Comparing Broadband Network Architectures in the Evolving Connectivity Landscape

Peter Fetterolf, Ph.D.

Executive Summary

This whitepaper provides a comprehensive analysis of the economic viability of various broadband network architectures in the evolving connectivity landscape. With an increasing demand for high bandwidth, network operators are exploring efficient ways to deploy fiber to homes and businesses across diverse geographical regions. The study examines three primary architectures: the traditional chassis-based PON (PMO1), the closed pizza box PON (PMO2), and the Ciena broadband solution powered by integrated router, uOLT and coherent pluggable (FMO). The evaluation focuses on the total cost of ownership (TCO), considering not only the initial capital expenditures (CapEx) but also the operational expenses (OpEx) over time.

Ciena's FMO solution stands out for its innovative integration of OLT and IP aggregation router into a single network element, delivering significant cost savings, especially in low-density and medium-density environments. The TCO analysis reveals that Ciena's solution can provide up to 43% savings in TCO in low-density scenarios when compared to the chassis-based architecture. Even in high-density contexts, where the chassis-based solution may have a slight edge in CapEx in a full fill scenario, which is not always the case, Ciena's model still offers substantial operational efficiencies. Against the closed pizza box architecture, Ciena's FMO solution shows consistent savings across all densities, highlighting its adaptability and long-term economic benefits. The whitepaper underscores the strategic advantage of Ciena's architecture, offering network operators a scalable, cost-effective, and future-proof solution in the competitive broadband market.

Overview

In the quest for extensive broadband connectivity, many network operators are leveraging a mix of Passive Optical Network (PON) and IP aggregation networks to service diverse geographies—rural, suburban, and urban. PON fiber access to homes and businesses typically uses IP aggregation networks consisting of fiber rings capable of 100G to 400G speeds. In the United States, initiatives such as the FCC Rural Digital Opportunity Fund and Broadband Equity, Access, and Deployment have spurred the growth of such networks, especially in underserved and unserved communities previously dependent on limited bandwidth solutions such as DSL or satellite services. These areas are now transitioning to high-performance, fiber-based services thanks to government-funded projects. Architecturally, while rural PON networks must cater to a sparse population over wide areas, suburban and urban networks handle denser populations with differing requirements. This paper discusses the various architectural approaches to constructing these networks and evaluates the economic implications of each.

Architecture Alternatives

Broadband networks are sophisticated ecosystems that consist of an array of technical components designed to provide end-to-end service. Figure 1 illustrates the key elements of such a network, which will be pivotal in discussing the architecture alternatives. Figure 1 also specifies the core and optional elements of the TCO model. In this paper we focus on the core elements.

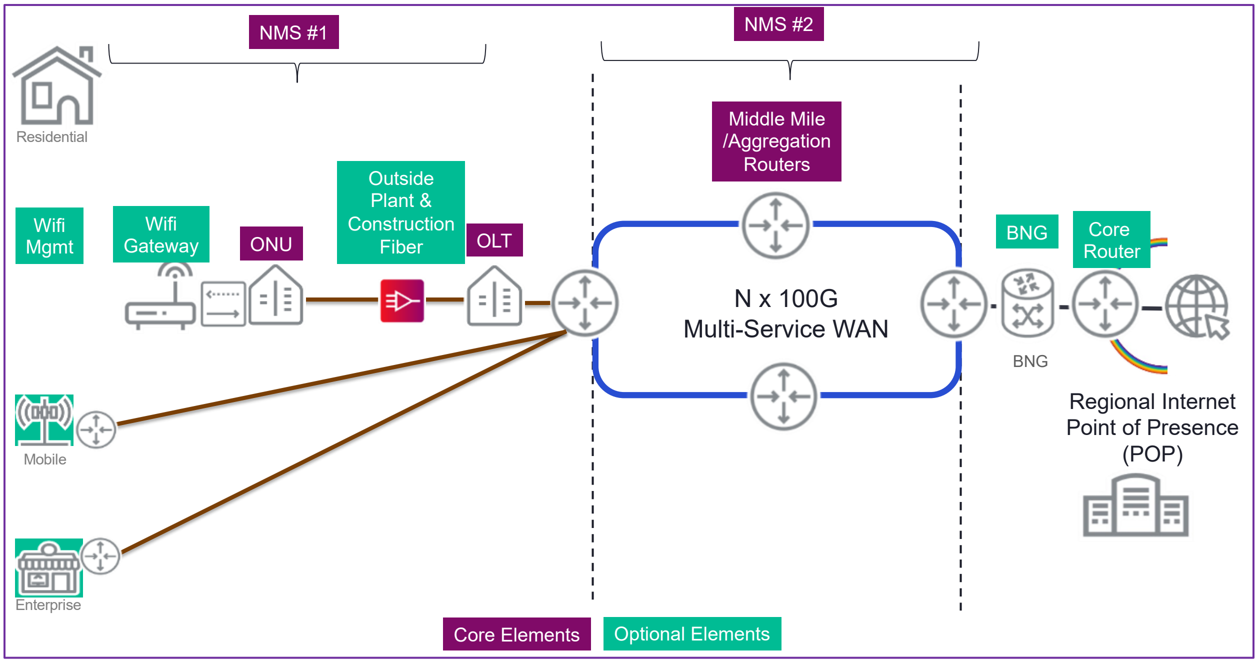

Figure 1. Access and Aggregation Network Architecture and Business Model Elements

Central to the architecture is the outside plant and construction fiber, which connects to the optical line terminal (OLT). The OLT is a critical component, serving as the service provider's endpoint of a PON. The diagram also features optical network units (ONUs) and WiFi gateways within the customer's premises, indicating the endpoint of the PON and the starting point for in-home WiFi, respectively.

An essential part of the architecture is the network management systems (NMS #1 and NMS #2), which oversee the operational aspects of the various network domains. These systems are integral for customer and services implementation, maintaining the health of the network, managing configurations, and troubleshooting issues. Either one or two NMS systems are required, depending on the PON and aggregation network solution.

The network further extends to the aggregation network with aggregation routers, which are responsible for directing traffic from the access network to the core network. These routers are connected in a ring topology, presumably to ensure redundancy and high availability, with each ring capable of supporting Nx 100G multiservice Wide Area Network (WAN) connections.

The broadband network gateway (BNG) is another crucial element, which controls users' authentication, access to the IP network, allocates resources, routes traffic, and potentially provides additional services such as quality of service. It is indicated that there can be a regional BNG setup, which may entail either centralized or virtualized and disaggregated BNGs. The latter would suggest the use of control and user planes separation, allowing for scalable and flexible service management. The core router stands as the backbone of the network, facilitating the connection to the regional Internet point of presence (POP), which then connects to the wider internet.

We compare three architecture alternatives using these components:

1. **PMO1: Chassis-Based PON Architecture:** This traditional approach separates the routing network from the PON access network, often involving different vendors and management systems. It uses a chassis-based OLT with line cards, suited for high-density urban environments but less efficient for scaling down.

2. **PMO2: Closed Pizza Box PON architecture:** Like PMO1 in terms of vendor and management separation, this architecture uses a pizza box model for the OLTs, which are stackable and provide a compact solution for high-density areas. However, this also faces challenges in scaling efficiently to less dense regions.

3. **FMO: Ciena Broadband Solution:** This innovative approach integrates the OLT directly into the router using pluggable optics. It allows ports to be added individually and offers a single-vendor, single NMS solution. This architecture is cost-effective, scalable across different densities, and allows easy upgrade paths, such as scaling to 25GS-PON with a pluggable optic. This solution also includes a perpetual software license, helping customers avoid the OpEx trap created by a subscription-based model.

These alternatives form the basis of our analysis in the TCO model, considering the implications of their deployment in various density environments and their impact on the economic and operational aspects of network deployment and management.

PMO1: Chassis-Based Architecture

The PMO1 architecture represents a chassis-based approach to FTTH networks. In Figure 2 this architecture is characterized by a clear separation between the OLT and the middle-mile aggregation routers, each managed by its own network management system (NMS).

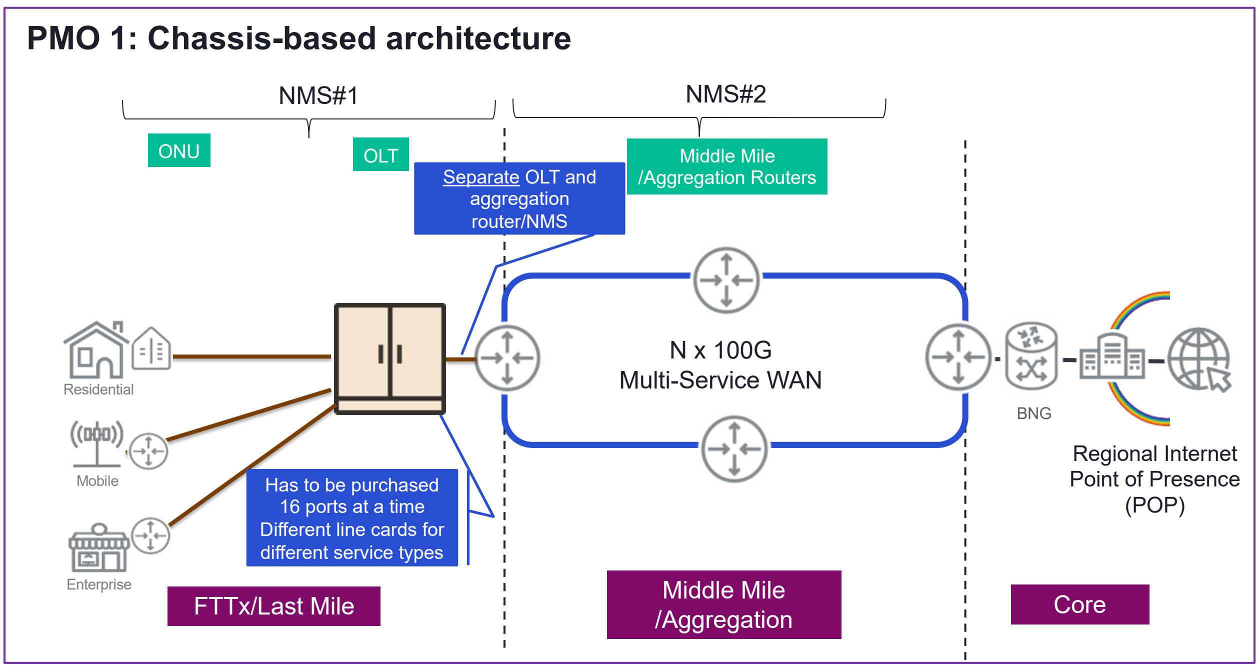

Figure 2. PMO1 Chassis-Based Architecture

In this setup, the OLT is housed in a large chassis that incorporates multiple line cards. These cards are modular, allowing for the addition of ports in increments, typically of 16. This method implies that service providers must anticipate demand and scale in relatively large steps, which can be cost-inefficient for areas with a slowly increasing subscriber base.

The OLT connects to the optical network units (ONUs) located at the customer's premises through the fiber to the last mile. The ONU is the demarcation point between the provider's network and the customer's in-home network, usually offering Ethernet or WiFi connectivity to the end-user’s devices such as phones, computers, and IoT devices.

Aggregation occurs in the aggregation/middle-mile part of the network, where traffic from multiple OLTs is directed through aggregation routers connected in a ring topology supporting 100G speeds. This ring structure is designed for redundancy and robustness, ensuring that the network can maintain service even if a single point fails.

The separate OLT and middle-mile aggregation router approach requires investment in line cards for different service types, potentially leading to underutilization if demand forecasting is inaccurate. The need for separate NMS for the OLT and the aggregation routers adds complexity to the network management, requiring operators to maintain expertise across different systems and potentially leading to higher operational costs.

This architecture is typically suited to scenarios where a high density of users can justify the investment in a chassis-based system, which is often the case in urban environments. However, its rigidity in scaling and the need for separate management systems can make it less economical in areas with more diverse or fluctuating service demands.

PMO2: Closed Pizza Box-Based Architecture

The PMO2 architecture, depicted in Figure 3, utilizes a closed pizza box-based design for the deployment of FTTH networks. This model emphasizes a modular approach in which the PON OLT devices, resembling the form factor of a pizza box, are stacked to scale the network capacity.

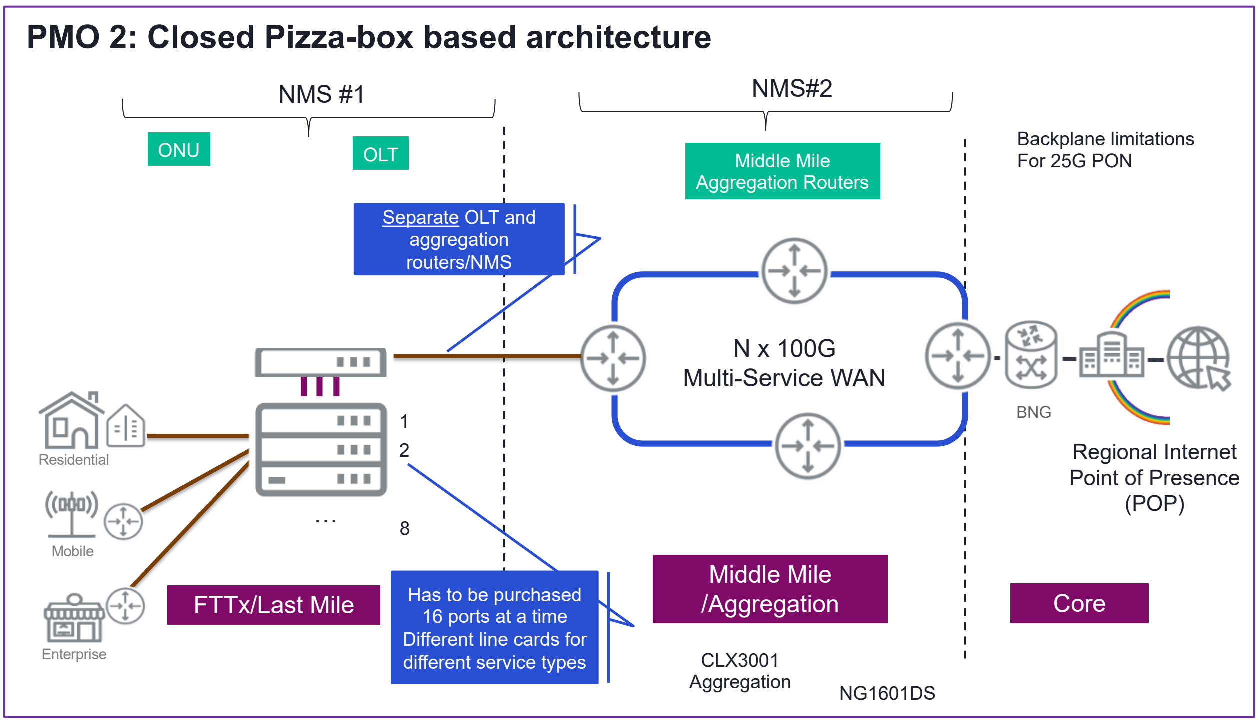

Figure 3. PMO2 Closed Pizza-Box Architecture

The following are the characteristics and implications of this architecture:

- **Separation of Elements**: The routing network and PON access network are distinct entities, often managed by different vendors and NMS. This separation can introduce complexities in network operations due to the need to coordinate between different systems.

- **Pizza Box OLTs**: The pizza box OLTs are standalone devices that can be stacked to increase capacity. Each device operates independently, which allows for a modular expansion of the network. However, this can also lead to increased physical space requirements and energy consumption as more boxes are added.
- **Port Purchases**: Like the chassis-based architecture, ports on pizza box OLTs are typically procured in increments of 16, which may not align with the granular growth patterns in medium- or low-density areas. This can result in inefficient capital expenditure with unused capacity.
- **Multiple NMS Systems**: Managing the network requires multiple NMS systems due to the separate components involved. This can increase operational complexities and staffing requirements, as technical teams need to be proficient in several systems.
- **Urban Design Focus**: Although this architecture is optimized for high-density urban areas, its scalability is not as efficient when transitioning to medium- or low-density suburban or rural areas. This limitation can result in higher costs per user in less dense environments due to underutilized capacity.
- **Subscription Model Licensing**: The OpEx for this architecture grows linearly with the number of users due to the subscription model licensing, which could be less economical as the user base expands. It is an OPEX trap that may appear less expensive but the cost grows very rapidly with the customer base.
- **Costly Evolution**: Upgrading or evolving the network infrastructure, particularly the access network components, can be costly. Replacing pizza box OLTs entails removing existing units and deploying new ones, which not only affects capital expenditure but can also lead to service disruptions during the transition.

The PMO2 closed pizza box-based architecture provides a modular and scalable solution for dense urban environments. However, its efficiency diminishes in lower-density settings, with economic and operational challenges arising from the inflexible scaling increments, the need for multiple management systems, and the linear growth in operational expenses. As network operators look to the future, architectures that allow for more granular scaling and integrated management could offer more sustainable economic models, particularly in diverse geographic settings.

FMO: Ciena Broadband Solution

The FMO architecture, as illustrated in Figure 4, is Ciena's innovative solution to FTTH networks that streamlines the traditional multi-component network design into a more integrated and scalable system.

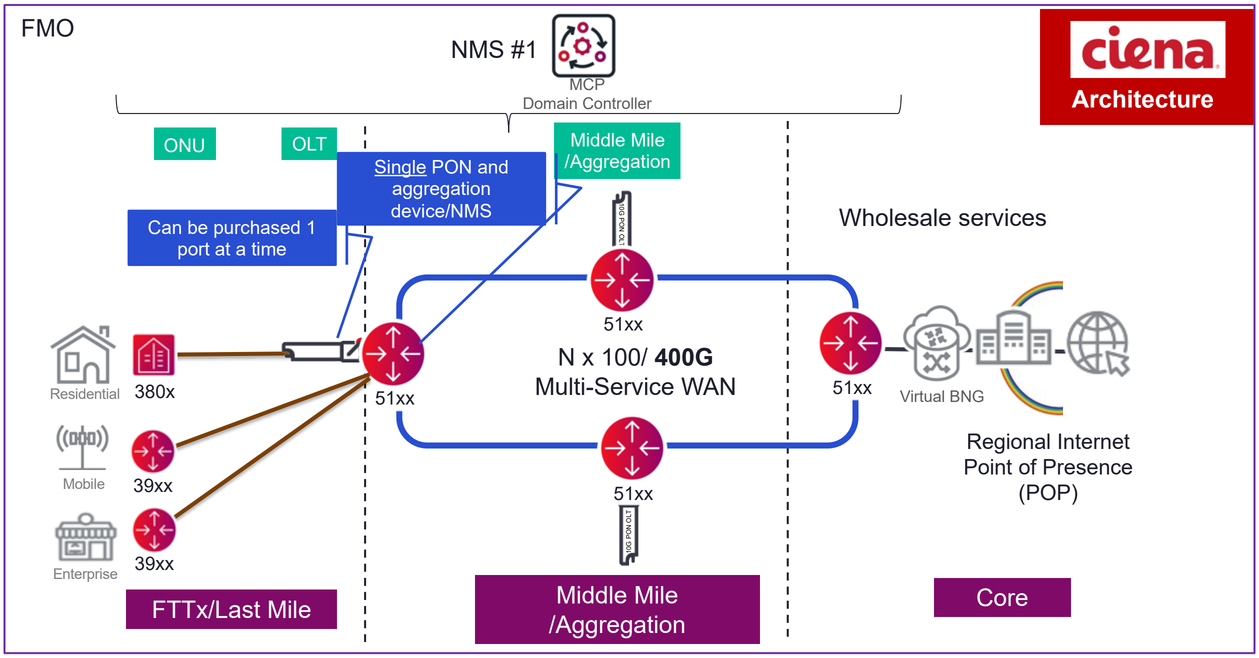

Figure 4. Future Mode of Operation with Ciena Integrated PON and Router Solution

This solution is characterized by several key advantages that stem from its unique architecture:

- **OLT on a Chip with Pluggable Optics:** Ciena's architecture employs an OLT on a chip, which utilizes pluggable optics technology. This integration allows for a more compact and energy-efficient design, reducing the physical footprint of network hardware.
- **Integrated OLT and Router:** Unlike traditional architectures that separate the OLT and router, Ciena's solution integrates the OLT directly into the router. This not only saves space and power but also simplifies network management and operations.
- **Granular Port Addition:** One of the most significant advantages of this architecture is the ability to add ports one at a time. This allows for precise scaling that aligns with customers' demands, avoiding the upfront costs of unused capacity that comes with purchasing ports in larger increments.
- **Single Vendor Provisioning:** The entire PON and router solution is provided by Ciena, which can offer benefits such as simplified procurement, integrated support, and streamlined software upgrades.
- **Unified NMS:** A single network management system manages both the PON, IP aggregation and optical transport, simplifying network operations, reducing training requirements, optimizing network resources utilization and potentially lowering operational expenditures.
- **Cost-Effective for Various Densities:** The architecture is designed to be economically viable across different network densities. Its scalability and cost-effectiveness are particularly advantageous in rural networks where the hardened and weatherproof form factor is essential.
- **Urban Network Scalability:** Although optimized for cost in rural settings, Ciena's architecture is also capable of scaling up to meet the demands of high-density urban broadband networks.
- **Perpetual License:** The licensing model is perpetual, avoiding recurring costs that can escalate with other subscription-based models.

- **Disaggregated BNG**: The Broadband Network Gateway is disaggregated, meaning that the user plane and control plane can scale independently. This provides flexibility in network management and can lead to better resource utilization.
- **Simplified Evolution Path:** As network demands grow, evolving the network is as simple as adding a 25G pluggable to transition to 25GS-PON, which is a straightforward and cost-effective upgrade path, protecting network operators' investments.

The FMO Ciena architecture represents a paradigm shift in designing and operating broadband networks. It addresses many of the limitations found in traditional architectures by offering a simplified, scalable, and cost-effective solution suitable for the diverse needs of modern telecommunications networks. Whether for low-density rural areas or high-density urban environments, Ciena's solution delivers both economic and operational efficiencies.

TCO Model Assumptions

The TCO analysis considers various services such as business PON, residential PON, and different Ethernet services, along with backhaul for mobile networks. The assumptions cover greenfield network deployments with service growth projected over five years, segmented into low-density, medium-density, and high-density networks. Traffic assumptions apply uniformly across these densities, factoring in an annual growth rate of 12%.

For all types of networks (low, medium, and high density) the following traffic assumptions are used:

- Business PON average peak traffic: 25Mbps and 12% growth rate
- Residential PON average peak traffic: 14.2 Mbps and 12% growth rate
- Business 1G Ethernet: 200Mbps and 12% growth rate
- Business 10G Ethernet: 2000 Mbps and 12% growth rate
- Mobile 10G Backhaul: 800 Mbps and 12% growth rate

The number of subscribers in each access central office for each type of region is provided in Table 1.

Service	Low Density Subscribers per Access Node	Medium Density Subscribers per Access Node	High Density Subscribers per Access Node
Residential PON	300	1,600	16,000
Business PON	50	50	1,000
10G Business Ethernet	1	1	10
1G Business Ethernet	3	3	300
10G Mobile Base Station Backhaul	0	0	10
25G Mobile Base Station Backhaul	0	0	5

Table 1. Number of Subscribers in Each Access Central Office for Different Network Densities

For each type of network deployment (low, medium, high) compare the TCO of 3 scenarios:

- PMO1
- PMO2
- FMO Ciena

TCO Results

Ciena's solution emerges as the most economically viable with the lowest TCO, because of the integration of the aggregation router and OLT into a single network element at the aggregation POP. This integrated approach simplifies network architecture and reduces the need for multiple network elements, which is particularly cost-effective in low-density deployments. However, the economic benefits extend across medium-density to high-density networks as well, making Ciena's solution scalable and adaptable to various deployment scenarios. The savings of the Ciena integrated architecture as compared to the PMO1 chassis architecture is presented in Table 2, and a comparison of Ciena with PMO2 pizza box architecture is presented in Table 3.

	Low Density	Medium Density	High Density
TCO	43% Savings	35% Savings	-1% Savings
OpEx	69% Savings	65% Savings	18% Savings
CapEx	29% Savings	26% Savings	-10% Savings

Table 2. TCO Savings of the Ciena FMO Solution as Compared to PMO1 (Chassis Architecture)

	Low Density	Medium Density	High Density
TCO	31% savings	14% savings	23% savings
OpEx	55% savings	38% savings	23% savings
CapEx	21% savings	9% savings	22% savings

Table 3. TCO Savings of the Ciena FMO Solution as Compared to PMO2 Closed Pizza Box Architecture

The comparative analysis of TCO for Ciena's FMO solution against traditional PMO1 and PMO2 architectures yields insightful economic implications across various network densities. The summary of results is as follows:

Against PMO1 (Chassis Architecture):

- **Low Density:** Ciena's FMO solution offers a substantial 43% savings in TCO, with operational expenses being 69% lower and capital expenditures reduced by 29%.
- **Medium Density:** The savings in TCO stand at 35%, with OpEx and CapEx savings of 65% and 26%, respectively.
- **High Density:** The FMO solution provides -1% savings in TCO, indicating a slightly higher cost than the PMO1 architecture. However, it still offers an 18% reduction in OpEx but with a -10% savings in CapEx, suggesting an initial higher investment cost. (It should be noted that this scenario assumes high port utilizations that sometimes are not achieved due to OLT NNI capacity limitations.)

Against PMO2 (Closed Pizza Box Architecture):

- **Low Density:** The FMO solution demonstrates a TCO savings of 31%, with a 55% reduction in OpEx and a 21% reduction in CapEx.
- **Medium Density:** TCO savings are at 14%, accompanied by a 38% reduction in OpEx and a 9% savings in CapEx.
- **High Density:** Ciena's FMO solution shows a more pronounced advantage with a 23% TCO savings, and both OpEx and CapEx savings are at 23% and 22%, respectively.

These results indicate that Ciena's broadband solution is particularly effective in low-density and medium-density environments, offering significant savings in both operational and capital expenses. Although the solution also provides benefits in high-density scenarios against the PMO2 architecture, its performance relative to PMO1 suggests a nuanced consideration where the FMO solution may incur slightly higher costs but still offers operational efficiencies.

The distinct reduction in OpEx across all densities and architectures highlights the efficiency of Ciena's FMO solution in network operation and maintenance, which can be a critical factor for network operators when considering long-term sustainability and profitability. The mixed results in CapEx indicate that initial infrastructure investment decisions may vary based on network density and the existing architecture.

The FMO solution by Ciena presents a strong economic case for network operators with the potential for substantial cost savings and operational efficiencies, particularly in less densely populated areas. The scalability of the Ciena solution also makes it a competitive option for high-density deployments in both scenarios with clearer benefits when compared to the closed pizza box architecture.

Conclusion

The deployment of broadband networks is an intricate endeavor that requires network operators to balance the immediate need for high-bandwidth services with the long-term sustainability of their network infrastructure. The findings of this whitepaper suggest that Ciena's broadband solution is a formidable contender in this space, providing scalable and cost-effective network architecture that caters to the diverse requirements of rural, suburban, and urban geographies. By integrating the OLT into the aggregation router and enabling the use of pluggable optics, Ciena offers a solution that significantly reduces both OpEx and CapEx, particularly in low-density to medium-density areas.

The analysis also indicates that although traditional PMO1 and PMO2 architectures may have their niches, particularly in high-density settings, they often incur higher operational costs and lack the agility to scale efficiently across varying densities. Ciena's broadband solution, with its single-vendor provision, unified NMS, and simplified evolution path, not only meets current technological demands but also positions network operators to seamlessly adapt to future advancements with minimal additional investment.

This whitepaper affirms that Ciena's broadband solution provides network operators with a powerful tool to meet the increasing demand for fast, reliable internet service while ensuring economic efficiency and operational excellence. It is a strategic investment that promises to keep pace with the rapid evolution of technology and users' expectations, solidifying network operators' market positions and supporting the growth of their customer base.

For network operators now considering various architecture for their broadband deployments, the ACG BAE Tool that was used to develop the results of this whitepaper can be applied to fit a service provider's particular market density (small, medium or high density) and the specific rollout for broadband that the network operator is forecasting. Contact your Ciena sales representative to learn more.

Peter Fetterolf

Peter Fetterolf, Ph. D. is an expert in network technology, architecture and economic analysis. He is responsible for financial modeling and whitepapers as well as software development of the ACG Research Business Analytics Engine. Dr. Fetterolf has a multidisciplinary background in the networking industry with over thirty years of experience as a management consultant, entrepreneur, executive manager, and academic. He is experienced in economic modeling, business case analysis, engineering management, product definition, market validation, network design, and enterprise, and service provider network strategy.