FTTx PON Architecture Considerations

Distributed Optical Taps

A Technical Paper prepared for SCTE by

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1. Introduction

Passive Optical Networks (PON) have come a long way in the Cox network since our initial Gigabit PON (GPON) deployments over 12 years ago. A key milestone for Cox Communications was the launch of IP Video and Telephony products via GPON in mid-2020, which enabled the elimination of Radio Frequencies over Glass (RFoG) technology and presented an opportunity to re-consider the architecture. We took this opportunity to relook at our FTTx deployments through a fresh lens and explore opportunities to improve operational efficiencies, including 10G PON evolutions, optical transport, and distribution network architectures.

In particular, the Optical Distribution Network (ODN) approaches were tailored to "right size" the cost and deployment options for the individual application, which led to different approaches for Single Family Units (SFU), Multi-Dwelling Units (MDU) and Commercial Business customers. Each had their own unique ODN architectures, which drove variation and complexity for field teams to support. There was an opportunity to harmonize those approaches with the additional benefit of making them easier to deploy and maintain.

This paper will explore a variety of architectural considerations and logic which drove decision-making around Cox Communication's next generation Fiber-to-the-X (FTTx) deployments, with a focus on a new approach to optical distribution and splitting methodologies.

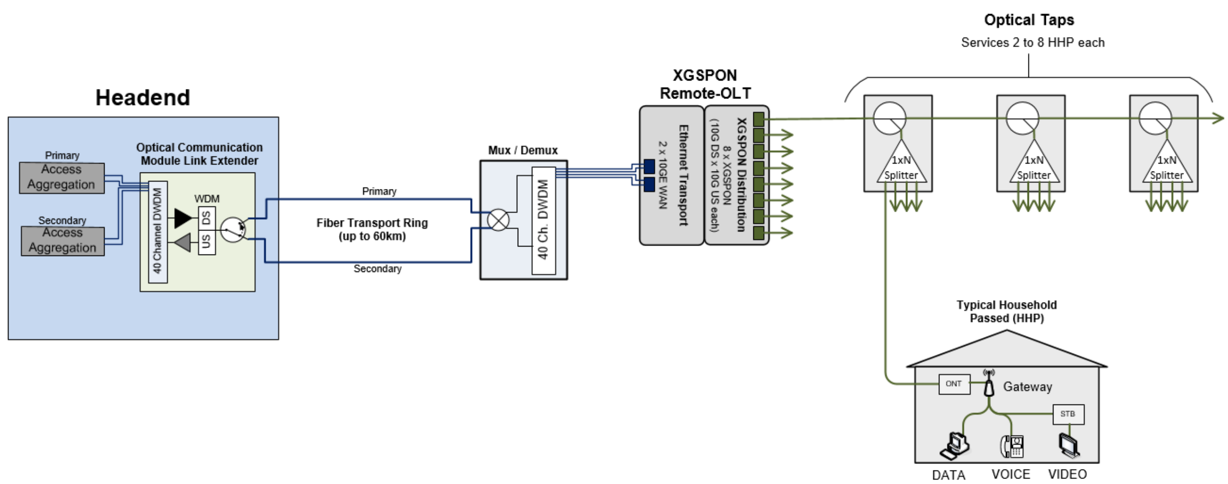
1.1. History of PON at Cox Communications, Inc

Our first deployments of 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. The key difference being the type of network carrying legacy data, video, and telephony products. Like many other cable operators at the time, we chose to leverage an RFoG technology to support these legacy products in greenfield fiber only deployments. Supporting RFoG and PON drove some unique considerations to Fiber-to-the-Home (FTTH) deployments which do not apply to PON alone, including but not limited to, a smaller optical budget and Optical Beat Interference (OBI). RFoG was intended to bridge the gap to All IP over PON, it turns out that gap lasted about 6 years and went through many evolutions until we launched all of our products over PON for residential services in 2020.

The PON portion of the FTTH network also went through a series of evolutions in the 2014 to 2020 timeframe. Initial deployments of GPON Optical Line Terminals (OLT) 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 for smaller targeted areas. The transport architecture used up until recently for the GPON Remote-OLT was a routed (layer 3) multi-hop ring solution, allowing up to 8 Remote-OLTs per ring. Recently it was decided to leverage synergies from our Distributed Access Architecture (DAA) solution used for Remote-Phy 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're in the process of launching 10 gigabit symmetrical PON (XGS-PON) OLT's, capable of supporting 10G symmetrical speeds.

The GPON distribution network architecture started at a 1:32 split ratio and increased to a fixed 1:64 split ratio a couple years in to optimize OLT port consumption efficiencies. In an effort to optimize fiber and labor efficiencies, the optical splitter array varied based on the application. SFU applications used a centralized splitting architecture, while MDU and commercial applications each used different distributed splitter approaches.

With the elimination of RFoG on our roadmap, it gave us an opportunity to relook improving operational efficiencies in the FTTx ODN. In 2019, we began investigating a distributed optical tap concept, using a combination of unbalanced and balanced couplers to control optical insertion loss in a more efficient manner (see Figure 1).



2. Optical Transport

Cox Communications current Optical FTTx Transport Network includes a pair of components called the Optical Communications Module Link extender (OCML) and Mux DeMux (MDM) which make up our standard DAA solution. The OCML is used to transport up to 40 DWDM wavelengths (20 channel pairs), redundantly up to 60km. The OCML is located in the headend and the MDM in the field. This same DAA solution is used by other deployments and is commonly shared with other network elements such as Remote-Phy nodes and Metro Ethernet links.

2.1. OLT Strategy

Up until this point, the vast majority of our FTTx deployments have been with GPON in alignment with ITU-T G.984.1, offering nearly 600,000 homes passed (HP) with gigabit symmetrical speed tiers today. In preparation to support 10G speeds in the future, we’ve recently started the process of transitioning all new PON deployments to XGS-PON exclusively in alignment with ITU-T G.9807.1.

While XGS-PON enables a path to 10G symmetrical speed tiers, long-term Next Generation PON 2 (NG-PON2) and/or Coherent PON (CPON) appear to be potential evolutions. Both NG-PON2 and CPON are still just being discussed and the picture isn’t fully clear exactly how it will be operationalized, but future considerations are being made to support either option. It will be important for each PON iteration to operate at different wavelengths to allow co-existence through migration periods. NG-PON2 will operate at 1530nm Downstream and 1600nm Upstream, but CPON wavelengths have yet to be determined. CPON is capable of speeds greater than 100G, and the calculated approach of the distributed optical tap system aligns well with the increased optical budget of the coherent optics allowing for extended optical reach and the potential for a truly passive plant without the need of remote OLT devices.

3. Optical Distribution Network

Up until recently, our PON distribution network was a conventional fixed 1:64 split ratio, which used a bank of optical splitters in an ODN cabinet. The two primary architecture types used were centralized splitters and distributed splitters. In a centralized splitter architecture, the entirety of the static split ratio is contained within the 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) within 400' of the customer premise (see Figure 2). 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 64 customers to feed, so those additional ports may get stranded. Furthermore, in a static split ratio architecture, the more of the split ratio that is distributed, even more ports may be stranded. Considering MDU's typically have a higher density per demarcation Cox chose to distribute a 1x8 splitter. For commercial applications a distributed 1x4 was the right balance between splitter capacity and splicing labor considering the varying densities in commercial zones.

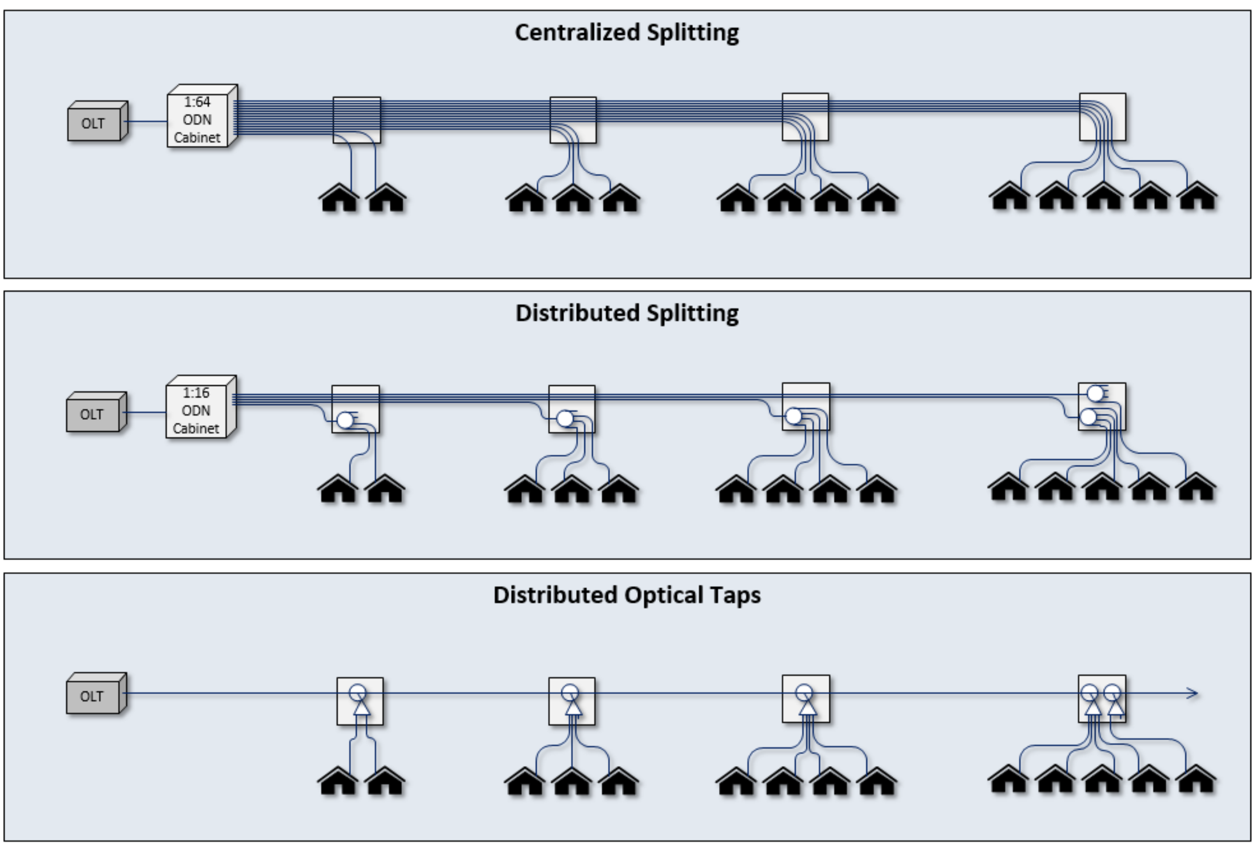


Figure 2 – FTTx ODN Architecture Concept Comparison

The insertion loss of the selected split ratio, fiber attenuation, and optical budget of each technology must be considered. Additional variables such as Co-Existence (CEx) WDM's, fusion splice and connector loss, may vary by operator, but also must be factored into optical reach calculations. Figure 3 below shows the relationship between split ratio and physical reach based on typical splitter loss characteristics. GPON assumes Class B+ optics, XGS-PON and NG-PON2 assume Class N1 optics, while the CPON specs are still being defined, but assumes worst case 35 dB optical budget operating in the C-Band. Both GPON and XGS-PON ITU standards assume a 20km physical reach limit; however, at Cox with standard 1:32 and 1:64 static split ratios, realistic operating ranges of GPON and XGS-PON are roughly 20km and 10km respectively, which include insertion loss characteristics of aforementioned variables.

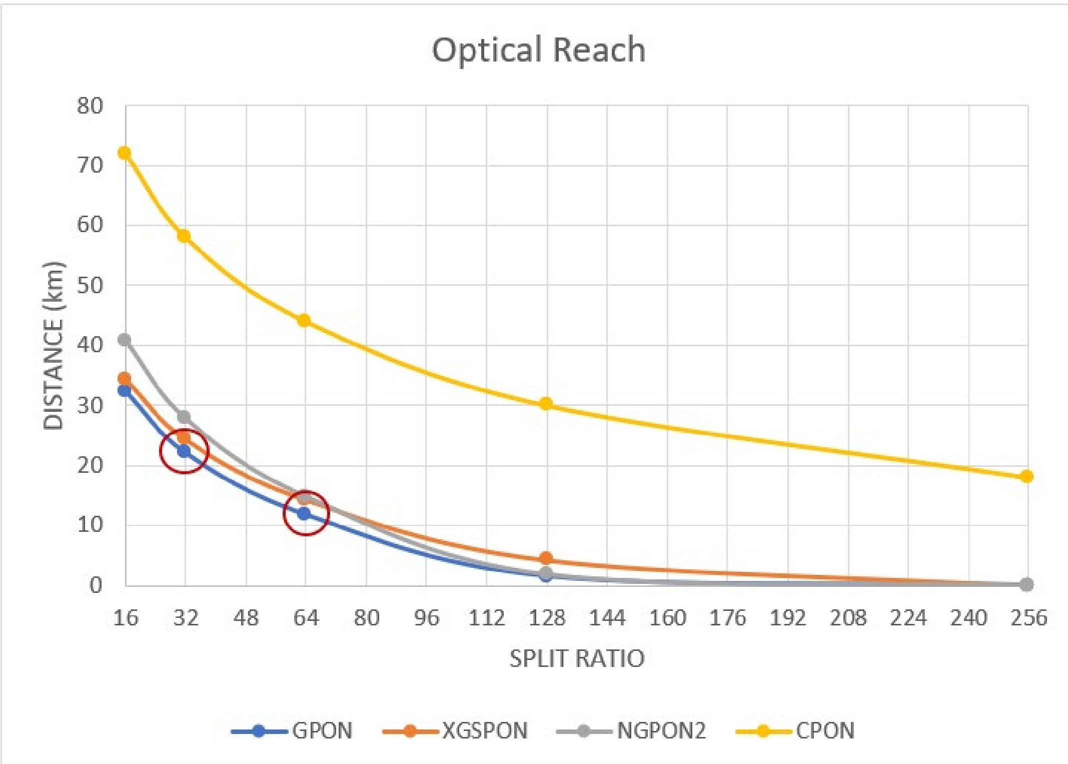


Figure 3 – Optical Reach with Static Split Ratios

3.1. Distributed Optical Tap Concept

Through the course of exploring all of these various splitting approaches it led us to a familiar concept, a tap (see Figure 4). The tap system is a controlled approach to managing signal levels to each customer throughout the network while optimizing fiber usage efficiencies 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.

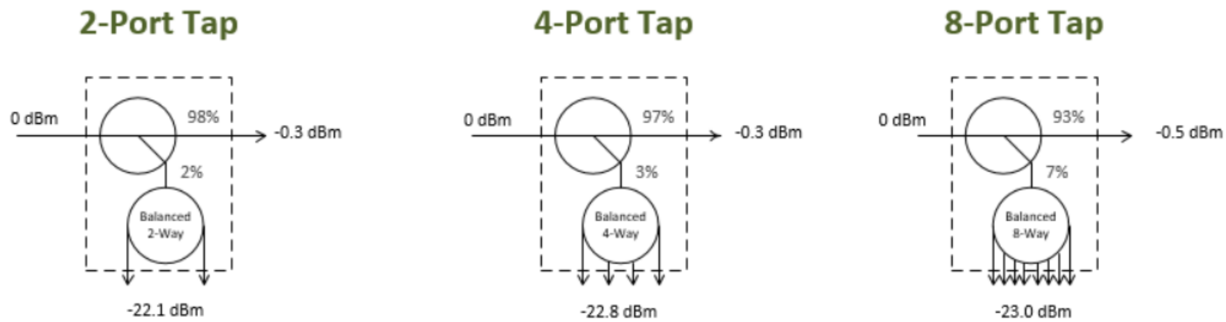


Figure 4 – Distributed Optical Tap Internal Scematics

The distributed optical tap solution takes the fiber efficiency concept a step further than a distributed splitter because much less fiber and fewer fusion splices are required than either conventional method described above. It also enables the user to control the 'size' (number of tap ports or legs) of the splitter included with the tap based on the number of legs needed and control the signal loss based on how much signal is received at a given location, and therefore is much less wasteful than the other approaches. The optical tap solution simplifies the application by pre-engineering combinations of a first stage coupler and a second stage splitter into a structured system of pre-integrated modular tap devices. A tap being "modular" refers to the fact that multiples of any tap type can be installed within any drop terminal. This contrasts with other solutions which integrate distributed splitters into a fiber enclosure, which does not allow for as much flexibility to add ports or control signal levels.

For example, if a user needs to add additional ports to a tap for new customers, they could replace a 2-port tap module with a 4-port tap module. As another example, if a technician needs more or less signal at a given location, they can simply replace the tap module with a different incremental value module. Both examples may trigger a network design change action in accordance with operational policies to maintain good record keeping, but the flexibility is feasible. In addition to the significant cost savings from minimizing fiber materials and fusion splice labor, this solution does not require a centralized cabinet for housing banks of splitters which may be expensive and challenging to get permission from municipalities to build in the right-of-way. The distributed optical tap solution also improves damage restoration time because a customer's service is dependent on fewer fibers and can be respliced quicker in the event of a damaged cable.

The distributed optical tap system intentionally mimics an HFC architecture, sharing many common principles (see Figure 5).

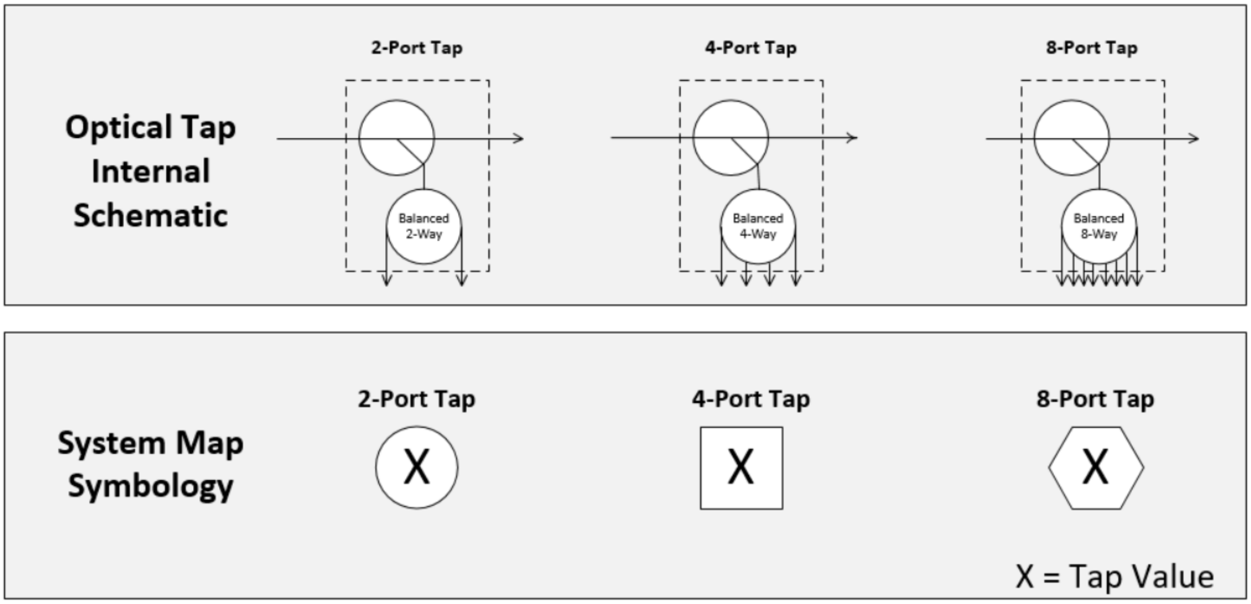


Figure 5 – Distributed Optical Tap Schematic and System Map Symbology

Optical tap devices will be installed into drop terminals (aka cross connects), which includes weather-tight fiber enclosures for pedestal, vault or aerial deployment, or PON wall-boxes for higher density MDU or commercial applications.

Additionally, more traditional optical splitters, such as a balanced splitters (2-Way & 4-Way) and asymmetrical directional couplers (DC) will be deployed into traditional splice enclosures to create additional branches as needed (see Figure 6). Similar to HFC, directional couplers will come in varying split ratios, like taps, the ‘value’ is representative of the down leg loss.

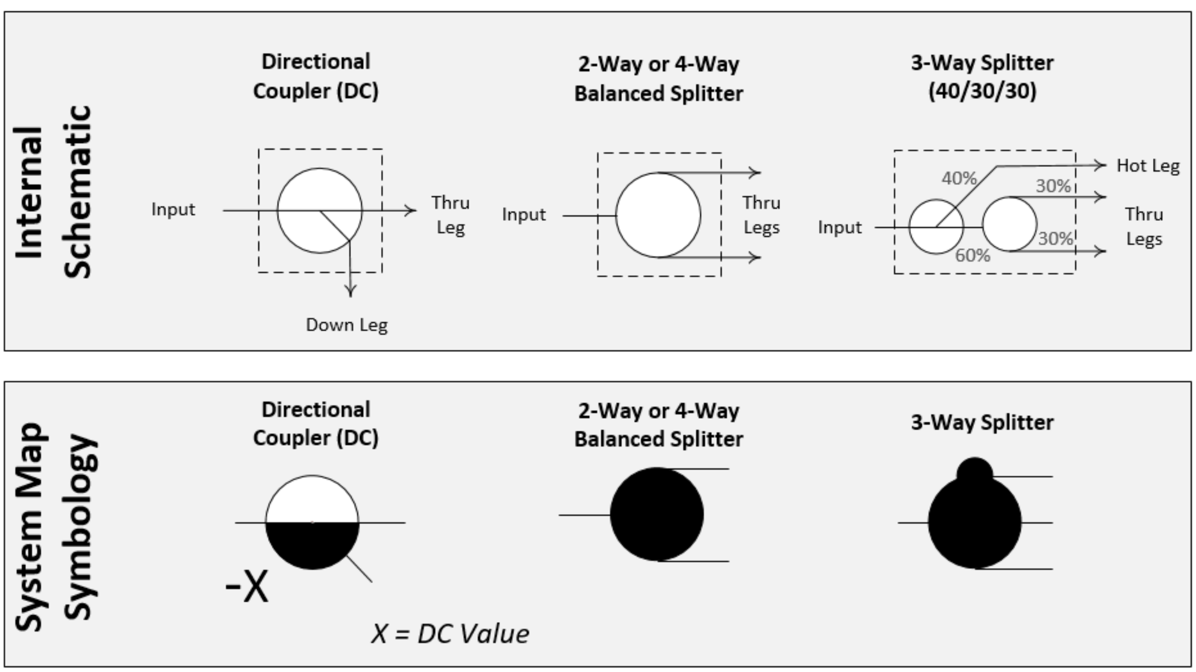


Figure 6 – Coupler/Splitter Internal Schematics and System Map Symbology

3.1.1. Optical Performance Characterization

Downstream, fiber splitter/couplers divide optical power from one common port to two or more split ports and upstream combine all optical power from the split ports to a common port (see Figure 7). 2-way optical splitter/couplers are often expressed in split ratio (SR), (e.g., 75:25).

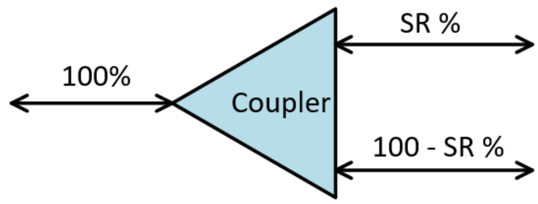


Figure 7 – Coupler Split Ratio Example

SR can be determined based on total optical power relative to the power passing through:

$$SR = \left(\frac{P_i}{P_T}\right) x\ 100$$

An industry standard formula was used to calculate insertion loss (IL):

$$IL\ =\ -10\ log\left(\frac{P_i}{P_T}\right)$$

Where:

IL = Splitter/coupler insertion loss for the split port, dB

P_i = Optical output power for a single port, mW or dBm

P_T = Total optical power output for all split ports, mW or dBm

Additionally, splitter/coupler excess-loss is a critical assumption that must be applied to factor in lost signal power due to imperfections in the manufacturing process and can range anywhere from 0.1 to 2.0 dB. Published insertion loss specifications from optical passive manufacturers often are expressed as "Typical" and/or "Maximum", but always factor in additional excess-loss. Based on lab testing and IL specifications from major optical passive manufacturers, we observed the higher calculated IL, the higher excess-loss variability, while the lower loss legs were more consistent. Lab testing data in Figure 8 below includes the average measured insertion loss of at least 3 samples of each type from each vendor.

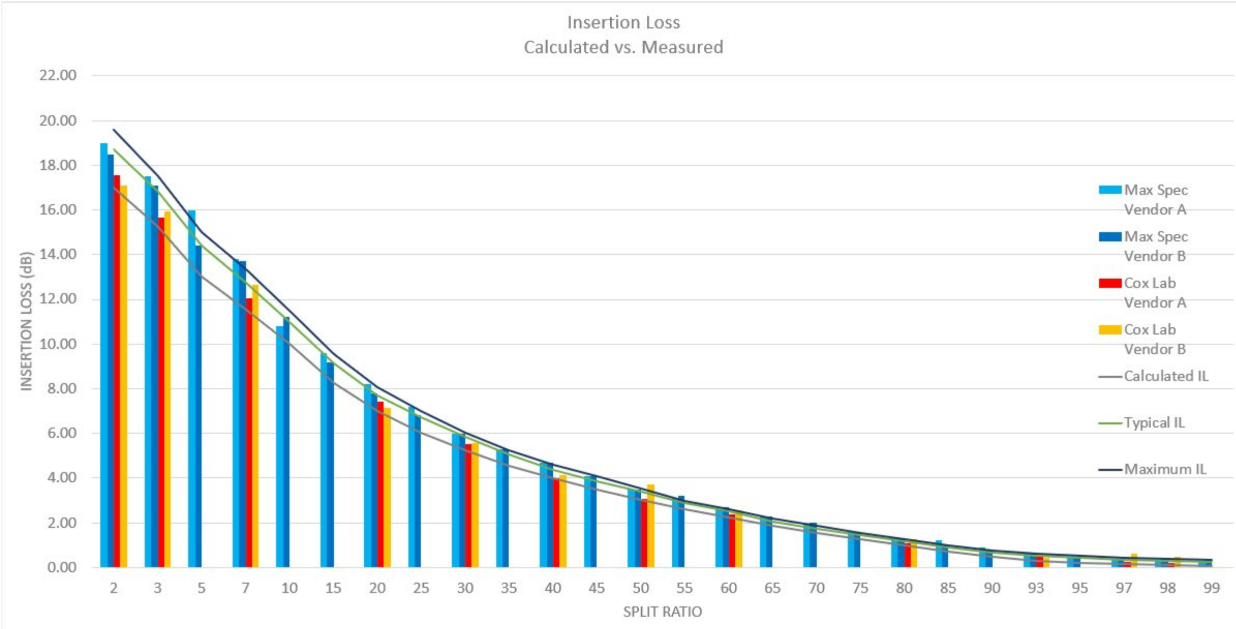


Figure 8 – Calculated Loss vs. Reported Loss

Both typical and maximum IL specifications are important for daily operations. It's important for field technicians to be mindful of maximum insertion loss while looking at individual events. However, if maximum loss were used for network design calculations of multiple taps spliced in series it would result in excessive amounts of cumulative loss margin. For this reason, it was decided to use typical insertion loss for network design calculations, which aligns closer to average measured loss.

3.2. Design Study

A design study was conducted to validate the optical tap concept in real-world network design scenarios against some of the aforementioned conventional methodologies. One of the many goals of the design study was to validate that we could repurpose some of the tools that we've been using for many years to design HFC networks. Additionally, we were seeking a larger sample size of network design data to help compare construction costs and network efficiencies against traditional splitting methods.

3.2.1. Design Parameters

Cox has been designing HFC networks via Lode Data Design Assistant to run RF calculations for many years. It turns out it is relatively easy to convert the core RF spec files to calculate optical levels instead. However, a significant amount of consideration was given to the core parameters that drive the design calculations to ensure a fair amount of margin for field variations without being overly conservative.

These are the key parameters and the assumptions we used (see Table 1 & Figure 9):

Table 1 – Key Network Design Parameters

Description	UOM	Parameter
Downstream OLT Transmit Power	dBm	+3.0
Downstream ONT Receive Power Minimum	dBm	-26.0
Downstream Tap Port Minimum	dBm	-23.0
Fiber Drop Loss (< 500') Maximum	dB	2.0
1490nm Attenuation (DS GPON)	dB/km	0.28
1310nm Attenuation (US GPON)	dB/km	0.34
1577nm Attenuation (DS XGSPON)	dB/km	0.25
1270nm Attenuation (US XGSPON)	dB/km	0.35
Maximum HP per OLT Port	HP	64

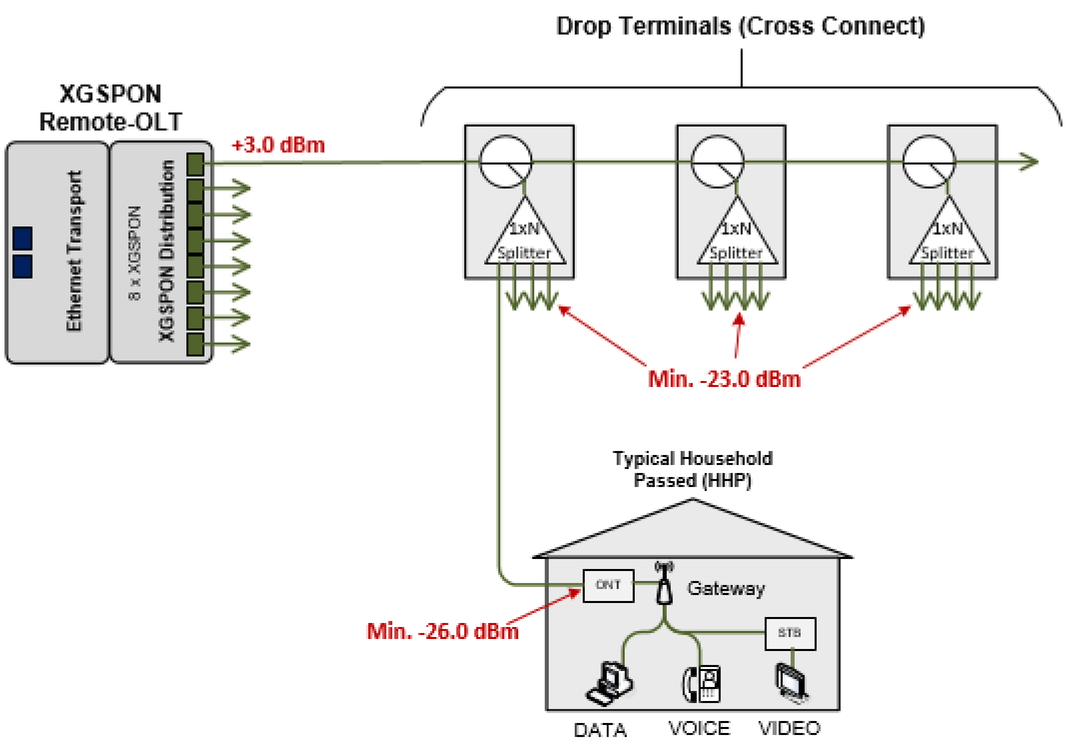


Figure 9 – ODN Diagram with Key Design Parameters

Considerations should be given to maximum versus typical, particularly when deciding what to design to, to balance performance and cost. In the case of the OLT launch power, per ITU-T G.984.1 the OLT transmit level can range from 1.5 to 5.0 dB, leading us to analyze the optical transmit power of over 17,000 OLT interfaces in our network to generate a histogram of OLT transmit power. Results found the OLT ports actually transmit at +3.63 dBm on average, with less than 1% of the population transmitting below +3.0 dBm (see Figure 10).

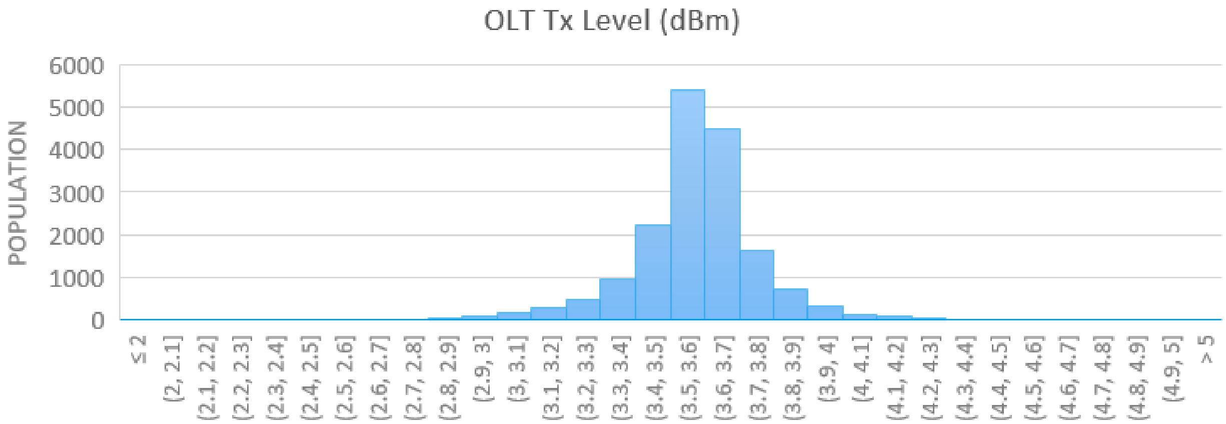


Figure 10 – OLT GPON Interface Population - Downstream Launch Power

Downstream tap port minimum (GPON & XGS-PON), for the sake of design calculations, was set at -23 dBm, but we allow -24 dBm acceptance criteria for field activations. This combined with OLT launch power margin provides 1 – 2 dB of margin for additional field variables, such as maximum insertion loss conditions, fusion splice loss, connector loss, etc. For the last 100' – 500', the drop network is given 2 dB of loss for the connectorized fiber drop from the tap port to the optical network terminal (ONT).

Also, considering this network type doesn't naturally control the number of HP per OLT port like a traditional fixed split ratio, we opted to implement a 64 HP limit policy which will be enforced at the individual design level. While there certainly is a healthy amount of optical budget in our current GPON and XGS-PON deployments to support many more than 64 HP, the spirit behind this policy was to mitigate potential network contention in the future. As technology and bandwidth demand changes this policy may be revisited.

3.2.2. Design Analysis

The actual design study included 5 SFU properties totaling 920 HP across 4 different markets, as well as 4 MDU properties totaling 799 HP across 4 different markets. Many data points were collected, but the two primary metrics being evaluated were fusion splicing requirements and OLT port optimization, because they have the most bearing on cost efficiency.

The SFU portion of the study considered standard centralized splits and distributed 1x4 or 1x8 splitters at a fixed 1:64 split ratio compared to the distributed optical tap concept (See Table 2).

Table 2 – SFU Design Study Results

SFU Properties		Centralized Splitters (Current)			Distributed Splitters			Distributed Optical Taps		
Market	HP	OLT Ports Used	HP per OLT port	Fusion Splices	OLT Ports Used	HP per OLT port	Fusion Splices	OLT Ports Used	HP per OLT port	Fusion Splices
Site 1	405	7	58	892	9	45	178	7	58	142
Site 2	85	2	43	178	2	43	39	2	43	29
Site 3	55	1	55	120	1	55	20	1	55	25
Site 4	240	4	60	526	5	48	86	4	60	91
Site 5	135	3	45	280	4	34	58	3	45	58
Averages:	***184***	***3.4***	***52***	***399***	***4.2***	***45***	***76***	***3.4***	***52***	***69***

When compared to centralized splitting in an SFU application, there was an 83% reduction in fusion splices required which is a significant labor cost driver. Furthermore, a centralized split is often considered the most efficient in regard to HP per OLT ports, but with distributed optical taps there was no change in OLT port efficiency. The distributed splitter model maintained the traditional fixed 1:64 split ratio but allowed the distributed splitter in the field to be either a 1x4 or 1x8 based on the number of passings at a given location. When looking at the distributed splitter solution versus centralized splitters it resulted in an 81% reduction in fusion splices, but costly OLT port usage requirements increased due to stranded capacity in the cross connect device at the curb.

For the MDU portion of the study, distributed 1x8 splitters at a fixed 1:64 split ratio were compared to the distributed optical tap concept. Centralized splits were not considered because previous cost modeling exercises in years past had already considered it and led to standardization of a distributed 1x8 for MDUs (see Table 3).

Table 3 – MDU Design Study Results

MDU Properties		Distributed 1x8 Splitter (Current)			Distributed Optical Taps		
Market	HP	OLT Ports Used	HP per OLT port	Fusion Splices	OLT Ports Used	HP per OLT port	Fusion Splices
Site 6	204	4	51	62	4	51	45
Site 7	287	6	48	106	5	57	75
Site 8	190	5	38	139	3	63	114
Site 9	118	3	39	48	2	59	31
Averages:	***200***	***4.5***	***44***	***89***	***3.5***	***58***	***66***

Distributed optical taps averaged 32% more efficient OLT port usage than our current distributed 1x8 splitter solution, which can be attributed to the flexibility allowed by the taps to choose the appropriate splitter size at each demarcation box. Furthermore, there was a 26% reduction in fusion splices required per property.

3.2.3. Cost Modeling

In addition to splicing and port efficiency improvements shown above, the ODN Cabinet was another important factor considered in the cost model. The distributed optical tap architecture solution assumes the ODN cabinet may be eliminated considering splitting will be distributed to the tap locations instead of a centralized bank of splitters in a cabinet or enclosure.

With the splicing and port efficiency improvements shown above, coupled with additional material and labor savings not directly tied to these drivers, we estimate approximately $65 and $40 per HP savings for SFU and MDU respectively, relative to our current architecture solution.

3.3. Product Development

As a cable operator with large groups of technical resources who are trained and educated on how to operationalize HFC, the goal of product development was to make it look and feel as much like HFC as possible. Small things like product naming and labeling were intentionally created to blend HFC terminology with fiber products for ease of knowledge transfer.

The physical form-factor of the devices was also carefully considered; it was important that the optical tap device was decoupled from the enclosure that it lives in. This provides the flexibility to deploy taps into any generic fiber terminal and deploy multiples of any combination of tap devices within the terminal based on the need of the given location. Generally speaking, our preference is fusion splicing whenever possible, because hard splices are inherently more reliable than mated connectors. For this reason, we decided the standard tap modules would have standard 250µm bare fiber leads on the input and through-legs to allow fusion splicing the cascades of taps in series, while the tap legs would be connectorized for drop connections. Additionally, we specified a connectorized cassette with bulkhead connectors on all ports. Cassettes will primarily be used for wall-mount applications, where long strings of multiple taps are not spliced together in series.

3.3.1. Product Specifications

Tap modules and cassettes contain two integrated balanced and/or asymmetrical optical couplers designed to a series of fixed insertion loss values (See Figure 11) just as RF taps are designed today.

Definitions:

1st Stage Coupler: Either balanced or asymmetrical two-way optical coupler, with one of the output legs fusion spliced to the input of a second stage optical splitter.

2nd Stage Splitter: Balanced 2-way, 4-way, or 8-way optical splitter.

Input Leg: The input fiber of the first stage coupler will feed out of the tap module.

Thru Leg: The second output fiber of the first stage coupler will feed out of the tap module.

Tap Legs: Output fibers of the second stage splitter will feed out of the tap module.

Thru Loss: The insertion loss from input to thru leg.

Tap Loss: The combined insertion loss from input through drop legs

Tap Value: Numeric identifier indicating the loss structure of the tap, which is closely related to the tap loss.

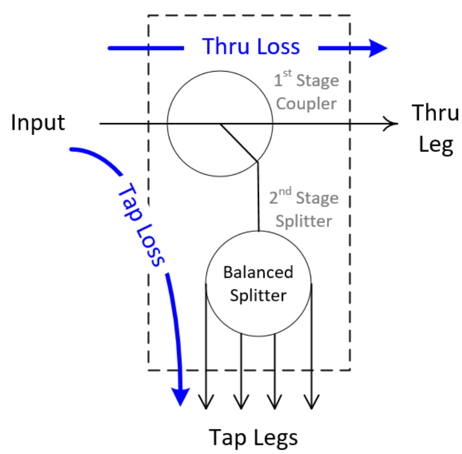


Figure 11 – Distributed Optical Tap Schematic

Insertion loss characteristics are expressed in both typical and maximum insertion loss characteristics of each tap variation across entirety of the passband (1260 – 1650 nm), not including connectors. Tap Loss Uniformity must be ≤ 1 dB.

Taps are available in 24 different size/value combinations and will be labeled with the following symbology (see Figure 12). Taps will be available in two form-factors: Outside Plant (OSP) Modules (see Figure 13) and Inside Plant (ISP) Cassettes (see Figure 14):

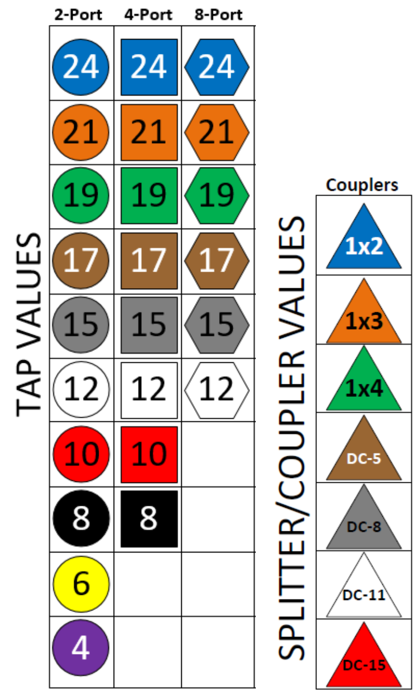


Figure 12 – Device Naming and Labeling

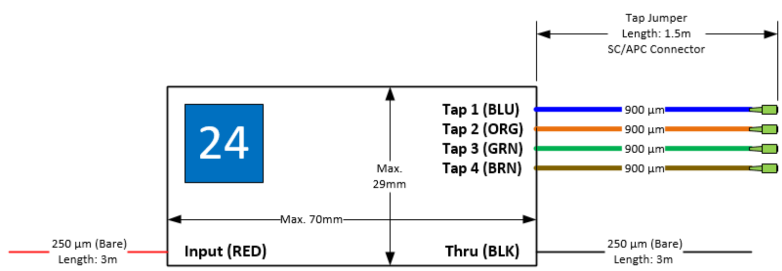


Figure 13 – Example of Tap Module Form-Factor

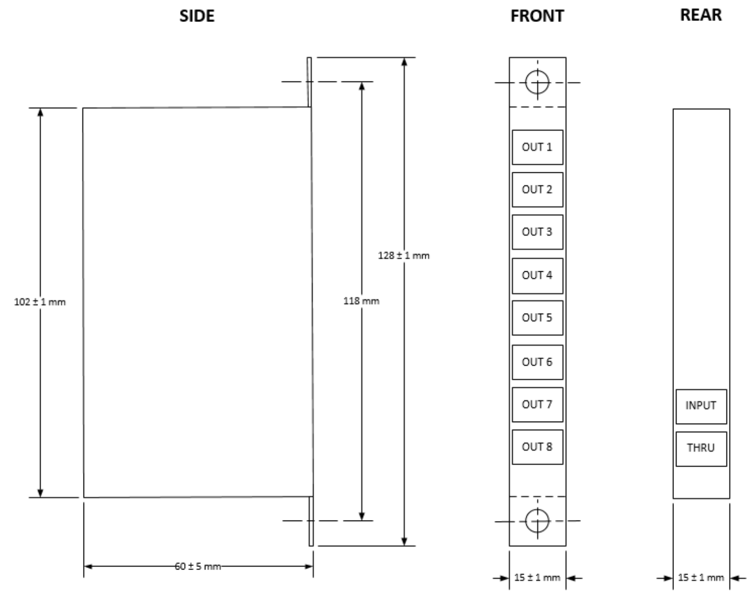


Figure 14 – Example of Tap Cassette Form-Factor

3.4. Field Trials

Prior to any customer facing deployments, full proof-of-concept networks were built in the lab with strings of couplers/splitters spliced together operating both GPON and XGS-PON networks successfully. As well as final product testing from multiple vendors, and mechanical form/fit/function testing within our standard fiber enclosures. Design tools such as our GIS database also needed further development to prepare for modeling of this type of network in digestible manner for field technicians. New object types were created, and fiber splicing documents were modified to support this type of network.

A reliability study was also conducted, which resulted favorably for a fusion-spliced distributed optical tap network with improvements in mean availability time, Mean Time Between Failure (MTBF), Mean Time to Restore (MTTR), and a reduction in annual maintenance truck rolls. While more customers are dependent on a single strand fiber in this type of network, there are fewer points of failure and in the event of a fiber impairment, services can be restored quicker.

The final step before full scale deployments was to gain some production experience to ensure processes are aligned and to identify any potential operational gaps. We conducted 5 field trials in 5 different Cox markets to demonstrate performance for the selected applications: greenfield, brownfield, SFU, MDU and commercial applications.

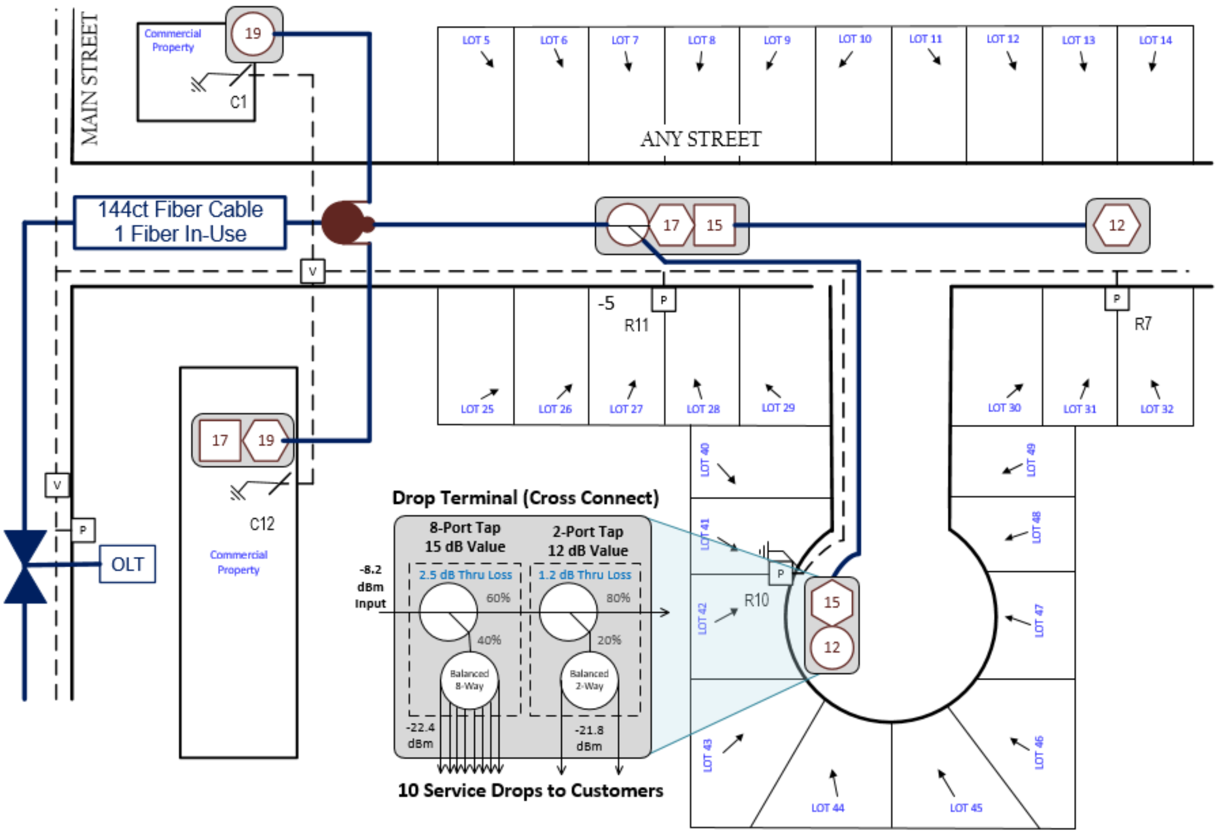


Figure 15 – Example of Field Trial Network Design

3.4.1. Lessons Learned

We successfully built and activated 5 different FTTx networks with the distributed optical tap solution and compared calculated design level versus actual measured levels. At the time the data was analyzed, levels had been collected from only 72 optical tap locations (see Figure 16).

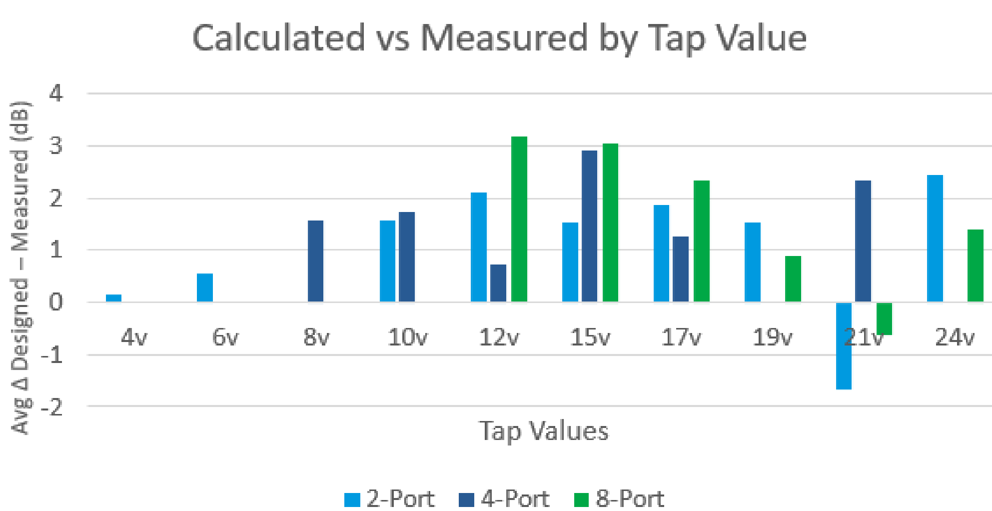


Figure 16 – Example of Field Trial Network Design

In most cases, measured levels were 1 - 3 dB better than calculated with few exceptions, which aligns with the built-in margin. In some cases, measured level was within the field acceptance criteria (-24 dBm), but lower than calculated, upon further investigation these were attributed to higher than typical splices but deemed acceptable. Considering all the variables involved and built-in margin we were comfortable with the results.

Be mindful of Optical Time Domain Reflectometer (OTDR) capabilities and limitations when designing turn up and troubleshooting processes. Characteristics of this type of network make obtaining OTDR shots particularly challenging due to relatively short distance links (< 2 km) with high insertion loss. We have observed good results when shooting 'in-line' into Thru Legs of taps but had very limited success shooting an OTDR into a tap leg. Tap legs, in particular of tap values greater than 17 dB, require a pulse width setting of at least 500ns, which decreases your resolution and creates lengthy dead-zones on the opposite side of the devices under test. This may be good enough to establish continuity back between two points, but events in between may not be visible. In contrast, in-line shots allow you to reduce pulse-width settings resulting in shortened dead-zones and with better resolution for the entirety of the link. We learned the addition of a connector on the last tap of the end-of-line circuit as an 'in-line' access point specifically for troubleshooting is valuable.

In the examples below (see Figure 17 & 18), OTDR shots are taken from the same 2-Port 12 dB value (2p12v) tap location into the tap leg versus the Thru leg; notice there is an additional ~10 dB of loss 400' from the test location which becomes much more difficult to discern with higher pulse width settings.

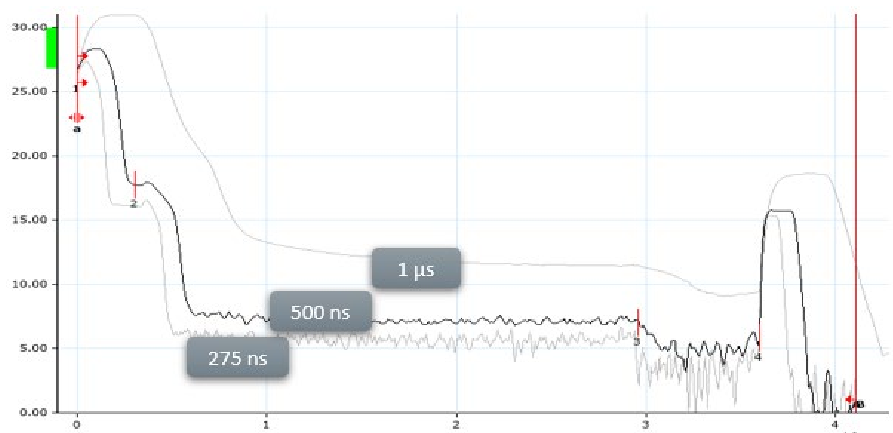


Figure 17 – Effects of Pulse Width Variation into Tap Leg of 12 dB Value Tap

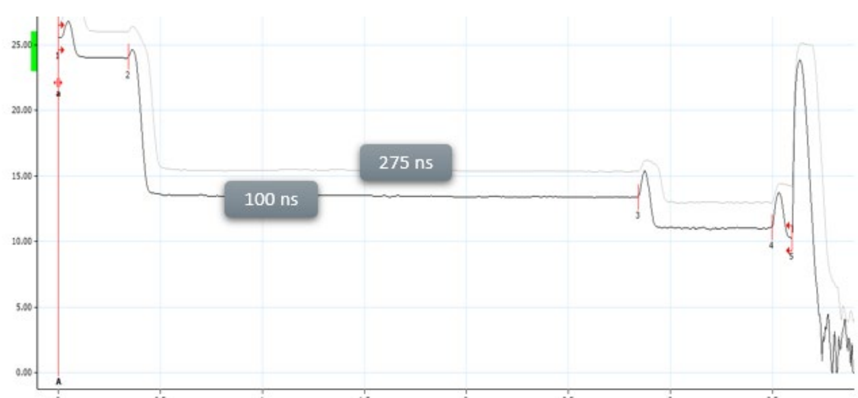


Figure 18 – Effects of Pulse Width Variation into Thru Leg of 12 dB Value Tap

Test equipment vendors are actively working to improve software profiles to make them more intuitive at identifying asymmetrical couplers and faults. In the interim, it takes a little more skill to read a traditional OTDR trace result and distinguish acceptable events from problematic events. We've found that the measured event loss of an OTDR can be very accurate (± 0.05 dB), the challenge is understanding the difference between a 'good' and 'bad' event. Historically any event greater than 0.5 dB was considered bad, in this type of network 5 dB of loss at one location could be 'bad' while the next is acceptable.

Figure 19 below is of a network with low levels (-27 dBm) at two locations, an OTDR was shot from end-of-line back toward the OLT. The technician must have a comprehensive view of the network design to compare anticipated loss to actual loss; in this case, the issue found was a bad splice on the input of the DC-8, which the anticipated loss was 1.5 dB, but the actual loss was ~7 dB.

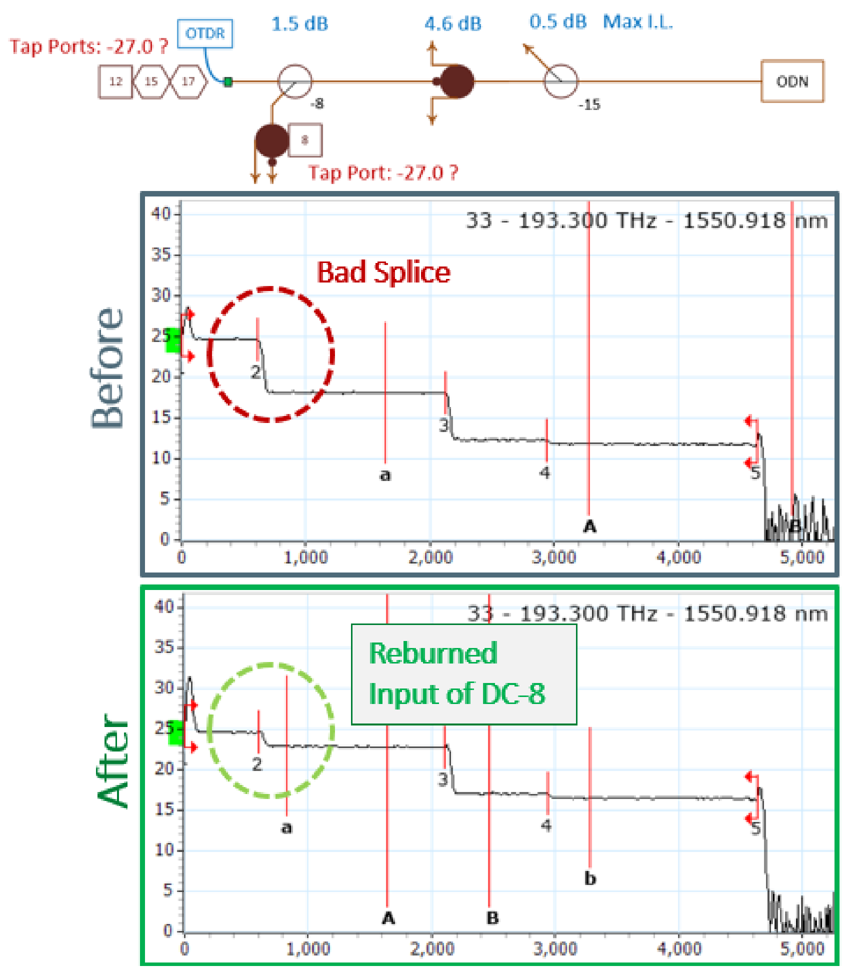


Figure 19 – OTDR Troubleshooting Example

4. Conclusion

Having completed lab testing, field trials and the early phases of production rollout, we feel confident in the distributed optical tap system serving as the standard optical distribution network for our PON deployments now and into the foreseeable future. Operationally, it fits well into many of our technicians existing skill sets and legacy RF design tools can be repurposed to model optical networks instead. This network is cost efficient, and more closely aligns network capacity with demand.

For network design parameters excess-loss must be factored in, but typical (as opposed to maximum) optical splitter insertion loss specifications from vendors is sufficient. Additional margin may be strategically applied to OLT launch power and/or drop loss instead.

An OTDR is a valuable tool for troubleshooting but must be performed in-line as opposed to a tap port. Consider fusion splicing versus optical connectors; well-placed connectors are valuable access points for troubleshooting purposes but can reduce optical reach and become future points of failure.

Abbreviations

BPON	Broadband Passive Optical Network
CPON	Coherent Passive Optical Network
DAA	Distributed Access Architecture
DC	Directional Couplers
DWDM	Dense Wave Division Multiplexing
FTTH	Fiber-to-the-Home
FTTx	Fiber-to-the-X
Gbps	Gigabit per second
GPON	Gigabit Passive Optical Network
HFC	Hybrid Fiber Coax
HP	Homes Passed
IL	Insertion Loss
ISBE	International Society of Broadband Experts
ISP	Inside Plant
MDM	Mux DeMux
MDU	Multi-Dwelling Units
NGPON2	Next Generation Passive Optical Network 2
OBI	Optical Beat Interference
OCML	Optical Communication Module Link extender
ODN	Optical Distribution Network
OLT	Optical Line Terminal
ONT	Optical Network Terminal
ONU	Optical Network Unit
OSP	Outside Plant
OTDR	Optical Time Domain Reflectometer
PON	Passive Optical Network
RFOG	Radio Frequencies over Glass
SCTE	Society of Cable Telecommunications Engineers
SFU	Single Family Units
SR	Split Ratio
WDM	Wave Division Multiplexing
XGSPON	10 Gigabit Symmetrical Passive Optical Network

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