

Traditional PON Versus Mixed PON/Active Architectures Based on Ciena's Universal Aggregation Solution

10G XGS-PON OPEX-centric Business Case

Introduction

The Passive Optical Network (PON) architecture employs shared fiber to achieve cost savings for network operators, which is quite cost-effective over short feeders. The major attraction of the PON architecture is that it has a completely passive Outside Plant (OSP), eliminating active electronics from the OSP which are often fault-generating points, thereby simplifying network operation. However, over long feeders, the OSP/Optical Distribution Network (ODN) cost for the traditional PON architecture, in which the Optical Line Terminal (OLT) is located at the Central Office/Local Exchange (CO/LEX), increases rapidly. Also, limitations in system reach/distance due to optical splitting power loss creates a major disadvantage for the traditional PON architecture.

Over long feeders, a mixed PON/active architecture enables network operators to achieve cost savings and PON reach extension. By deploying a pluggable mixed PON/active architecture based on Ciena's Universal Aggregation (UA) solution, network operators can achieve both leased feeder fiber OPEX savings and PON reach extension.

This white paper develops a business case employing Ciena's 5170 Platform to quantify the OPEX savings achieved and determine feeder distances at which the pluggable mixed PON/active architecture becomes more cost-effective, compared with traditional PON architecture for different optical splitting ratios as follows:

- 10G PON with 1-> 32 total optical splitting of feeder fiber
- 10G PON with 1-> 64 total optical splitting of feeder fiber
- 10G PON with 1-> 128 total optical splitting of feeder fiber

This business case assumes an OPEX-centric model in which the network operator feeder infrastructure is leased. The OPEX-centric business model is typically adopted by subdivisions and communities, electric cooperatives, and cities and towns that deploy broadband PON FTTx access architectures to serve residents and would lease feeder fibers to connect their networks to the CO/LEX of major network operators, such as AT&T and Verizon.

1. Ciena's Universal Aggregation solution summary

Network operators are looking for comprehensive solutions to address their main pain point around deploying PON-based broadband access networks—the PON OSP/ODN cost and PON reach limitation.

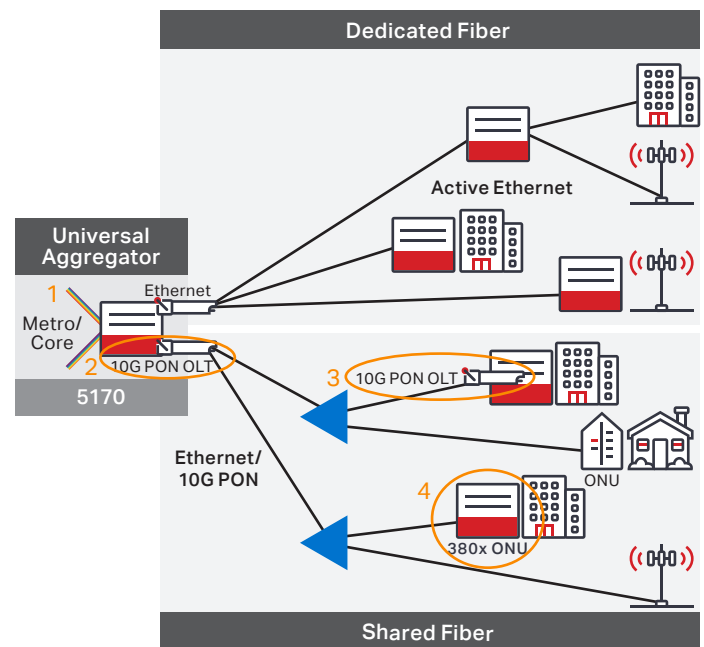


Figure 1. Ciena's UA solution



Figure 1 shows Ciena’s UA solution. This solution provides network operators with increased choice and control of tangible business value assets like coherent optics, dedicated and shared pluggable fiber optics, and Adaptive IP™. By supporting all services, including mobility 4G/5G services, Ciena’s UA solution expands a network provider’s application space and competitiveness. Choice—enabled by a smaller footprint, increased capacity, PON reach extension, and larger interconnect scale in platforms that automate and simplify deployment and turn-up tasks—results in operational flexibility and significant cost savings for network operators now and in the future.

- Solution components:
 1. 5170 Platform
 2. 10G PON uOLT SFP+
 3. 10G PON uONU SFP+
 4. 380x 10G XGS PON ONU

2. The 10G XGS-PON FTTx architecture

2.1 Traditional PON architecture with OLT located in CO

Figure 2a shows the implementation of the traditional PON FTTx architecture, where symmetrical 10G XGS-PON OLTs are located at the CO/LEX and traffic is aggregated upstream on Ciena’s UA solution with the 5170. Each 10G XGS-PON OLT is connected to the cabinet node on a feeder fiber, wherein a single feeder fiber from the CO/LEX OLT is split into N-fiber distribution cable (where N = 32, 64, or 128) by 1->N optical splitters located at the cabinet node as shown, assuming a centralized (local convergence) optical splitting. The cabinet distribution area contains 1024 subscribers. Each 10G PON’s required number of feeder fibers

splitters located at the cabinet node, as shown, assuming a centralized (local convergence) optical splitting. The cabinet distribution area contains 1024 subscribers. Each 10G PON’s required number of feeder fibers is M, and average bitrates per subscriber for 1->N optical splitting (where N = 32, 64, or 128) are as follows:

- For optical splitting: 1->N = 128; average bitrate per subscriber = 78 Mb/s and M = 8
- For optical splitting: 1->N = 64; average bitrate per subscriber = 155 Mb/s and M = 16
- For optical splitting: 1->N = 32; average bitrate per subscriber = 311 Mb/s and M = 32

Consequently, in the traditional PON access architecture, the required number of feeder fibers—and, hence, leased feeder fiber OPEX—increases linearly as feeder length and/or delivered bitrates increase.

2.2 PON/active FTTx architecture (based on Ciena’s UA solution) with OLT remoted to cabinet node

Figure 2b shows the implementation of the PON/active FTTx architecture based on Ciena’s UA solution, with the 10G XGS-PON OLTs now remoted to a cabinet node and the traffic between the CO/LEX and the cabinet node aggregated on a pair of fibers using a pair of Ciena’s 5170s, as shown. At the cabinet node, signal carried by each 10 Gb/s XGS-PON OLT is then split into N-fiber distribution cable (where N = 32, 64, or 128) by 1->N optical splitters located at the cabinet node as shown, assuming a centralized (local convergence) optical splitting. The cabinet distribution area contains 1024 subscribers. Each 10G PON’s required number of feeder fibers

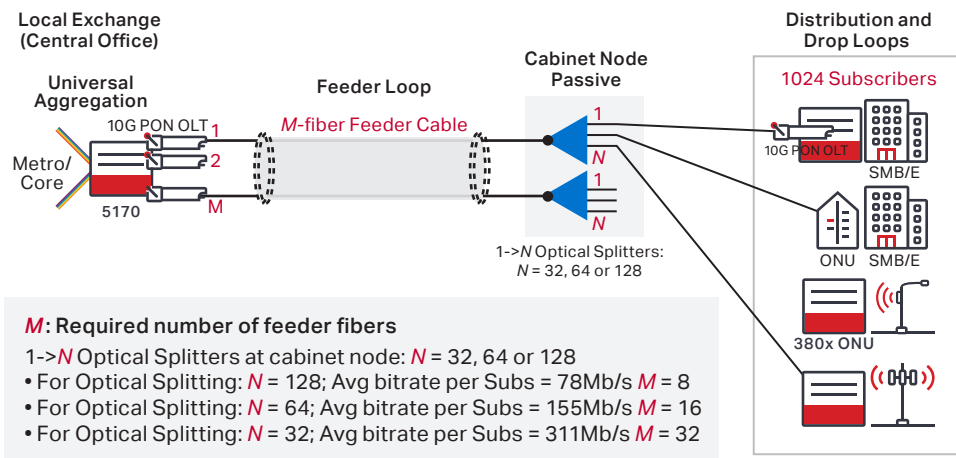


Figure 2a. Traditional PON FTTx architecture with OLT located in CO/LEX

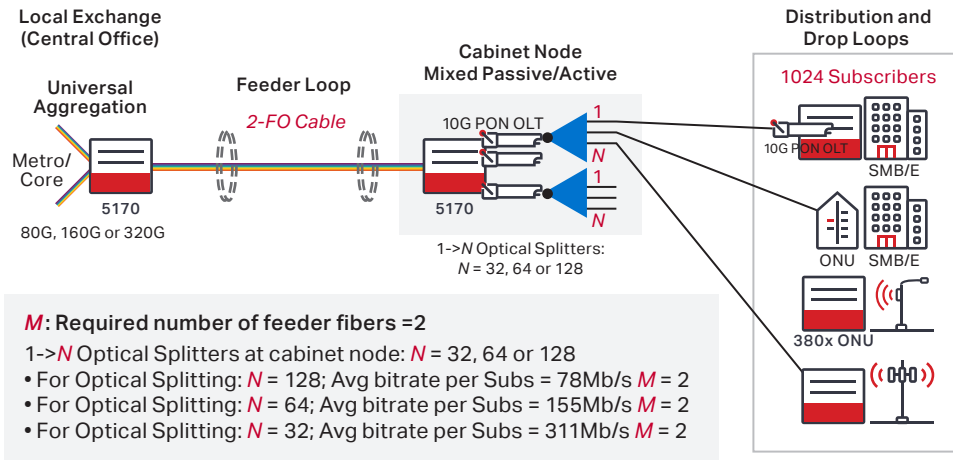


Figure 2b. PON/active FTTx architecture (based on Ciena's UA solution) with OLT remoted to cabinet node

is M, and average bitrates per subscriber for 1->N optical splitting (where N = 32, 64, or 128) are as follows:

- For optical splitting: 1->N = 128; average bitrate per subscriber = 78 Mb/s and M = 2
- For optical splitting: 1->N = 64; average bitrate per subscriber = 155 Mb/s and M = 2
- For optical splitting: 1->N = 32; average bitrate per subscriber = 311 Mb/s and M = 2

The required number of feeder fibers is two for all split ratios. Hence the leased feeder fiber OPEX increases only marginally as feeder length and/or delivered capacity increase.

2.3 10G XGS-PON business case: Sizing Ciena's UA capacity requirement for different optical split ratios

Figure 2c shows the sizing of the required aggregator capacity for various optical split ratios as follows:

- For optical splitting: 1->N = 128; required aggregator capacity: 80 Gb/s (=10 Gb/s x 8 feeder fibers)
- For optical splitting: 1->N = 64; required aggregator capacity: 160 Gb/s (=10 Gb/s x 16 feeder fibers)
- For optical splitting: 1->N = 32; required aggregator capacity: 320 Gb/s (=10 Gb/s x 32 feeder fibers)

# of Subs in Cabinet Area	Capacity per 10G XGS-PON: (Gb/s)	Optical Splitting of a Feeder Fiber: 1->N (N=16, 32, 64, 128)	Average Capacity/Subs: (Mb/s)	Req'd Capacity of Cabinet Area: Gb/s	Trad-PON Solution Feeder Loop	PON/Active Solution* Feeder Loop+ Aggreg. Sizing
1024	10.0	1->128	78	80	8-FO	2-FO + 80G 5170
1024	10.0	1->64	156	160	16-FO	2-FO + 160G 5170
1024	10.0	1->32	311	320	32-FO	2-FO + 320G 5170

*based on Ciena Universal Aggregation solution

Figure 2c. Sizing Ciena's UA capacity requirement for different optical split ratios

3. Cost modeling

Figures 3a and 3b show the network cost components of the traditional PON FTTx architecture and the mixed PON/active FTTx architecture based on Ciena’s UA solution, respectively. An OPEX-centric business model is assumed where subdivisions and communities, electric cooperatives, and cities and towns that deploy broadband PON FTTx access architectures typically lease feeder fibers from major network

operators, such as AT&T and Verizon, to connect to a network. The network cost components include:

- (i) CO/OLT node: electronics: 10G PON OLT, Ciena’s 5170, software and power
- (ii) Feeder loop: Lease OPEX: per strand per km per month: \$19.7 (or \$236 per year)
- (iii) Cabinet node: optical splitters, electronics: 10G PON OLT, Ciena’s 5170, power, enclosure, Controlled Environmental Vault (CEV) to house active electronics

3.1 Network cost components of traditional PON FTTx architecture

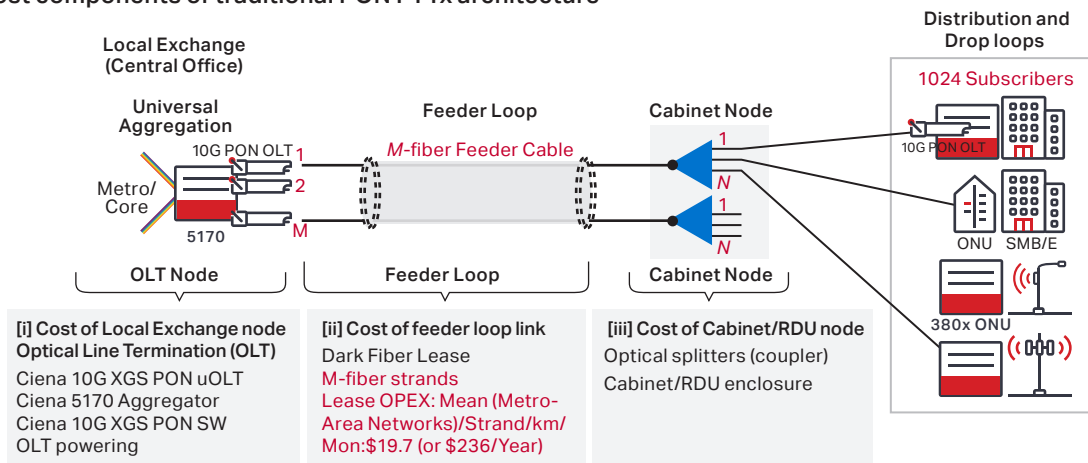
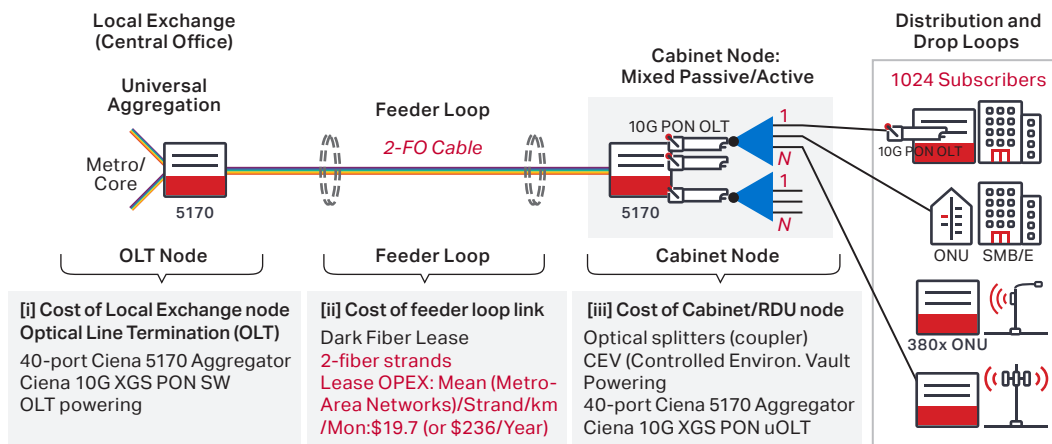


Figure 3a. Network cost components of traditional PON FTTx architecture

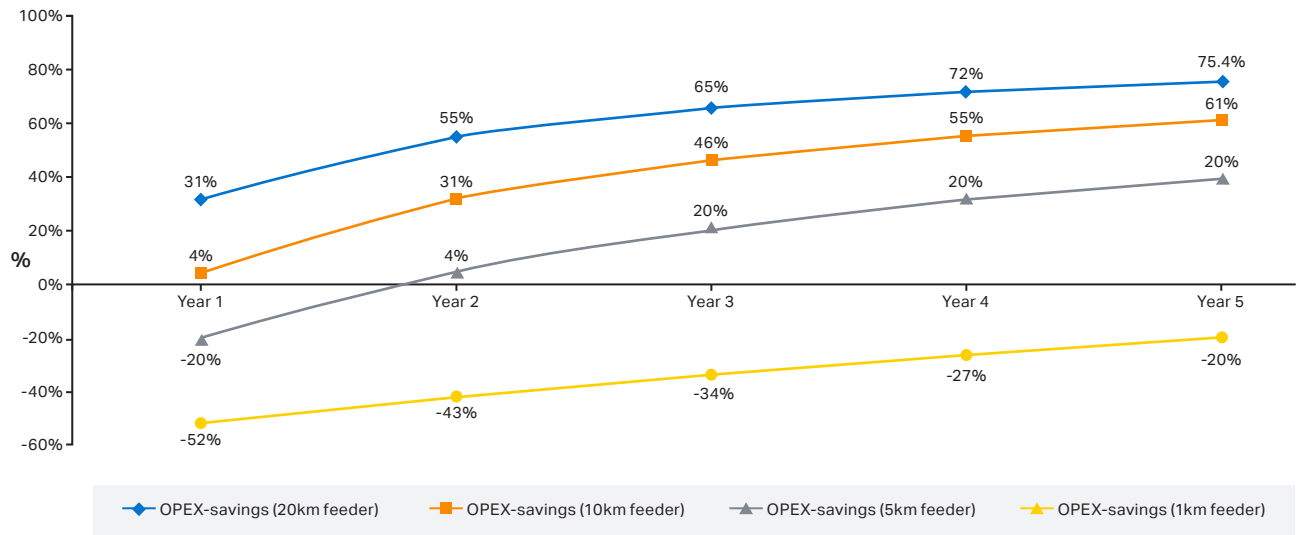
3.2 Network cost components of mixed PON/active FTTx architecture based on Ciena’s UA solution



*based on Ciena Universal Aggregation solution

Figure 3b. Network cost components of mixed PON/active FTTx architecture based on Ciena’s UA solution

Leased Feeder Fiber OPEX-saving Achieved with Mixed PON/Active Architecture* versus Traditional-PON Architecture (1->32 Optical Split of Feeder Fiber; Average Bitrate per Subs: 311 Mb/s)



*based on Ciena Universal Aggregation solution

Figure 4. Leased feeder fiber OPEX savings as a function of feeder distance and time; optical splitting of feeder fiber: 1->32

4. Cost modeling results: Leased feeder fiber OPEX savings achieved by mixed PON/active architecture based on Ciena’s UA solution versus traditional PON architecture

The chart of figure 4 shows the leased feeder fiber OPEX savings achieved over a five-year period by deploying the mixed PON/active architecture compared to the traditional PON architecture for an optical split ratio of 1->32 — for feeder distances of 1km, 5km, 10km, and 20km.

Analysis

- **Feeder distance of 1km:** The cumulative leased feeder fiber OPEX savings achieved with the mixed PON/active architecture negative: -52 percent in year one and -20 percent in year five. Consequently, the traditional PON architecture is more cost-effective than the mixed PON/active architecture over five years for a feeder distance of 1km.
- **Feeder distance of 5km:** The cumulative leased feeder fiber OPEX savings achieved with the mixed PON/Active architecture is negative: -20 percent in year one but becomes positive by year two: four percent and increases to 39 percent by year five. Consequently, for a feeder distance of 5km, the mixed PON/active architecture becomes more cost-effective than the traditional PON architecture by year two and achieves a cumulative leased feeder fiber OPEX savings of 39 percent over five years.

- **Feeder distance of 10km:** The cumulative leased feeder fiber OPEX savings achieved with the mixed PON/active architecture is positive as soon as year one: four percent which grows to 31 percent by year two and increases to 61 percent by year five. Consequently, for a feeder distance of 10km, the mixed PON/active architecture is more cost-effective than the traditional PON architecture as soon as year one and achieves a cumulative leased feeder fiber OPEX savings of 61 percent over five years.
- **Feeder distance of 20km:** The cumulative leased feeder fiber OPEX savings achieved with the mixed PON/active architecture is positive as soon as year one: 31 percent which grows to 55 percent by year two and increases to 75.4 percent by year five. Consequently, for a feeder distance of 20km, the mixed PON/active architecture is more cost-effective than the traditional PON architecture as soon as year one and achieves a cumulative leased feeder fiber OPEX savings of 75 percent over five years.

5-Year Cumulative OPEX-savings Achieved with Mixed PON/Active Architecture* versus Traditional-PON Architecture

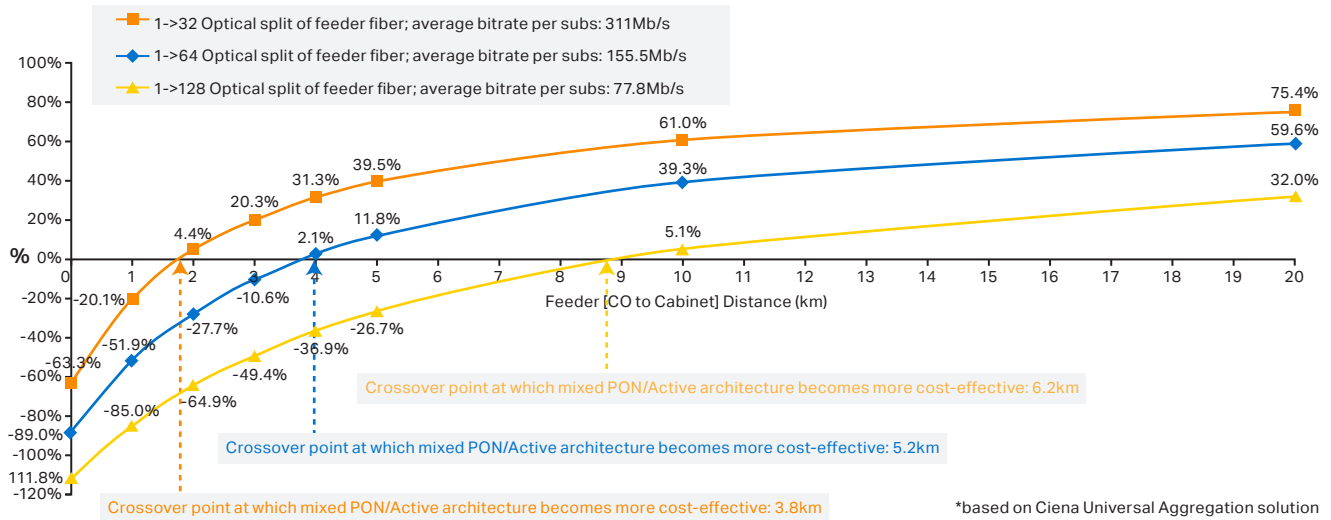


Figure 5. Five year cumulative leased feeder fiber OPEX savings achieved with mixed PON/active architecture* versus traditional PON architecture at different optical split ratios of a feeder fiber as a function of the feeder [CO to cabinet] distance

5. Conclusions: Cost comparison of 10G XGS-PON solutions: Traditional PON versus pluggable mixed PON/active architectures based on Ciena's UA solution

This white paper analyzes an OPEX-centric business case model in which network operators lease feeder infrastructure. The OPEX-centric business model is typically adopted by 1000's cities and towns, subdivisions and communities and electric cooperative who deploy broadband PON FTTx access architectures and then lease feeder fibers from major network operators, such as AT&T and Verizon, to connect to a network.

The white paper modeled a business case employing Ciena's 5170 Platform to quantify the leased feeder fiber OPEX savings achieved and determine the feeder distances at which the pluggable mixed PON/active architecture becomes more cost-effective versus the traditional PON architecture for different optical splitting ratios as follows:

- 10G PON with 1-> 32 total optical splitting of feeder fiber
- 10G PON with 1-> 64 total optical splitting of feeder fiber
- 10G PON with 1-> 128 total optical splitting of feeder fiber

The network cost components included:

- CO/OLT node: electronics: 10G PON OLT, Ciena's 5170, software and power
- Feeder loop: Lease OPEX: per strand per km per month: \$19.7 (or \$236 per year)

- Cabinet node: optical splitters, electronics: 10G PON OLT, Ciena's 5170, power, enclosure, Controlled Environmental Vault (CEV)

Figure 5 shows the leased feeder fiber OPEX savings achieved with mixed PON/active architecture based on Ciena's UA solution, at optical split ratios of 1->128, 1->64 and 1->32 of a feeder fiber as a function of the feeder [CO to cabinet] distance.

- **For optical split of feeder fiber: 1->128 (average bitrate/subscriber: 77.8 Mb/s):** the mixed PON/active architecture based on Ciena's UA solution becomes more cost-effective at a feeder distance of 8.9km and results in a cumulative leased feeder fiber OPEX-savings of 5.1 and 32 percent at feeder lengths of 10km and 20km, respectively.
- **For optical split of feeder fiber: 1->64 (average bitrate/subscriber: 155.5 Mb/s):** the mixed PON/active architecture becomes more cost-effective at a feeder distance of 3.8km and results in cost savings of 39.3 and 59.6 percent at feeder lengths of 10km and 20km, respectively.
- **For optical split of feeder fiber: 1->32 (average bitrate/subscriber: 311 Mb/s):** the mixed PON/active architecture becomes more cost-effective at a feeder distance of 1.8km and results in cost savings of 61 and 75.4 percent at feeder lengths of 10km and 20km, respectively.

1->32 Optical Split of Feeder Fiber; Average Bitrate per Subs: 311 Mb/s

Feeder Length (km)	# of Customers	Traditional PON Architecture		Mixed PON/Active Architecture*		Leased Feeder Fiber OPEX Savings Achieved with Mixed PON/Active Architecture*	
		Req'd # of Feeder Fibers	Fibers-km	Req'd # of Feeder Fibers	Fibers-km	Annual	Over 5 Years
5	1024	32	160	2	10	\$22,786	\$113,928
5	100,000	3,125	15,625	195	977	\$2,225,156	\$11,125,781
10	1024	32	320	2	20	\$58,186	\$290,928
10	100,000	3,125	31,250	195	1,953	\$5,682,188	\$28,410,938
20	1024	32	640	2	40	\$128,986	\$644,928
20	100,000	3,125	62,500	195	3,906	\$12,596,250	\$62,981,250

*Lease cost: Mean (Metro-Area Networks)/Strand/km/Year:\$236

Figure 6: Leased feeder fiber OPEX savings achieved with mixed PON/active architecture for a network with 100,000 customers and 1->32 optical split ratio and for feeder distances of 5km, 10km, and 20km

6. Main takeaway: Leased feeder fiber OPEX savings achieved with mixed PON/active architecture is significant

Network operators are looking for comprehensive solutions to address their primary pain point around deploying fiber in the access network—OSP/ODN cost and PON reach limitation.

To understand the significance of the leased feeder fiber OPEX savings achieved with mixed PON/active architecture based on Ciena's UA solution, Figure 6 shows the actual dollar values estimated for a network with 100,000 customers—and 1->32 optical split ratio and for feeder distances of 5km, 10km, and 20km.

OPEX for leased feeder dark fiber was \$19.7 per strand per km per month, which is very conservative, compared to the leased dark fiber OPEX in annex—and yet yields huge OPEX savings for network operators.

- At a feeder of 5km, the leased feeder fiber OPEX savings achieved for 100,000 customers with mixed PON/active architecture based on Ciena's UA solution is \$2.2M annually and a cumulative \$11.1M over five years.

- At a feeder of 10km, the leased feeder fiber OPEX savings achieved for 100,000 customers with mixed PON/active architecture based on Ciena's UA solution is \$5.7M annually and a cumulative \$28.4M over five years.
- At a feeder of 20km, the leased feeder fiber OPEX savings achieved for 100,000 customers with mixed PON/active architecture based on Ciena's UA solution is \$12.6M annually and a cumulative \$63M over five years

10G XGS-PON CAPEX-centric Business Case
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This white paper establishes that the mixed PON/active architecture—based on Ciena's UA solution—addresses/mitigates network operators' major pain point in deploying fiber in the access network to support broadband services, which is the high cost of the OSP/ODN while at the same time removing a technical limitation of the traditional PON access architecture, which is a reach limitation due to optical splitting loss. Therefore, the mixed PON/active architecture based on Ciena's UA solution is the comprehensive solution that network operators are seeking.

Dark Fiber Leasing/IRU for Rural Long Haul Routes (Source: CTC Technology & Energy: Dark Fiber Lease Considerations)	Effective price: per strand per mile per month (assumes purchase of pair)	Effective price: per strand per mile per month (assumes purchase of pair)
CA rural/suburban	4.68	56.16
IL rural	3.44	41.28
IL rural/suburban	6.77	81.24
NC rural	3.65	43.80
MD rural	45.00	540.00
Mean (Long Haul Networks)/Strand/mile/Month (or per Year)	\$12.7	\$152.5
Mean (Long Haul Networks)/Strand/km/Month (or per Year)	\$7.9	\$95.3

Dark Fiber Leasing/IRU for Metro-Area Routes (Source: CTC Technology & Energy: Dark Fiber Lease Considerations)	Effective price: per strand per mile per month (assumes purchase of pair)	Effective price: per strand per mile per month (assumes purchase of pair)
IL rural/suburban	6.87	82.44
Burbank	14.58	174.96
Burbank	11.25	135.00
TN small town	41.60	499.20
TN small town	83.00	996.00
Mean (Long Haul Networks)/Strand/mile/Month (or per Year)	\$31.5	\$377.5
Mean (Long Haul Networks)/Strand/km/Month (or per Year)	\$19.7	\$236.0

Dark Fiber Leasing/IRU for Large Urban Routes (Source: CTC Technology & Energy: Dark Fiber Lease Considerations)	Effective price: per strand per mile per month (assumes purchase of pair)	Effective price: per strand per mile per month (assumes purchase of pair)
Palo Alto	236.00	2,832.00
CA Large urban	210.00	2,520.00
IL urban	13.75	165.00
VA urban	162.50	1,950.00
Mean (Long Haul Networks)/Strand/mile/Month (or per Year)	\$155.6	\$377.5
Mean (Long Haul Networks)/Strand/km/Month (or per Year)	\$97.2	\$236.0

Source: <https://www.ctcnet.us/DarkFiberLease.pdf> Dated: 2012

7. Annex: Dark fiber lease OPEX information

The dark fiber lease OPEX shown in the table below were built from the source <https://www.ctcnet.us/DarkFiberLease.pdf> and covers OPEX for (i) rural long haul routes, (ii) metro area routes and (iii) large urban routes. This white paper is based on (ii) metro area routes leased dark fiber OPEX which is \$19.7 per strand per km per month (or \$236 per strand per km per year).

Dark Fiber Pricing Information

0–5 miles of fiber	\$89.97 per fiber, per mile, per month
5.1–10 miles of fiber	\$85.48 per fiber, per mile, per month
10.1–20 miles of fiber	\$76.48 per fiber, per mile, per month
20.1–30 miles of fiber	\$67.48 per fiber, per mile, per month
30.1–40 miles of fiber	\$58.48 per fiber, per mile, per month
40.1–50 miles of fiber	\$47.24 per fiber, per mile, per month
≥ 50.1 miles of fiber	\$44.99 per fiber, per mile, per month

Extension from Backbone: Customer bears total construction cost to extend fiber optic cable from fiber optic backbone to designated demarcation point on customer's property

Fiber Maintenance fee: \$0.078 per foot of extension (total extension length, not fiber optic strands leased).

MED bears responsibility for maintenance and repair of the fiber optic network.

Source: <https://murfreesboroelectric.com/wp-content/uploads/2018/08/Guidelines-for-Dark-Fiber-Leasing.pdf> Dated: August 1, 2018

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