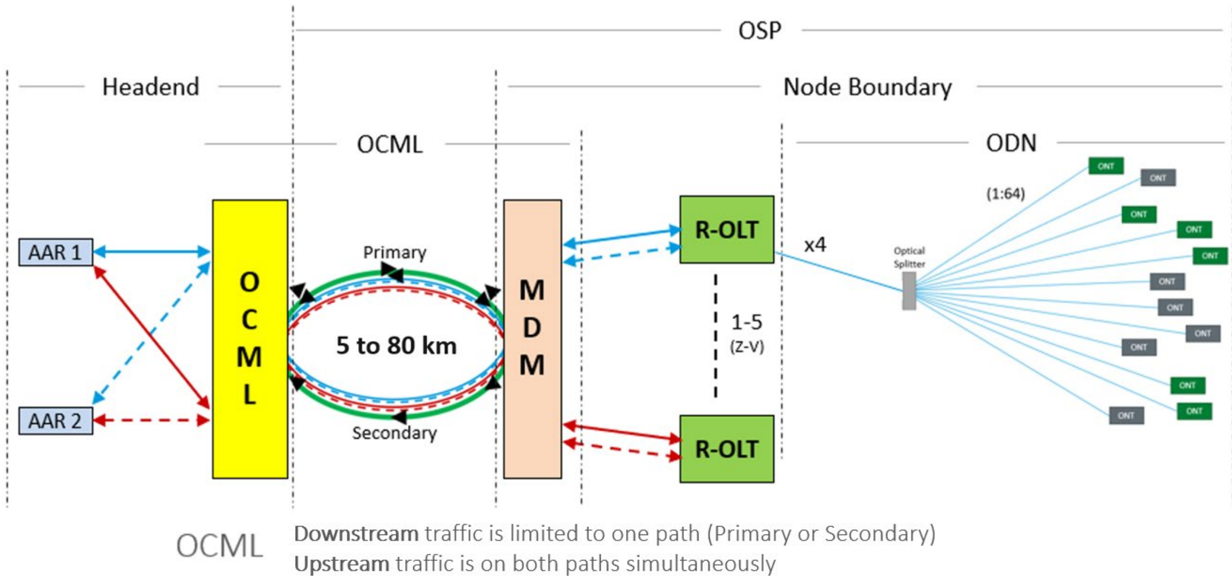

Figure 5 - OCML Architecture

Cox uses two versions of OCML modules depending on the distance from the facility to the MDM. The version 1 modules support distances from 0km to 40km. The second version includes dispersion compensation to support fiber lengths up to 80km. One drawback of OCML is that the system only supports one MDM per OCML, so all 40 channels (20 channel pairs) drop/add at a single location in the field. Because the MDM is passive, it is not possible to get Realtime analytics from that point in the network. To overcome some of the shortfalls of an all-passive system, in the field, Cox has implemented an Optical Time Domain Reflectometer (OTDR) monitoring tool. The system monitors both the primary and secondary fiber routes, for all OCML modules, and alerts the Network Operations Center (NOC) if a fiber path changes.

With OCML, both network uplinks route over the same optical path (fiber) but at the headend terminate on separate routers. Layer 2 protection provides a combined aggregate of up to 20Gbps of capacity. Since the OLTs we deploy have 8-16 ports, most deployments require multiple OLTs, which require multiple channel pairs, some deployments require up to 16 channel pairs (8 OLTs).

In addition to being a backhaul strategy for RPDs and FTTH, Cox Business also uses OCML to provide up to 10Gbps Active Ethernet (AE) connections to customers. AE are Point-to-Point connections between the customer and a Cox facility. These connections are used to serve Cox's triple play services (Voice, Video, and Internet). When AE is carried over OCML, and fiber redundancy is available, then the OCML provides path protection. Seldom is an OCML deployed solely for Cox Business, but Cox Business frequently utilize OCMLs that have been deployed for RPD/FTTH deployments.

2.3. Cabinet ROADM Backhaul

OCML has proven to be a powerful tool whenever the distance limitation can be met. Some of the BEAD and RDOF opportunities are well beyond the distance limitation of OCML in which case Cox deploys Reconfigurable Optical Add/Drop Multiplexers (ROADMs). ROADMs allow multiple add/drop locations on a fiber ring, which is also beneficial as Cox targets customers that are further away from existing facilities.

ROADMs have greatly simplified the deployment challenges that came with Fixed Optical Add / Drop Multiplexers (FOADM). ROADMs allow nodes and channels to be added to the system without complicated and manual engineering efforts. They also support much higher bandwidths with the introduction of coherent optics. This also simplifies the deployment models by removing Dispersion Compensation (DC).

When Cox uses ROADM in cabinets for backhaul, two muxponder cards are installed in the cabinet, and a pair are installed in the headend facility. Muxponder cards have a 100G DWDM network interface and 10x 10Gbps client interfaces. The cards are bookended (muxponder to muxponders), routed across each side of the ring providing 20x 10Gbps circuits between the cabinet and the facility. In the cabinet, OLT1 has two ports connected to the muxponder cards, one port connects to each card. At the headend facility, port 1 on the first muxponder connects to AAR1 and port 1 on the second muxponder connects to AAR2. Just like with OCML deployments, network protection is handled at Layer 2.

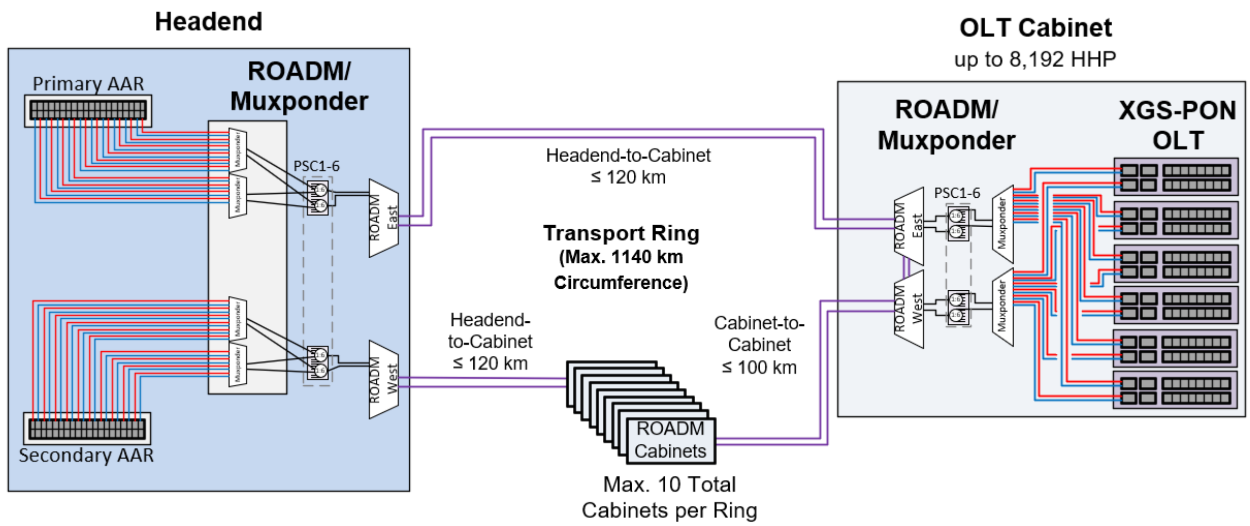

Figure 6 – ROADM Transport Architecture Example

In terms of optical reach, we've run a variety of distance models for our application and have established the following guidelines:

- 120 km Max from Headend to first cabinet on each side of the ring
- 100 km Max between cabinet locations
- Up to 10 cabinet locations per ring
- 1,140 km Max ring circumference

These are the safe operating guardrails that we use for network planning purposes, however each unique scenario gets engineered prior to an actual activation. The guidelines above can be exceeded, but typically will require pre-engineering prior to network planning estimates.

2.4. Fiber Aggregation Facility Backhaul

A new deployment strategy for Cox to deploy fiber deeper, is to use Fiber Aggregation Facilities (FAFs). FAFs are concrete huts (facilities) with room for 5-10 data racks. As Cox started working through the design criteria of many of the BEAD/RDOF projects, it became apparent that cabinets with ROADMS would be needed to cover the distances from the facilities. These cabinets would house OLTs for FTTH and would serve communities that otherwise could be served with R-OLTs. OLTs are more expensive than R-OLTs, as they have more ports. It became obvious that the better solution for many locations would be to deploy something that looks like a mini facility, a FAF. FAFs have a lot of the benefits of a standard facility including redundant air handlers, battery backup with a fixed generator, and can be entered by personnel, keeping equipment safe from the elements when being serviced.

A benefit to this architecture is that a FAF has additional room for AARs, and OCMLs. With the AARs installed in the FAF, network connectivity is backhauled using ROADM. In this case, the single ROADM can be used to serve a much greater number of HHP. The muxponder cards Cox uses can also operate as a transponder (100G DWDM/network to 100G gray/client). The cards are bookended just like when they are used as a muxponder. This architecture provides diverse routes over the optical network for a combined aggregate of 200Gbps. If more bandwidth is needed, then more cards can be added to increase the number of 100G connections. More AARs can also be added if there is a need to aggregate more than 48 OLTs. AAR port counts are driven up not only by the OLTs in the FAF but also from OLTs backhauled to the facility. The FAF will aggregate both OLTs (in cabinets) and R-OLTs using OCML, or OLTs in cabinets using ROADM.

Just like a standard Cox facility, all the various FTTH deployment architectures are supported out of a FAF:

- R-OLT over OCML
- Cabinet (rack) based OLTs using either OCML or ROADM
- Rack based OLTs installed in the facility

Cox has standardized on a new rack-based OLT for deployment in facilities/FAFs. This OLT is 1RU tall and can provide 32 ports of XGS-PON. A first for Cox is using grey 25G transceivers to connect the OLT to the AARs, for a combined aggregate of 50Gbps. This is possible because the OLTs are installed within close proximity to the AARs and the AARs have SFP-28 ports. The OLTs do not have SFP-28 ports so Cox also uses QSFP to an SFP-28 adapter to facilitate these connections.

In the example below, by placing a FAF, (6) ROADM cabinet locations are now replaced with (2) standard cabinets and (4) R-OLT locations serviced by lower cost OCML transport instead. The location of the FAF was centered in the highest density area so it can be leveraged as an OLT location to direct feed PON to the passings in the immediate area.

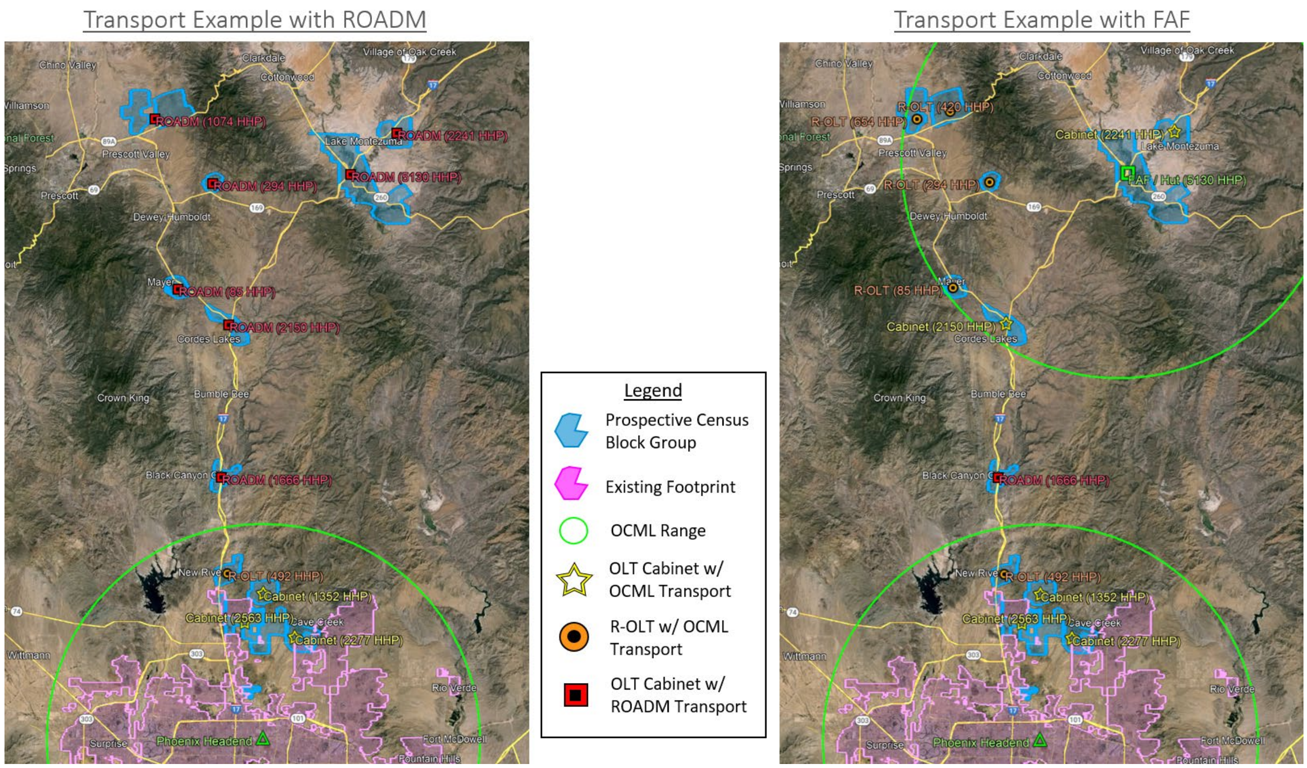

Figure 7 – FTTH Transport Examples with ROADM (left) and FAF (right)

3. OLT Deployment Methodologies

While we at Cox still have a large population of customers fed from GPON networks, all of our new PON deployments are exclusively XGS-PON in alignment with ITU-T G.9807.1. Typically, our go-to OLT of choice is a small 8-Port R-OLT. Similar to an RPD Node, it is a passively cooled, strand-mount clamshell device, which at a traditional 1:64 split ratio can serve up to 512 HHP. This type of device works especially well within our existing Hybrid Fiber Coax (HFC) footprint, because it is designed to accept 60 – 90 Volt AC quasi-square wave type of power. When deploying an R-OLT outside of our footprint, it also requires an HFC style power supply to be deployed in parallel.

To a much lesser extent, we also deploy rack-mounted OLT devices. The version we use today is a (1) Rack Unit (RU) shelf, which can support (2) line cards; typically, each card supports (8) XGS-PON ports. We can deploy these in either an environmentally controlled cabinet, inside a headend facility or remote hut. The advantage of a facility-based deployment is reliability and scalability. However, in these rural areas it is not likely an existing facility is within the reach of PON, which means you would need to build one. A street side cabinet can be a quicker, more cost-effective method to deploy rack-mounted OLTs. Additionally, the power plant of an OLT cabinet is self-contained, and it can support additional rack-mounted equipment such as transport amplifiers and Ethernet routers for commercial services. Cabinets are powered by a metered 240VAC commercial service line from the power company and rectified to -48VDC for distribution to rack-mounted devices. For network management purposes and to stay within reasonable cabinet capacities, we limit OLT Cabinets to a maximum of (8) OLT shelves, each shelf supports up to (16) XGS-PON ports, at a 1:64 split ratio maxes out at 8,192 HHP. We also recently started deploying a double-density OLT card in facility-based applications, which supports up to (32)

XGS-PON ports per RU. Because cooling and powering capacity is more limiting in cabinets than physical dimensions, we have not yet found enough benefits to justify them for cabinet-based applications.

Figure 8 – OLT Types

3.1. Cost Modeling

We performed a cost modeling exercise to compare R-OLT deployments to OLT cabinet costs with associated transport costs.

Actual dollar amounts are protected by non-disclosure agreements, so cost modeling data provided below is intended to illustrate relative cost differences of solutions considered.

Included	***Not Included (Assumed to be cost-neutral)***
• *OLT Electronics* • *Transport Electronics* • *All associated optics* • *Structures (pedestals, cabinets, etc.)* • *Headend Service Port Consumption* • *Licensing* • *Powering* • *Labor (enterprise average rates)* • *Permitting*	• *Fiber Cable Construction*

Run rates were established based on data collected from historical designs across our enterprise for each network element. The enterprise average for OLT port efficiency was assumed at a rate of 51.2 HHP per port. For example, R-OLT costs illustrated below scale in increments of 410 HHP each despite their maximum capacity of 512 HHP, with exception of the PON optic costs which were applied per port used. OLT cabinet costs scale in increments of 819 HHP per shelf up to a maximum cabinet capacity of 6,554 HHP.

For OLT deployments within 80km of optical distance our standard OCML was assumed for both R-OLT and cabinet-based applications. We found R-OLT costs outpace OLT cabinet cost beyond 1,230 HHP (i.e. up to (3) R-OLTs).

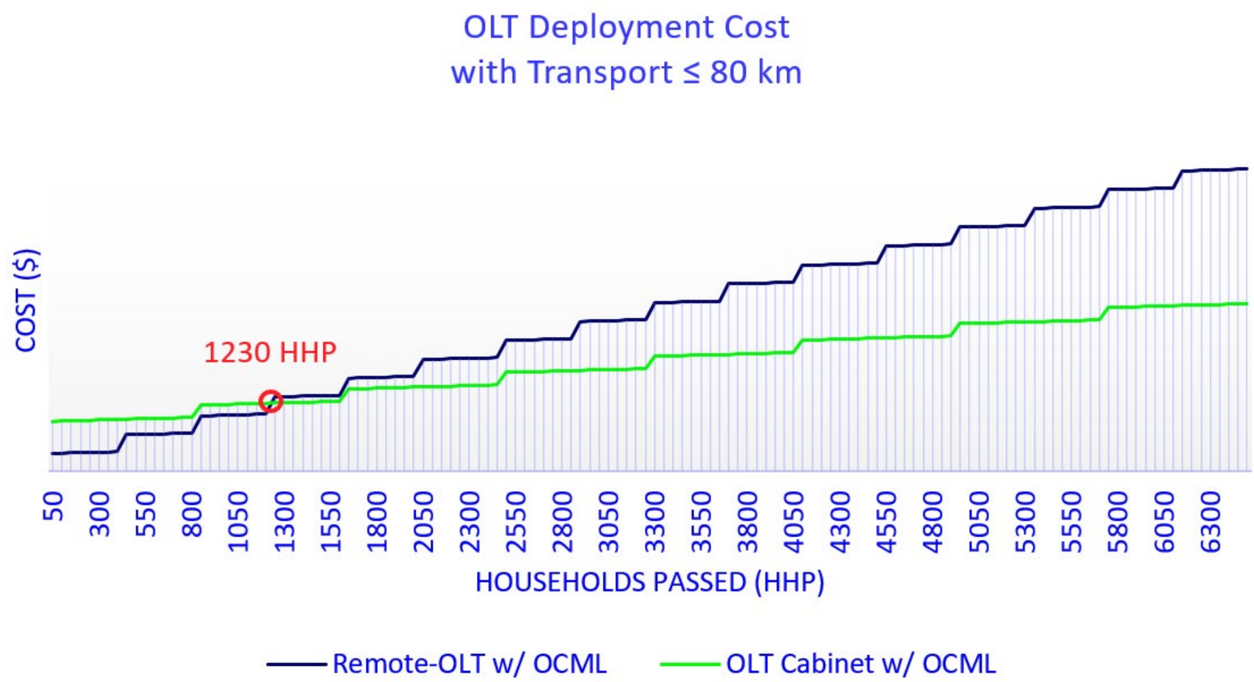

Figure 9 – OLT Deployment Costs up to 80 km Optical Distance

For OLT deployments outside the 80 km optical reach limit of OCML, a strand-mount EDFA solution was considered in conjunction with OCML modules servicing R-OLTs, which was compared to a cabinet-based ROADM solution servicing rack-mounted OLTs. The cost crossover point was at 550 HHP, which considering the use-case for R-OLTs greater than 80 km and less than 550 HHP is relatively low, we opted not to use a strand-mount EDFA solution. As a point of reference, there is about a 30% cost adder for an OLT cabinet with ROADM vs. an OLT cabinet for standard distance applications at less than 80 km of optical reach. Numerous other factors other than cost were considered, such as reliability, maintenance, future growth, network complexity and our existing internal tool ecosystems, before ultimately deciding to standardize on cabinet-based ROADM solutions for all deployments outside of 80 km. ROADM has the added advantage of allowing a multi-hop ring approach to help extend reach even further and spread out costs in areas with multiple communities in a similar geographic area.

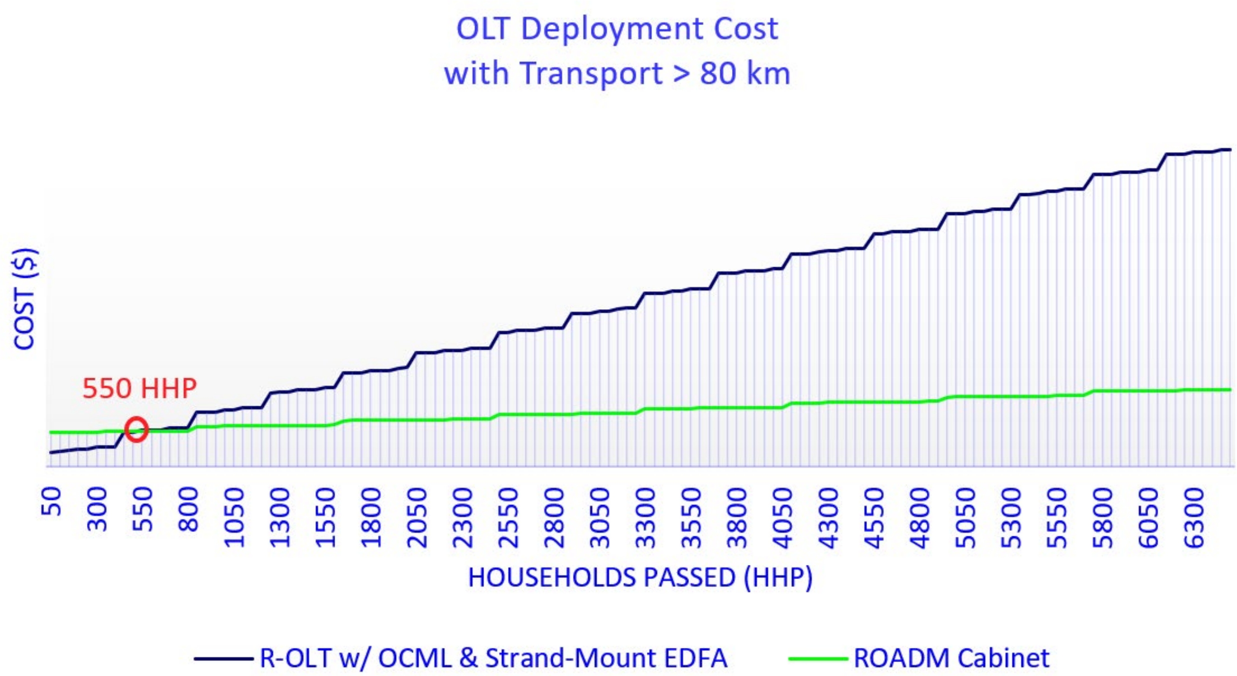

Figure 10 – OLT Deployment Costs greater than 80 km Optical Distance

3.2. Decision Tree

For network planning purposes we developed the following simplified decision tree to solve for most scenarios, which aligns with logic from aforementioned design studies. In some cases, a more in-depth design may need to be considered. For example, larger geographic areas with greater than (6) ROADM cabinets required, a FAF / Hut with subtended R-OLTs may be more cost effective.

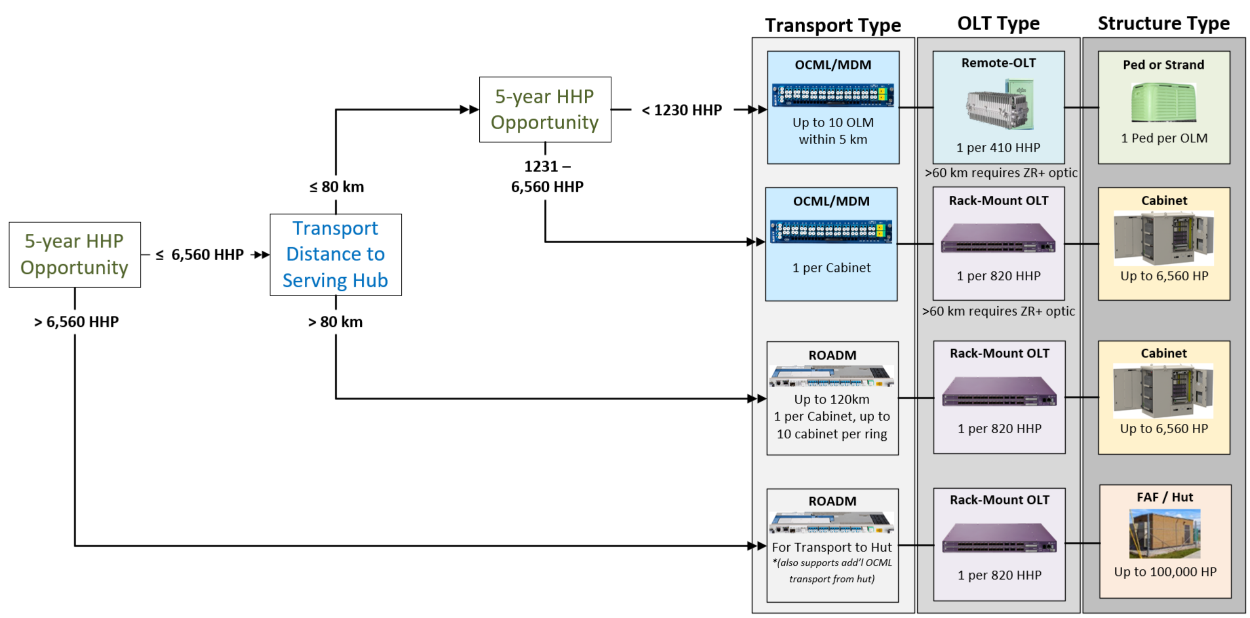

Figure 11 – Transport / OLT Decision Tree

4. PON Distribution Network

Downstream of the OLT in the Optical Distribution Network (ODN), there are a variety of options to consider for splitting. At some point in time, we at Cox have deployed each of the following splitting methodologies, but ultimately landed on a distributed optical tap concept to optimize fiber and labor efficiencies. The two most common architecture types used are centralized splitters and distributed splitters at either 1:32 or 1:64 split ratios. In a centralized splitter architecture, the entirety of the static split ratio is contained within an ODN cabinet. In this configuration each customer may get their own dedicated fiber spliced in parallel from the cabinet to customer premise. A distributed splitter architecture is also based on a pre-determined static split ratio, but a portion of that split ratio is distributed to a drop terminal (aka cross connect) closer to the customer premise (see Figure 12). This can be achieved with any combination of balanced 1xN splitters. For example, it may be common for an operator to distribute a 1x4 splitter near the customer and assume the first 1x16 of the total 1:64 split ratio is in the cabinet. The advantage of distributing splitters over centralized splitters is the reduction in fiber and splices required to build the network, which may result in cost savings. However, it can be wasteful, because with any static split ratio it is uncommon to have exactly the same number of customers as the splitter size, so those additional ports often get stranded.

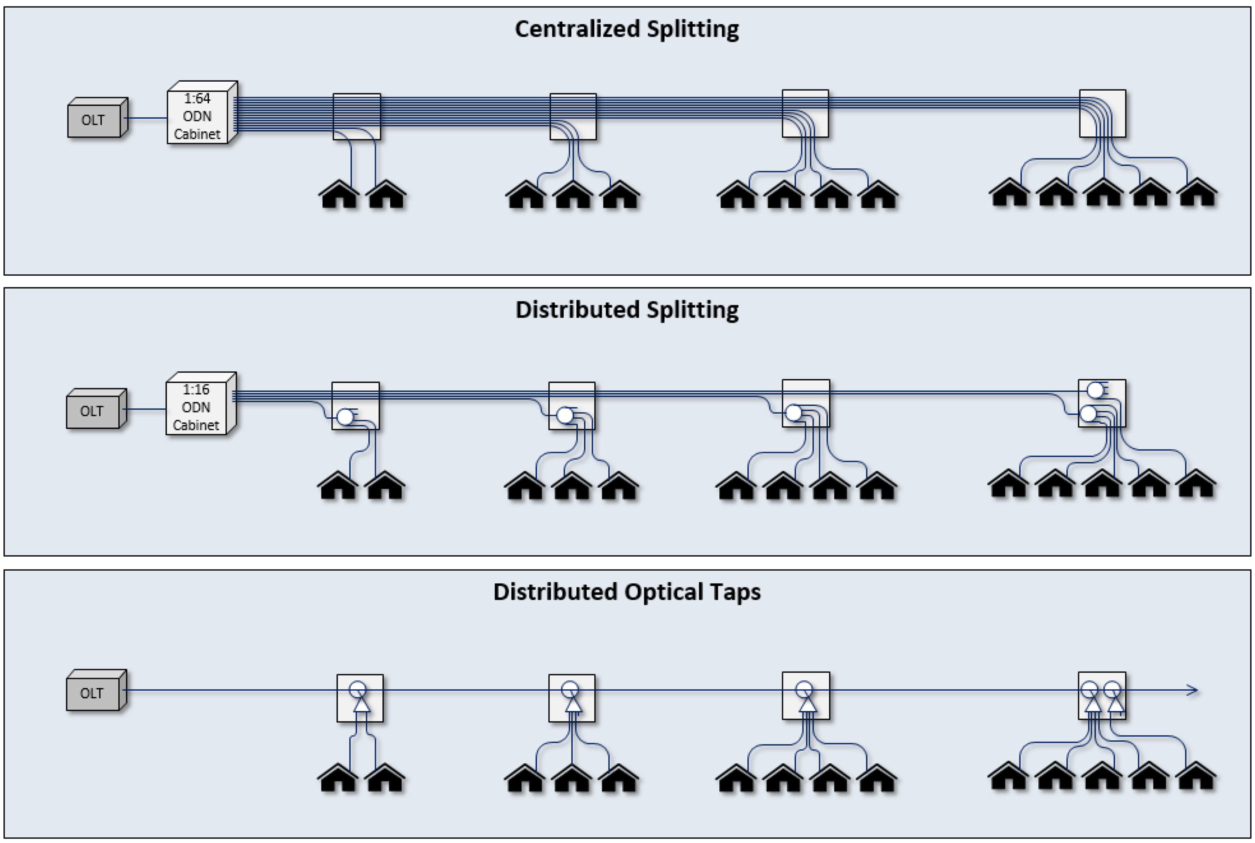

Figure 12 – FTTx ODN Architecture Concept Comparison

Much like HFC, the optical tap system is a controlled approach to managing signal levels to each customer throughout the network while optimizing splitter sizing and maximizing reach. A tap is characterized by a split-ratio, which is indicative of a percentage of signal received by the tap that continues through the tap to downstream devices versus a percentage of signal that is split off for creating network terminations at the customer premise (See Figure 13). This approach works especially well in low-density rural applications, because it allows the optical budget to be spread out much more efficiently. While there are many benefits to distributed optical tap systems, one challenge is it requires a custom design of each network segment, very similar to HFC design. A much more in depth analysis of the distributed optical tap system can be found in a technical paper written for the 2021 Fall technical forum: FTTx PON Architecture Considerations: Distributed Optical Taps

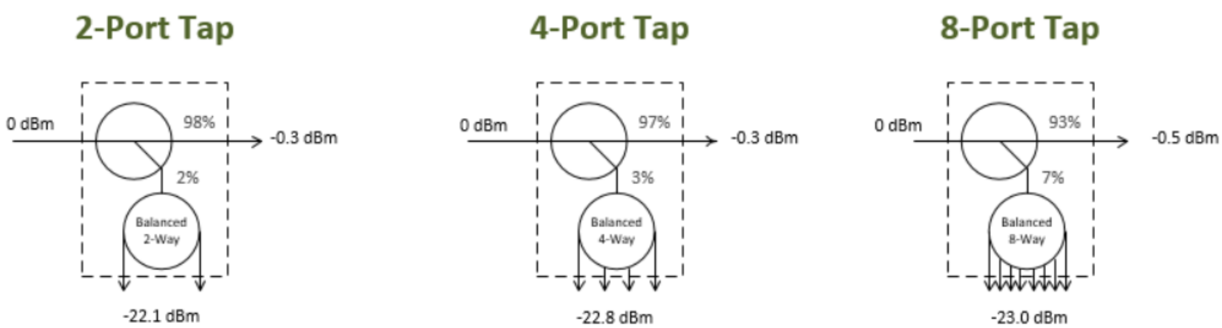

Figure 13 – Distributed Optical Tap Schematics

4.1. ODN Distance and Density Study

To illustrate the optical reach tradeoffs of static splitting versus optical taps we put together a distance sensitivity study. It is worth noting, that the XGS-PON specs increased the upstream optical budget by 3 dB over downstream to compensate for the elevated fiber attenuation of 1270nm. Despite the higher optical budget, at 13.6 km of distance the upstream attenuation overcomes the 3 dB delta and upstream loss becomes the dominant limiting factor. In prior generations, the upstream and downstream optical budgets of GPON were exactly the same so that at distance, upstream became the dominant factor more quickly.

Each operator needs to consider their network design parameters carefully. We have opted to assume a 1.5 dB placeholder at the front end of each splitting cascade in all cases for co-existence of future PON technologies, such as 25G, 50G or Coherent PON. We also reserve 2 dB for loss in the drop network, considering the various fiber connector counts and types used between tap and Optical Network Terminal (ONT), we find it to be a reasonable operational assumption. Fiber attenuation figures below are considered maximum attenuation by the predominant fiber manufacturer that we deploy. Additionally, 0.05 dB/km is assumed for fusion splice loss.

Table 1 – Distance Sensitivity of Static Splitters

Network	Budget (dB)	Wavelength (nm)	Attenuation (dB/km)	Static 1x32 Range (km)	Static 1x64 Range (km)
Downstream GPON	29.0	1490	0.25	26.67	15.00
Upstream GPON	29.0	1310	0.34	20.51	11.54
Downstream XGS-PON	29.0	1577	0.23	28.57	16.07
Upstream XGS-PON	32.0	1270	0.45	22.00	15.00

Summary of the key network design parameters used in the Cox FTTH network:

Table 2 – Key Distance Study Network Design Parameters

Description	UOM	Parameter
Downstream OLT Transmit Power	dBm	+3.0
Downstream Tap Port Minimum	dBm	-24.0
Downstream ONT Receive Power Minimum	dBm	-26.0
Upstream ONT Transmit Power	dBm	+6.0
Upstream Tap Port Minimum	dBm	+4.0
Upstream OLT Receive Power Minimum	dBm	-26.0
1490nm Attenuation (DS GPON)	dB/km	0.25
1310nm Attenuation (US GPON)	dB/km	0.34
1577nm Attenuation (DS XGS-PON)	dB/km	0.23
1270nm Attenuation (US XGS-PON)	dB/km	0.45
Fusion Splice Loss	dB/km	0.05
Co-Existence Filter Insertion Loss	dB	1.5
1x2 Splitter Insertion Loss	dB	3.5
1x4 Splitter Insertion Loss	dB	7.0
1x8 Splitter Insertion Loss	dB	10.5
1x16 Splitter Insertion Loss	dB	14.0
1x32 Splitter Insertion Loss	dB	17.5

With optical taps, there are a lot more options and variables enabling each circuit to be tailored to the given scenario. However, this makes distance modeling a bit more complicated. For example, tap sizes, splitter/coupler usage and even where the tap falls within a given circuit will impact distance sensitivity. We modeled 4 different scenarios (see Figure 14) and in the chart below (see Figure 15) we're showing the average HHP serviceable at each distance of those scenarios. In all cases, all of the taps were located within the last 1 km of the circuit, which drove the lowest potential tap values.

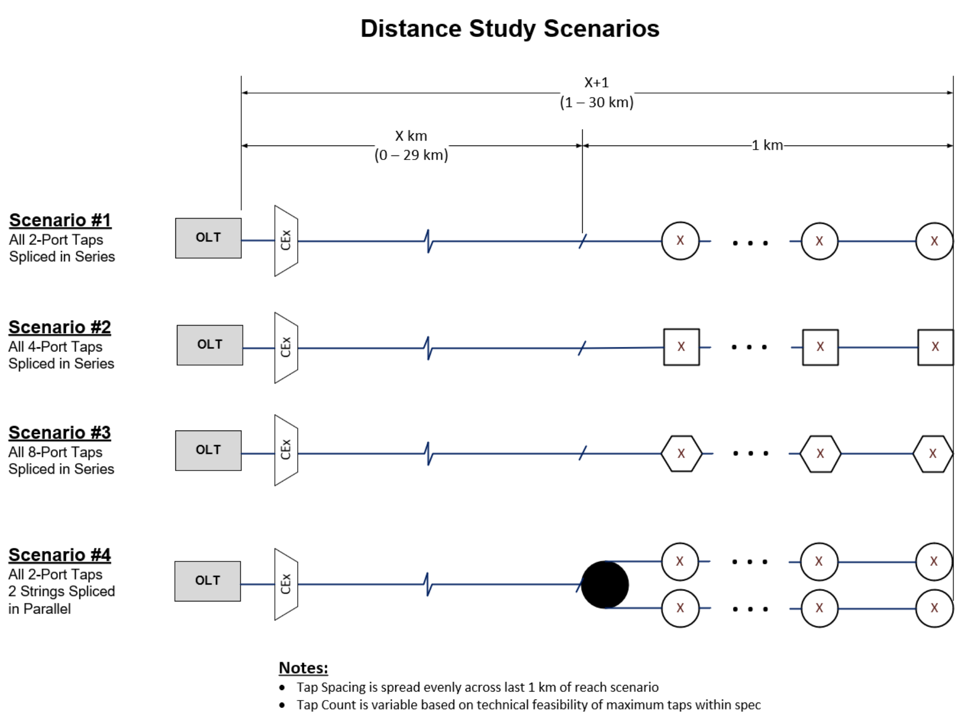

Figure 14 – Optical Tap Distance Sensitivity Scenarios

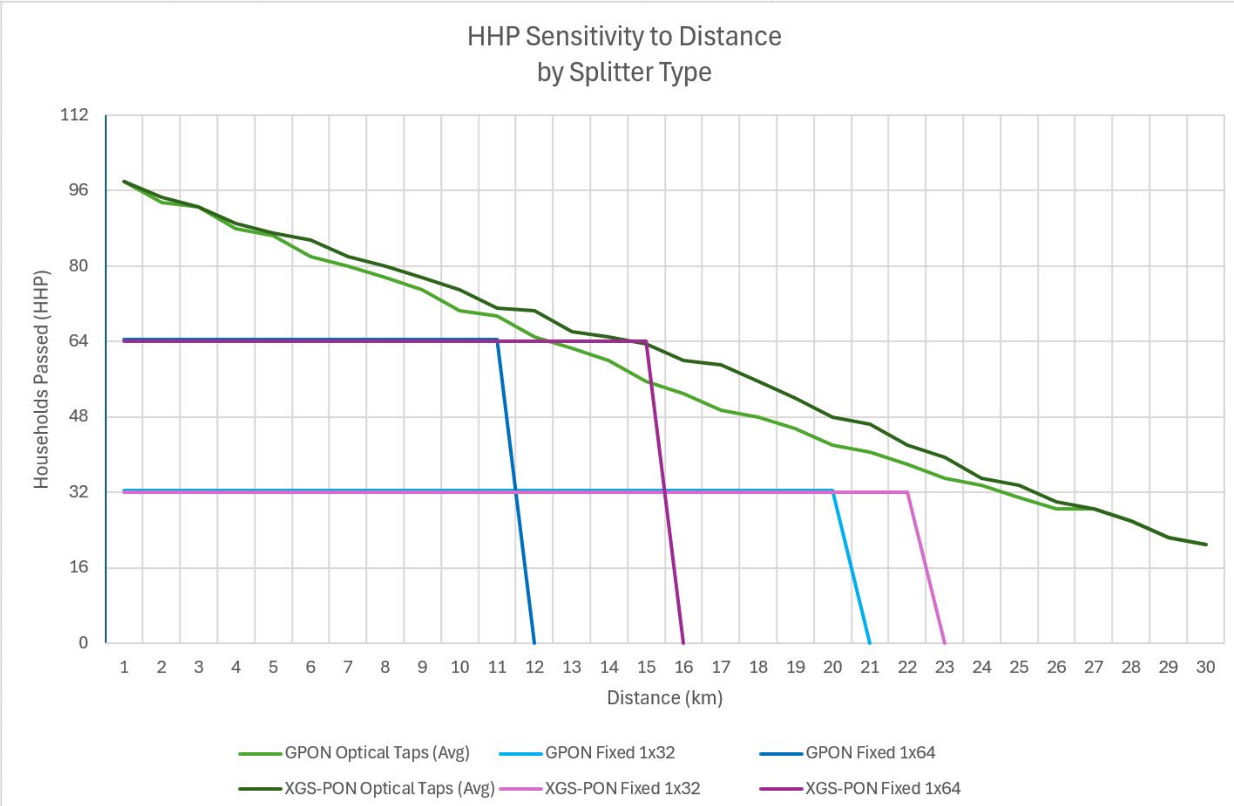

Figure 15 – ODN Sensitivity to Distance and Density

In each static split ratio scenario, the potential households passed is flat until optical budget is consumed. The physics of optical taps enable greater than 64 HHP within 15km, but by policy we limit the number of actual passings to 64 to manage contention. In Figure 15 above, the assumption is each splitter port is allocated to a potential household passed. Often natural geography reduces the actual HHP / OLT Port efficiencies. Optical taps can help drive higher efficiencies by allowing for more splitter ports than HHP policy limitations. Furthermore, low density rural areas often need to stretch the ODN to reach the last couple of HHP within a given area. Those last few kilometers of optical reach can be the difference between installing another OLT and using what you already have.

5. Conclusion

The Rural Broadband challenge is exciting and interesting, but distance to these areas is much further afield forcing us to consider transport technologies traditionally reserved for backbone and metro links. There is no one size fits all solution, but the addition of ROADM in the residential access network for transport can be a valuable tool in the toolbox. However, ROADM does come at a cost premium, and should only be reserved for opportunities outside the reach of existing transport solutions. Furthermore, ROADM costs can be offset by a well-placed FAF / Hut solution, enabling an anchor point in a rural community, which can host lower cost transport solutions.

While there is still a place for smaller R-OLT solutions, OLT cabinets may offer the most bang for your buck to service an average sized rural community. A single cabinet can contain power plant, transport devices, OLT shelves and commercial service routers, enabling quicker and simpler deployment timelines. The use of optical taps for distribution can help stretch the reach of the PON network and minimize the number of OLT devices deployed.

Abbreviations

AAR	Access Aggregation Routers
AE	Active Ethernet
BEAD	Broadband, Equity Access and Development
BPON	Broadband passive optical network
CBG	Census Block Group
DAA	Distributed Access Architecture
DWDM	Dense Wave Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
FAF	Fiber Aggregation Facility
FOADM	Fixed Optical Add / Drop Multiplexer
FTTH	Fiber-to-the-Home
FTTx	Fiber-to-the-X
GPON	Gigabit passive optical network
HFC	Hybrid Fiber Coax
HHP	Households Passed
MDM	Mux/DeMux
NOC	Network Operations Center
OCML	Optical Communication Module Link extender
ODN	Optical Distribution Network
OLT	Optical Line Terminal
ONT	Optical Network Terminal
OSP	Outside Plant
OTDR	Optical Time Domain Reflectometer
PON	Passive Optical Networks
RDOF	Rural Digital Opportunity Fund
ROADM	Reconfigurable Optical Add / Drop Multiplexer
R-OLT	Remote Optical Line Terminal
RPD	Remote-Phy Device
RU	Rack Unit
SFU	Single Family Units
XGS-PON	10 gigabit symmetrical passive optical network
ZTP	Zero Touch Provisioning

Bibliography & References

ITU-T G.984.1-200803: *Series G: Transmission Systems and Media, Digital Systems and Networks; Gigabit Passive Optical Networks (GPON): General characteristics; Telecommunication Standardization Sector of ITU*

ITU-T G.9807.1-201606: *Series G: Transmission Systems and Media, Digital Systems and Networks; 10-Gigabit-capable symmetric passive optical networks (XGS-PON); Telecommunication Standardization Sector of ITU*

"FTTx PON Architecture Considerations: Distributed Optical Taps" NCTA/SCTE technical paper 2021 Fall technical forum Paper - FTTx PON Architecture Considerations: Distributed Optical Taps - NCTA Technical Papers