

When it comes to deploying fiber to the business, MSOs have traditionally faced two significant challenges. First, many operators find they don't have enough fiber in their networks to dedicate fiber pairs to every potential business customer and still support the growing network demands of residential services. At the same time, running new fiber from the headend or hub to potential business customers can be a cost-prohibitive solution.

Today, there are cost-effective alternatives enabling MSOs to deploy fiber to the business using their existing fiber plant. Let's explore three of the most common fiber-to-the-business architectures and their associated link losses.

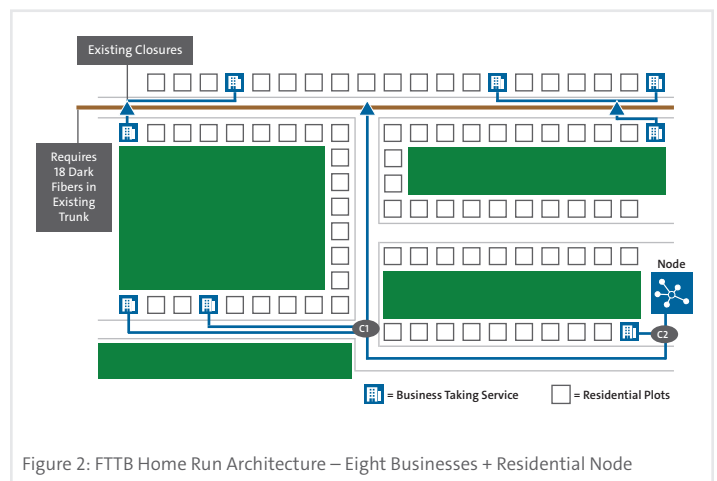
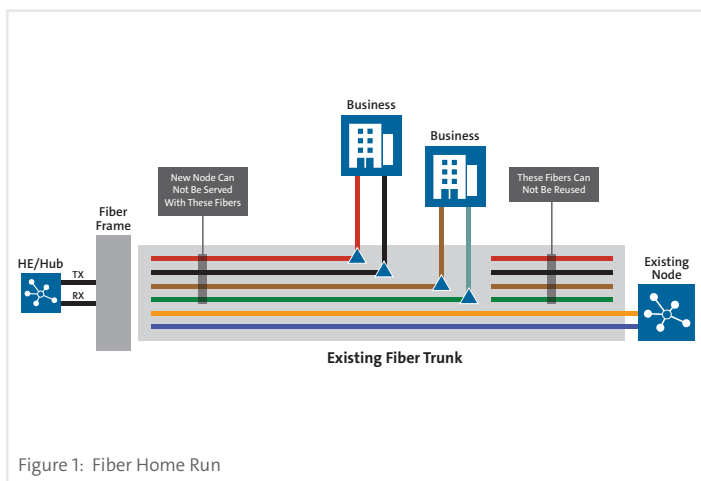
Home Run

The most common FTTB architecture deployed today, the fiber home run uses spare or "dark" fibers to feed each individual business.

In Figure 1, an existing fiber trunk feeds a residential node and two businesses. In this architecture, two fibers have to be "tapped" from the existing fiber trunk to support the business service. Usually these fibers are tapped from the existing 4-6 fibers that feed a residential node. In this scenario, the fibers downstream from the tapped fibers cannot be reused unless a new cable is spliced into the trunk cable.

Let's examine this architecture in greater detail. Figure 2 shows an area with eight potential business customers as well as a new residential area requiring a fiber node. To deliver service to the businesses and homes, an operator would have to re-enter an existing closure to splice 18 dark fibers in an existing trunk cable. As mentioned above, many operators find that they don't have enough unused fibers in their trunks for new business customers, mainly because many of the spare fibers installed during upgrades have already been used for splitting/segmenting nodes or extending the plant into new residential areas.

Where spare fibers are available, however, the implementation of coarse wavelength division multiplexing (CWDM) and/or dense wavelength division multiplexing (DWDM) augmentation can be used to increase capacity for business services instead of using dedicated strands.



		Probability			
Video @ 1310 nm		99.99997%	99.997%	99.87%	97.72%
Margin	dB	4.3	4.5	4.6	4.8
Transmission Budget	dB	12.0	12.0	12.0	12.0
Calculated Loss Budget	dB	7.7	7.55	7.40	7.25
		Probability			
Data Up/Down @ 1550 nm		99.99997%	99.997%	99.87%	97.72%
Margin	dB	19.5	19.7	19.8	20.0
Transmission Budget	dB	25.0	25.0	25.0	25.0
Calculated Loss Budget	dB	5.5	5.35	5.20	5.05

Adjust Con Loss Here		
Mean Loss per Unit	SD per Unit	Mean + 3 x Sigma
0.3	0.07	0.51

Adjust Dist Here	
Mean Loss per Unit	SD per Unit
Max Dist	20.0 km

Out of Spec

Table 1: Link-Loss Budget for Fiber Home Run

For the sake of analyzing the fiber home run link-loss budget side by side with other architectures, we will assume a 20 km distance and include the loss in cabled fiber, mated connector pairs, and fusion splices. As shown in Table 1, the home run link-loss budget is 7.7 dB at 1310 nm and 5.5 dB at 1550 nm.

This loss budget also compares two transmission budgets, 12 dB for 1310 nm video transmission and 25 dB for 1550 nm data transmission. For this example at 20 km, both the data and video have positive margin at a 99.99997% confidence interval.

From a technical perspective, the pros and cons of the fiber home run architecture include:

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Pros</p> <ul style="list-style-type: none"> • Excellent network reach of 60 km given a 25 dB link budget • Purely passive system that is protocol agnostic | <p>Cons</p> <ul style="list-style-type: none"> • High utilization of existing fiber plant • 18 dark fibers required for eight businesses and a node |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Passive Optical Network

In the passive optical network (PON), an MSO lights up one or two dark fibers to feed up to 16 or 32 businesses. 1G and 10G EPON tend to be the MSO's PON technologies of choice in accordance with IEEE 802.3av. 10G EPON wavelength utilization (1575-1580 nm downstream and 1260-1280 nm upstream) allows for coexistence with RF video (1550-1560 nm) and GPON/1G EPON (1480-1500 nm downstream; 1260-1360 nm upstream). With DOCSIS provisioning over EPON (DPoE), the EPON OLT and subscriber ONU perform like a CMTS and cable modem would using familiar DOCSIS management systems.

Figure 3 illustrates how an existing fiber trunk feeds a residential node and two businesses using a PON. In this architecture, one fiber is tapped from the existing fiber trunk to support bidirectional traffic for business customers. An optical power splitter is used in the field to split a broadcast signal to multiple businesses. The standard wavelengths used in a PON are 1490 nm for downstream data and 1310 nm for upstream data. An analog video signal can be multiplexed in at 1550 nm. Two more fibers are needed for the residential node. In this scenario, the fibers downstream from the tapped fibers can be reused if enough optical power is available.

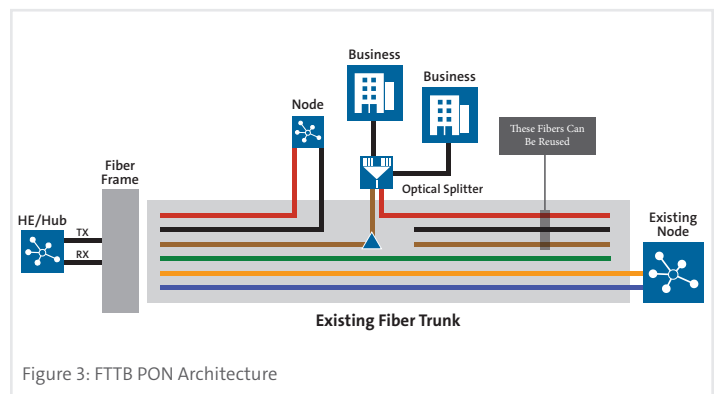


Figure 3: FTTB PON Architecture

Using the same scenario as we used in the fiber home run, we will explore how a PON architecture can support up to eight new business customers and a new residential node.

As shown in Figure 4, to reach the eight businesses and residential node, the operator now only needs three dark fibers. In this scenario, the operator would have probably split a 1x32 PON into two or four PON networks by using a passive optical splitter in the headend or hub. A field-hardened, passive 1x8 splitter is then deployed in an outside plant terminal. From the terminal, 1- or 2-fiber drop cables are run to the customer premise. These terminals and drop cables can be preterminated with optical connectors in order to decrease the time and cost of fusion splicing.

		Probability			
Video @ 1310 nm		99.99997%	99.997%	99.87%	97.72%
Margin	dB	4.3	4.5	4.6	4.8
Transmission Budget	dB	12.0	12.0	12.0	12.0
Calculated Loss Budget	dB	7.7	7.55	7.40	7.25
		Probability			
Data Up/Down @ 1550 nm		99.99997%	99.997%	99.87%	97.72%
Margin	dB	8.0	8.4	8.4	9.1
Transmission Budget	dB	25.0	25.0	25.0	25.0
Calculated Loss Budget	dB	17.0	16.62	16.24	15.86

Adjust Con Loss Here		
Mean Loss per Unit	SD per Unit	Mean + 3 x Sigma
0.3	0.07	0.51

Adjust Dist Here	
Mean Loss per Unit	SD per Unit
Max Dist	20.0 km

Out of Spec

Table 2: Link Budget for PON

Again assuming a 20 km distance and taking into account the loss in cabled fiber, connectors, optical splitters (1x8), and fusion splices, Table 2 shows the PON architecture link-loss budget is 7.7 dB at 1310 nm (based on a direct fiber connection to the node) and 17.0 dB at 1550 nm.

This link-loss budget also compares two transmission budgets, 12 dB for 1310 nm video transmission and 25 dB for 1550 nm data transmission. For this example at 20 km, both the data and video have positive margin at a 99.99997% confidence interval.

The pros and cons of the PON architecture include:

Pros

- Better utilization of existing fiber plant, 1 or 2 fibers per PON
- Adding a residential CATV node requires 2 additional fibers-businesses and a node
- Purely passive system

Cons

- Shared bandwidth
- Distance limited by optical loss and protocol

Wavelength Division Multiplexing

The wavelength division multiplexing (WDM) access network is the last architecture we will analyze. Traditionally used in the long-haul and metro network to transport large amounts of data from point-to-point, today’s operators see WDM as an effective way to deliver fiber to the business.

There are two main types of WDM: dense wavelength division multiplexing (DWDM) and coarse wavelength division multiplexing (CWDM). DWDM platforms use temperature-controlled distributed feedback (DFB) lasers and have very tight channel spacing (50-200 GHz). These systems are ideal for networks that require higher wavelength counts (16-64). CWDM systems can use lower-cost, athermal DFB lasers and wider channel spacing (20 nm). These platforms are typically found where lower wavelength counts (4-8) are required.

The International Telecommunication Union (ITU) provides recommendations for wavelength planning. The ITU document G.694.1 provides the spectral grids for DWDM applications, while G.694.2 provides the spectral grids for CWDM applications.

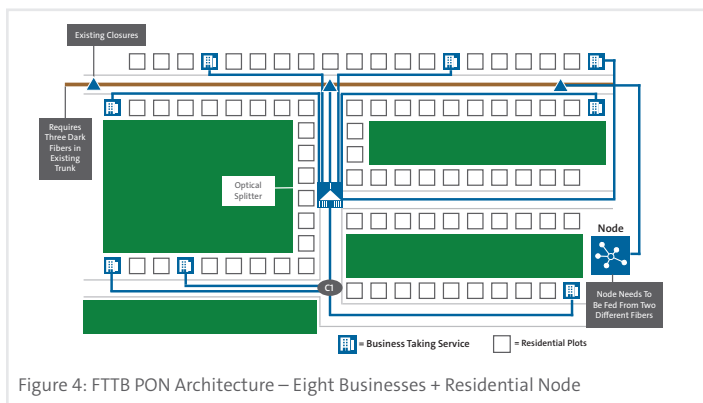


Figure 4: FTTB PON Architecture – Eight Businesses + Residential Node

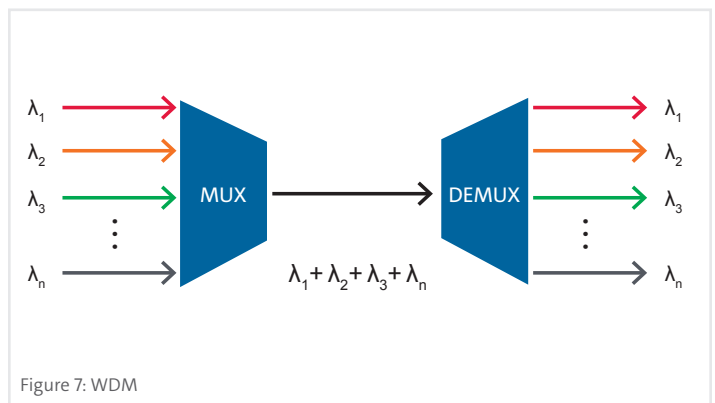


Figure 7: WDM

In a WDM access network, the operator may use 1 or 2 fibers from an existing trunk to deliver individual wavelengths to multiple business customers. In a 2-fiber system, as depicted in Figure 8, each customer has a specified wavelength that can be used for both transmit and receive traffic. In this system, operators can also transmit and receive 1310 nm to new or existing fiber nodes over the same pair of fibers.

The WDM access network uses transmitters and receivers which are tuned to the specified ITU-grid. Individual wavelengths or channels are aggregated onto a single fiber using a passive WDM mux device in the headend or hub. Then a passive WDM demux device, located in an outside plant terminal, drops the appropriate wavelength to the subscriber. All other wavelengths are dropped to other subscribers or are passed through and continue onto the network as shown in Figure 9. On the return fiber, wavelengths are aggregated onto the network as they pass through each mux device.

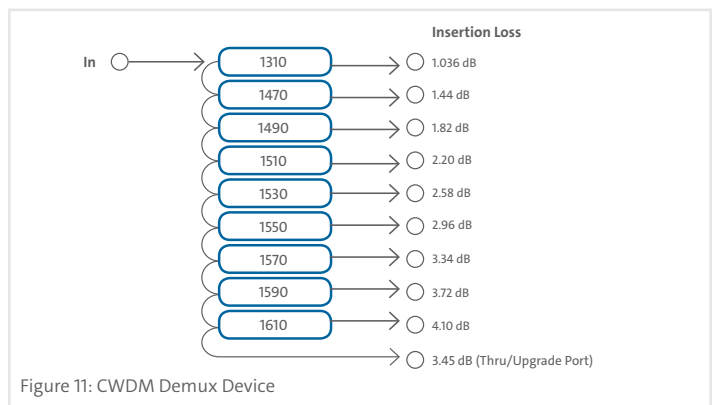
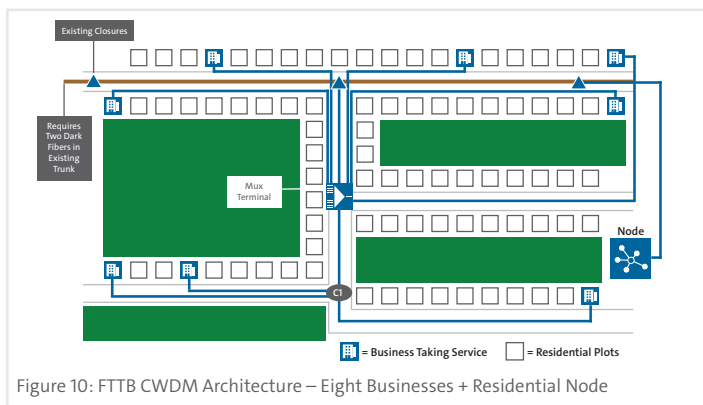
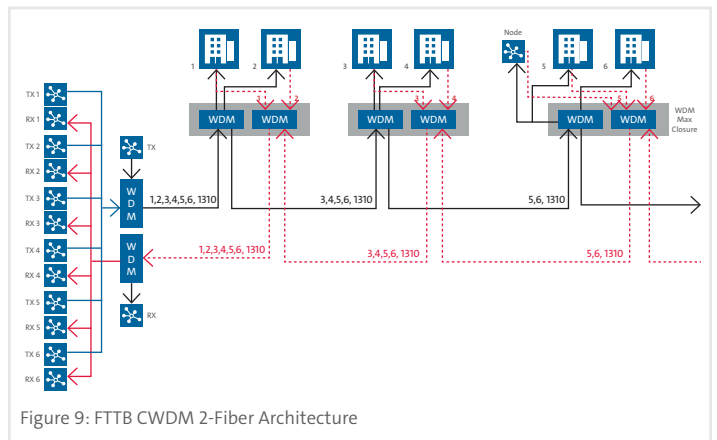
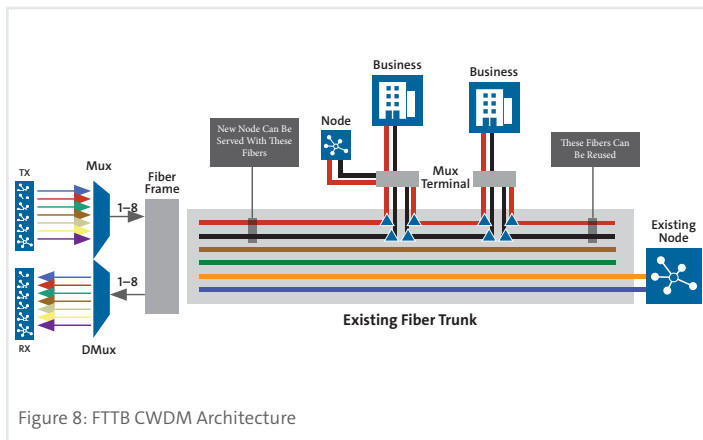
WDM mux terminals are a key component in the WDM access network as they provide a safe and reliable environment for field-hardened passive devices. Unlike standard splice closures, mux terminals allow for operators to easily install, maintain, add, and test WDM mux devices in the field.

An operator could also use a 1-fiber WDM architecture, in which two wavelengths are required per customer for upstream and downstream traffic. A 1-fiber WDM architecture with eight wavelengths can serve up to four businesses. A disadvantage to the 1-fiber architecture is that the operator cannot transmit bidirectional 1310 nm traffic to new nodes.

In Figure 10, we see the same eight new mux businesses and the new node, this time only requiring 2 dark fibers in the existing trunk cable for service.

There are several possible approaches to deploying this type of FTTB network (i.e. bus, star, ring). This analysis uses a star architecture to maximize subscribers and to reduce optical loss.

While the link-loss budget still includes cabled fiber, connectors, WDM filters, and splices, it's important to remember that the WDM access network gives the operator the flexibility to maximize the link loss for individual channels. The example shown in Figure 11 uses a passive CWDM filter, dropping the 1310 nm wavelength first with an insertion loss of approximately 1 dB.



		Probability			
Video @ 1310 nm		99.99997%	99.997%	99.87%	97.72%
Margin	dB	-0.2	0.3	0.7	1.2
Transmission Budget	dB	12.0	12.0	12.0	12.0
Calculated Loss Budget	dB	12.2	11.72	11.27	10.82
		Probability			
Data Up/Down @ 1550 nm		99.99997%	99.997%	99.87%	97.72%
Margin	dB	9.2	9.7	10.1	10.6
Transmission Budget	dB	25.0	25.0	25.0	25.0
Calculated Loss Budget	dB	15.8	15.32	14.87	14.42

Adjust Con Loss Here		
Mean Loss per Unit	SD per Unit	Mean + 3 x Sigma
0.3	0.07	0.51

Adjust Dist Here	
Mean Loss per Unit	SD per Unit
Max Dist	20.0 km


 Out of Spec

Table 3: Link Budget for WDM

The loss budget also compares two transmission budgets, 12 dB for 1310 nm video transmission, and 25 dB for 1550 nm data transmission. The link loss for this WDM access network is 12.2 dB at 1310 nm and 15.8 dB at 1550 nm, as shown in Table 3.

At 20 km, the data has positive margin and the video has -0.2 dB margin at a 99.99997 percent confidence interval.

The pros and cons of the WDM architecture include:

Pros

- Best utilization of existing fiber plant
- 2 fibers for data and residential CATV node
- Purely passive, protocol-agnostic plant
- Virtually unlimited bandwidth

Cons

- Distance limited by optical loss

Link-Loss @ 20 km for Eight Businesses and One Node			
	1310 nm Loss (dB) for Residential Node	1550 nm Loss (dB) for Downstream Data	Dark Fibers Required
Fiber Home Run	7.7	5.5	18
PON	7.7	17	3
WDM	12.2	15.8	2

Table 4: Link-Loss Summary

Analyzing the technical differences of the home run, PON, and WDM architectures in this model serving eight businesses and one residential node, we can look at a number of different parameters as shown in Table 4.

The summary shows that the fiber home run requires 18 dark fibers (2 fibers per business x 8 businesses = 16 fibers + 2 fibers for the residential node = 18 fibers). The PON architecture requires 3 fibers (1 fiber for the PON and 2 fibers for the residential node) and incurs the highest loss at 1550 nm. In the WDM architecture, 2 fibers feed all eight business customers and the residential node.

Table 5 shows a general side-by-side technical comparison of the three architectures. Given a link-loss budget of 25 dB, the fiber home run boasts the longest reach and the highest utilization of existing assets. Based on current standards, the PON's reach is typically limited to 20 km, whereas WDM can reach 35 km. In comparing the bandwidth of these three architectures, the main takeaway is that the PON is a shared bandwidth, while the fiber home run and WDM architectures deliver dedicated bandwidth.

Eight Businesses + One Node Example					
Architecture	Dist-Given 25 dB Loss Budget	Distance Limitation	Bandwidth: Shared or Dedicated	Protocol	Dark Fiber Requirements
Fiber Home Run	60 km	Power	Dedicated	Any	High
PON (2-fibers)	20 km	Protocol or Power	Shared	ATM or Ethernet	Med
WDM	35 km	Power	Dedicated	Any	Low

Table 5: Bandwidth Comparison

Conclusion

Commercial subscribers represent a significant opportunity for CATV operators to grow their revenues quickly with immediate returns on investment. A large percentage of the commercial market revenue resides with customers who are looking for more bandwidth scalability and flexibility. With today's fiber-to-the-business solutions, MSOs are well-positioned to deliver fiber services to these customers by leveraging their existing assets.



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