



Intelligent PON Node

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21 December, 2009

Abstract

Service providers face a variety of common problems in deploying higher-performance access network offerings to businesses, cell-tower backhaul, and residential subscribers that largely boil down to the need to be able to economically support communications over longer distances, to more customers, over a finite fiber plant. Traditional solutions to these problems include installation of new trunk/feeder fibers, optical amplifiers, remotely-locating central office equipment in the field, or the use of specialized optics. Teknovus' Intelligent PON Node provides a comprehensive, cost-effective solution that leverages commonly-available components in a dense and low-power form factor that addresses all of these situations.

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1. Executive Summary

Service providers face a variety of common problems in deploying higher-performance access network offerings to businesses, cell-tower backhaul, and residential subscribers that largely boil down to the need to be able to economically support communications over longer distances, to more customers, over a finite fiber plant. Traditional solutions to these problems include installation of new trunk/feeder fibers, optical amplifiers, remotely-locating central office equipment in the field, or the use of specialized optics. Teknovus' Intelligent PON Node provides a comprehensive, cost-effective solution that leverages commonly-available components in a dense and low-power form factor that addresses all of these situations.

The paper begins with an overview of service provider problems and market drivers, followed by a discussion of available (and not so available) solution options. The Intelligent PON Node is introduced along with several use case examples, its potential Revenue, CapEx, and OpEx impacts, and a comparison model of North American deployments.

2. Market Drivers

Higher speed Internet access, triple-play with HDTV delivery, fixed-mobile convergence, and 3G/4G rollout are familiar market drivers of next-generation access networks. EPON is increasingly recognized to be the most viable solution, with over 30M subscribers deployed by the end of 2009. But problems remain that, once addressed, will enable support for many otherwise economically-unreachable businesses, cell-tower backhaul, and residential customers.

The fundamental problems are a combination of three factors:

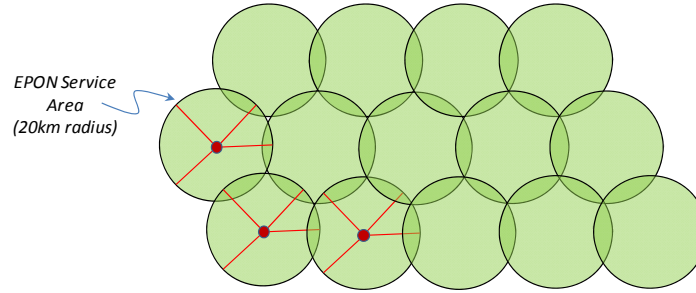
1. **Split ratio**: the need to serve more subscribers from the service provider's OLT ports;
2. **Service reach**: the need to increase the distance that may be supported between the service provider's facilities and the subscriber;
3. **Limited availability and/or capacity of trunk/feeder fiber**: the need to serve more subscribers without installing more fiber.

Even cable-TV multiple system operators (MSOs) who have extensive preexisting fiber networks face practical issues such as these in their choice of PON technology and deployments.

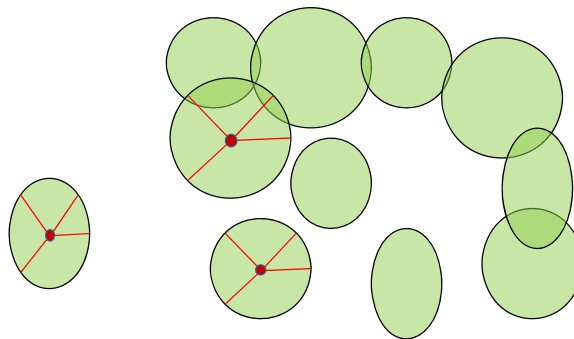
Some common examples:

- **Fill Service Gaps** – A significant percentage of potential subscribers are at a longer distance between termination points than typical 20km PON networks. It is estimated that 20%-30% of potential MSO subscribers in the U.S. are more than 20km away from the head-end where the OLT would typically be located. And some carriers want to consolidate central offices in order to save costs of power, facilities and personnel – exacerbating the situation.

An “ideal” coverage strategy offers 100% coverage with minimal overlap:

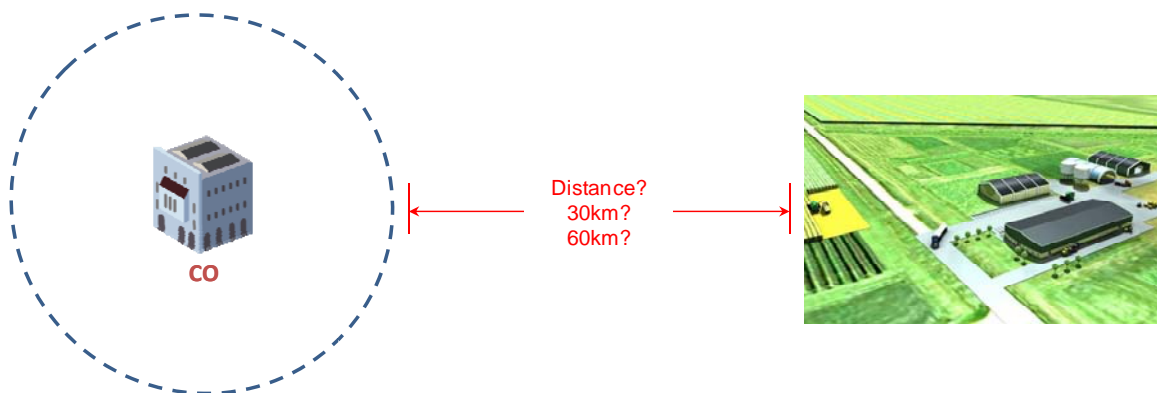


As a practical matter, due to central office locations (distance to subscribers), geography, local zoning, and right-of-way, service maps illustrate service availability gaps:

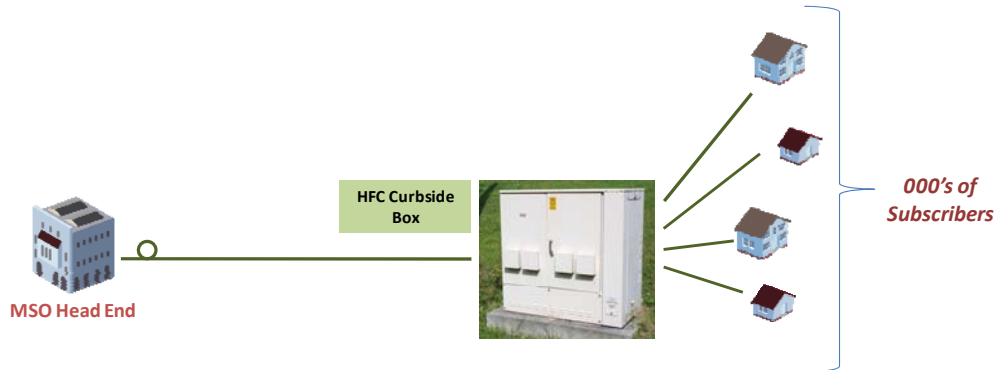


In a metropolitan area the gaps may miss revenue opportunities with hundreds of potential residential, business services, and backhaul subscribers.

- **Rural Deployments** – Rural customers are often difficult to serve economically due to their distance from the central office and low area density which limit economical amortization of the OLT ports and insufficient utilization of trunk fiber. Although urban and suburban subscribers offer the most attractive market because of their density, rural customers (residential and enterprise) offer important incremental revenue opportunities.

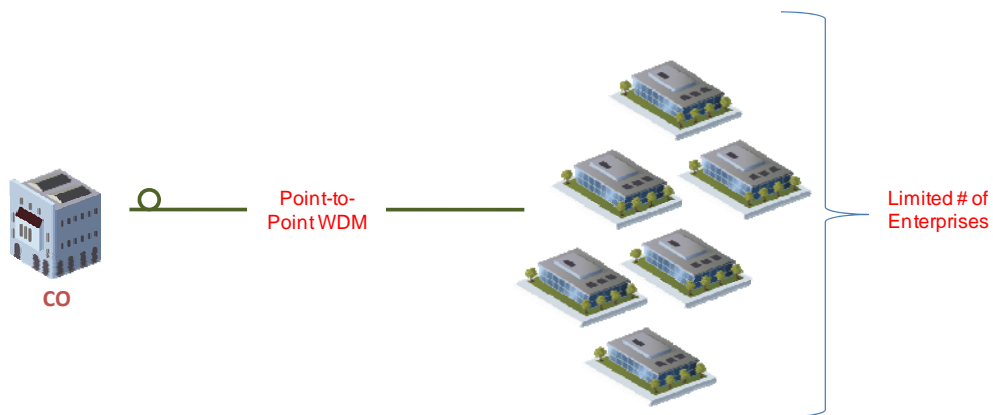


- MSO/HFC Subscriber Coverage** – A typical PON ODN (optical distribution network) is expected to serve 32-64 subscribers, whereas HFC plants have much larger serving groups (as measured by households passed), driving the need for larger PON OLT:ONU split ratios, which are limited by the optical power budget and distance between OLT and ONUs.



- Limited Fiber Availability and Capacity** – although installed fiber capacity was at one time thought to be over-built and underutilized, the demand for business, residential, and backhaul services has grown at rates that have or will soon exhaust current supply.

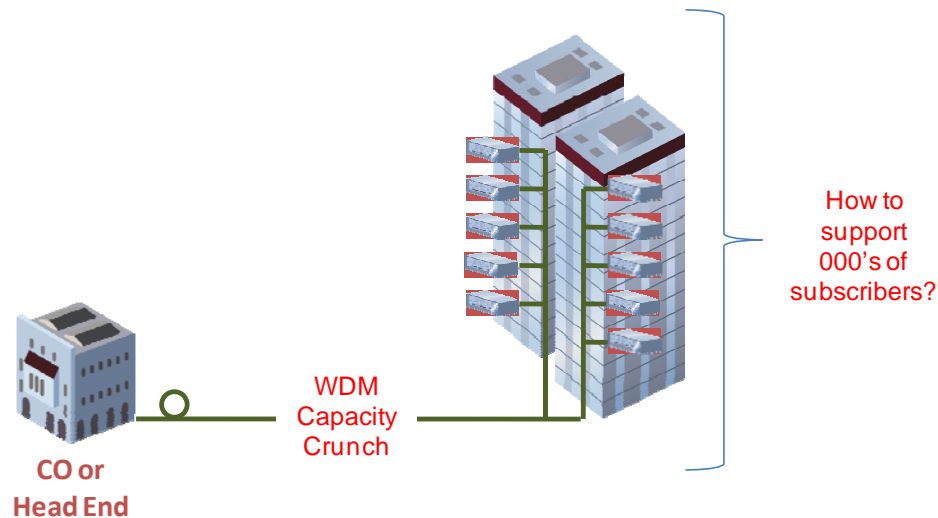
For example, business and enterprise customers have been supported with point-to-point (P2P) links, providing high connection speeds, reliable service level agreements (SLAs), and long distances. However, even using WDM, the number of clients that may be supported is limited to the number of wavelengths available, and as more enterprises request service the fiber resources are being depleted.



Use of WDM to extend P2P trunk fiber capacity also introduces the problem of wavelength/lambda “inventory management”: allocating and tracking assigned wavelengths, stocking and equipping field technicians with a variety of wavelength-specific optical transceivers, and coordinating installation of compatible colors at both ends of the link – adding a significant increase to OpEx costs.

- Deploying FTTH in High-Density Residential Applications** – Although Multiple Dwelling Units (MDUs) present the highest concentration of residential subscribers (with an FTTH fiber to each unit), MSOs interested in deploying PON over the fiber plant may also face limited resources.

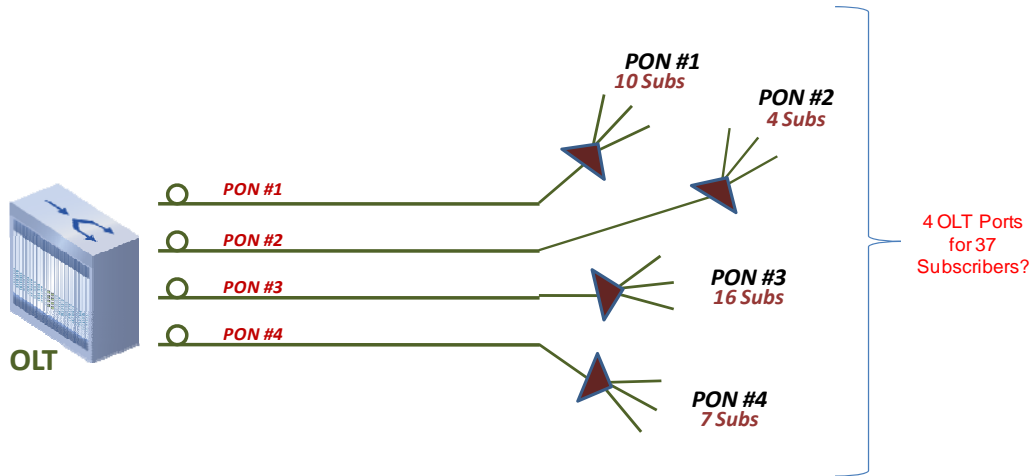
As with HFC/SFR (single-family residence) service, MDU plants may need to support hundreds of subscribers with trunk fiber capacity that had been sized accordingly for traditional cable-TV. And while a remotely-located (e.g., MDU basement) OLT would enable the use of WDM over the trunk (thus expanding its subscriber capacity), R-OLTs add significant CapEx and OpEx expense due to their higher complexity, installation requirements (environmental, security, power), and maintenance.



Multi-System Operators (MSOs) in North America deploy “fiber nodes” at the end of their optical distribution networks (FNs) with 2-6 fibers to serve 400-500 households. In this case, the number of trunk fibers needed may be estimated in a couple of simple ways:

- **Bandwidth/Subscriber**
How much average bandwidth will be provided to each subscriber, and is there a sufficient quantity to rationalize the use of statistical multiplexing to oversubscribe the network? These are challenging questions particularly as the market moves from DSL/DOCSIS speeds to rates that support HD-IPTV. As an example, if an FN’s subscribers are allocated 30Mbps, and there are 300 subs (60% take rate), this would require 9,000Mbps. With an EPON supporting 1Gbps, this bandwidth would require 9 trunk fibers – significantly more than are usually available.
- **Split-Ratio**
Another important consideration is the fiber “split ratio,” which defines the maximum number of individual subscribers supported for each trunk. The typical split ratio for PON is 32. Increasing this number reduces the optical link budget and distance that standard optical lasers and receivers can support. Thus, at a 1:32 split ratio 300 subscribers would require 10 (integer value of $300/32 = 9.38$) trunk fibers.

- Optimizing ODN/PON Economics** – New deployments begin with a foundation of OLT installations in central offices, enabling carriers to cultivate new customers and build the subscriber base. Until the number of subscribers reaches a minimum threshold (which is different for every carrier and locale) the amortized cost/OLT port and trunk fiber over a limited number of subscribers may be uneconomical and difficult to finance.



While not insurmountable, these issues present expensive technical and operational challenges that may hinder deployments, subscriber additions, or return on investment. Obvious solutions abound, from installing new fiber, adding amplifiers, and deploying remote OLTs.

Solution Options	Install More Trunk Fiber	Add Amplifiers to ODN	Deploy Remote OLTs
Service Gap Fill	✓	✓	✓
Rural Deployments		✓	✓
HFC Subscriber Coverage	✓		✓
Expand Enterprise Ethernet Base	✓		
MDU FTTH	✓		✓

2. Solution Alternatives

There are several obvious “solutions” that present a variety of operational and economic problems that lead to increasing CapEx and OpEx:

- Installing New Trunk Fiber** – The most direct approach to the problem of reach and coverage is to simply add additional fibers from the hub-site/central-office to the distribution node. While this is easy to conceive, the economics and logistics for this approach are prohibitive to most operators at least until Greenfield developments enable early access to cable burial, pole mounts, and building access provisioning. For example, the cost of pulling new fiber ranges from \$10K to \$40K/mile, not including basic infrastructure (utility poles, trenches, conduit).

- **ODN Amplifiers** – Optical only and Optical-Electrical-Optical amplifiers are available that blindly repeat signaling on the fiber, extending service reach. As a practical solution, however, remote management (for operational monitoring and fault diagnosis) is limited and requires an additional management module integrated into the service provider’s EMS/NMS.

There are two main amplifier types, Semiconductor Optical Amplifier (SOA), and Erbium Doped Fiber Amplifier (EDFA), that have very different characteristics and capabilities:

Feature	SOA	EDFA
Operating Wavelength Range	Wide	Narrow (~30nm): DWDM
Supports Burst Mode	Yes	No: incompatible with upstream ONU transmissions, required for PON TDMA
Works in Standard EPON	Yes	No: Optical transceivers must be changed to DWDM wavelengths
Supports WDM	No: suffers from severe crosstalk	Yes
Performance	High noise, relatively low gain = short distance extension capability	
Affect on Network CapEx		Increased due to need for more costly DFB lasers in ONU (instead of FPs), and non-standard wavelengths
Commercially Available	Advertised yet not readily available; very limited trial deployments	Yes, although not currently compatible with PON

In summary, SOAs are not appropriate due to their limited distance extension performance, inability to support WDM, and lack of availability; EDFAs are not economical or practical due to the need for non-standard/high-cost optics and lack of support for burst mode TDMA communications.

- **Remote OLTs (R-OLTs)** – Particularly for high-density deployments such as FTTH within MDUs, a remote OLT is appealing. WDM could be used to multiplex multiple PONs onto a small quantity of trunk fibers to the basement-located OLTs, which would then employ a traditional hub and spoke architecture to the home units. In general, though, MDU management companies are reluctant to house expensive, large, and power hungry equipment whenever possible. The service providers, too, must add costly WDM functionality to both ends of the trunk, along with associated management infrastructure.

MSOs also consider using R-OLTs in fiber nodes, yet even without trunk fiber considerations face important obstacles to their use, including:

- The fiber node enclosures are physically small and often cannot house the quantity of R-OLTs needed to service the households passed (HHP) density.
 - High CapEx: R-OLTs are complex, providing full Layer-2 MAC functionality, remote management, traffic management, and network security. The low trunk utilization of R-OLTs and high cost of head-end/edge router ports drives providers to add L2 aggregation switches in front of the edge router, adding to CapEx costs and complicating QoS and SLA management.
 - High OpEx: By their nature, R-OLTs draw more power and have higher failure rates.
- **Alternative Optics** – The use of specialized (high-power and/or WDM) optics is also sometimes considered as a way to increase fiber reach or subscriber capacity. “WDM PON” refers to ONUs that run on different lambda pairs than are supported by standard PONs. This means that a single fiber can support multiple PONs (thus more subscribers), which increases the fiber’s effective bandwidth capacity and split-ratio.

These options are quickly discarded due to obvious disadvantages, including:

➤ **Non-Standard = Higher Cost**

The IEEE standards do not provide specifications for higher-power or multiple WDM wavelengths for EPON, particularly with support for upstream burst mode operation. Even if the base components may be borrowed from P2P or other applications, they will not reach the scale economies of mainstream optics modules.

➤ **Higher-Power = Increased Deployment Complexity**

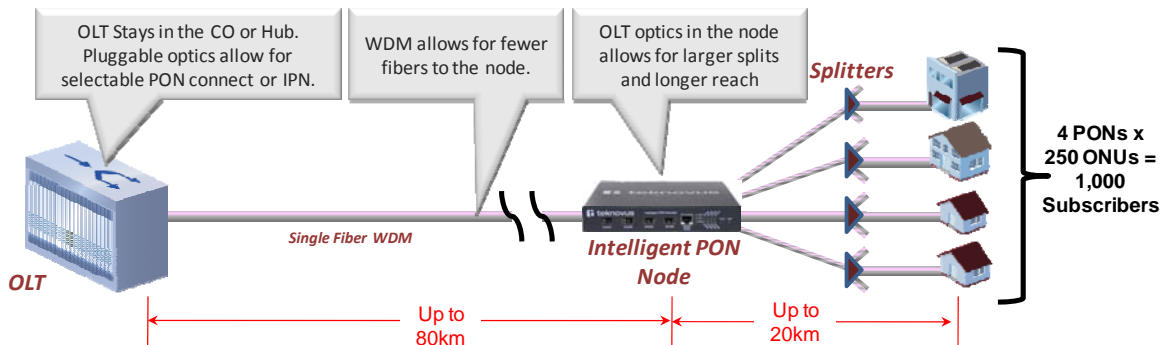
Transmitter power is matched to receiver sensitivity to seamlessly support communications over the standard 10km or 20km service areas. Introduction of higher-power optics will necessitate the use of attenuators for shorter-distance subscribers and/or prevent deployment of mixed-distance (short vs. long) networks. Field technicians would need to be equipped with additional test and installation components.

➤ **Inventory Management Complexity and Cost**

Since specialized optics will always cost more than standard units, service providers will need to stock a larger variety of OLTs, ONUs, and optics – thus complicating inventory management and leading to higher operating expenses. “Tunable” lasers may someday be available, but at what cost? And they will still require use of selectable receive filters to avoid interference between shared-fiber PONs.

3. Introducing the Intelligent PON Node

Teknovus has developed a new system – the “Intelligent PON Node” (IPN) – that provides a service-transparent solution that supports distance extension, service gap filling, expanded service coverage for MDUs and cable MSOs, increased trunk fiber capacity, and remote reconfiguration/load-balancing for optimizing OLT:ONU split ratios. The IPN is flexible, manageable, physically small, and consumes low-power: ideal for basement, pole-mount, and curbside installations:



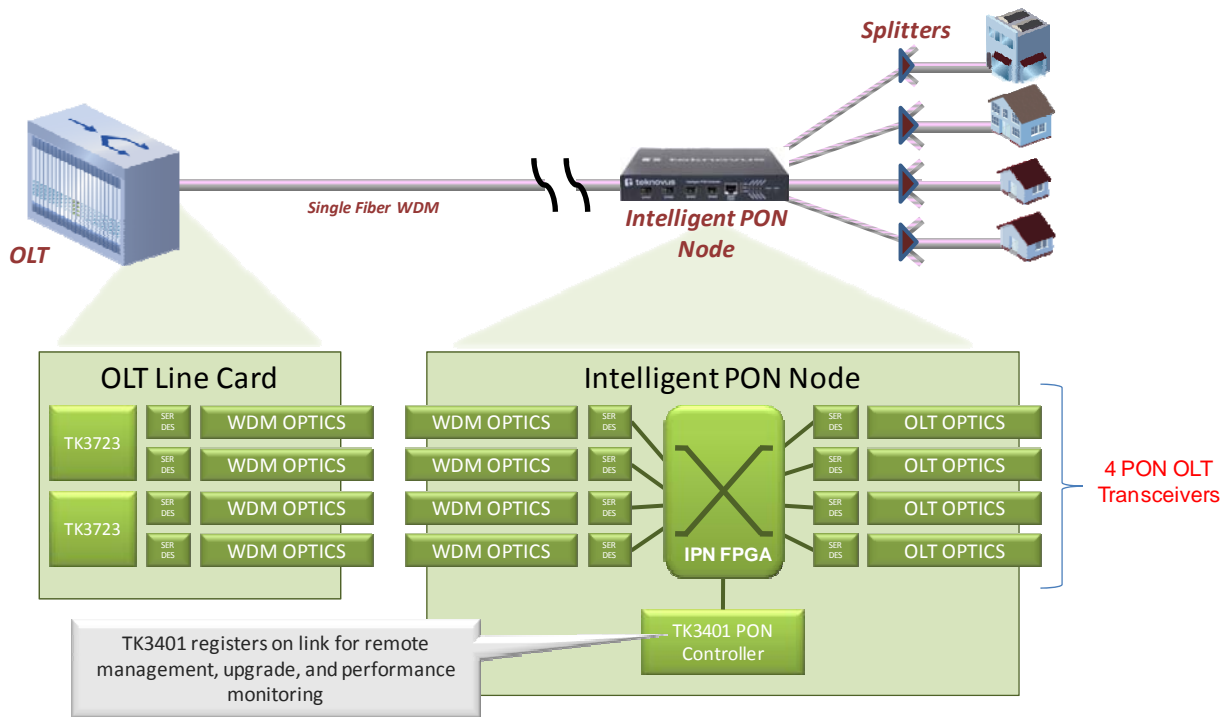
With the IPN, the OLT remains in the hub or central office. Off-the-shelf WDM optics may be inserted directly into OLT ports, providing the long-distance reach to the IPN and multiplexing of multiple PONs onto a single fiber. For the PON side of the IPN, conventional OLT optics provide either 1Gbps or 2Gbps EPON communications to downstream ONUs, located up to 20km away.

- **Intelligent PON Node Features and Benefits**

Features	Benefits
20-100km distance from OLT to ONU	Enables economical support of subscribers that would otherwise be out of the EPON service area
OLT may use continuous transceivers or PON transceivers on the trunk side	Use of standard PON transceivers allows operation as a conventional EPON OLT; continuous mode optics enables trunk fiber capacity expansion to >500 subscribers
Fully manageable, with support for multiple fibers between OLT and IPN for fast protection switching, remote diagnostics, loopback, and firmware upgrades	Non-service interrupting loopback, diagnostics, statistics, remote upgrade, optical monitoring. Integrates with provisioning and management systems, with resiliency and low MTTR.
Supports TDM circuit emulation, ITU-T G.8262 Synchronous Ethernet, 1PPS phase transport	Efficient deployment of 2G/3G/4G mobile backhaul, both TDD and FDD
Re-clocks EPON signaling on fiber	Robust communications independent of range
IPN supports up to 4 fully loaded PONs	Supports up to 1000 subscribers
20W total power consumption for 4 multiplexed EPONs	Low-power consumption in field installation

- **TK3401 Intelligent PON Node Controller**

At the heart of the IPN is Teknovus' TK3401, Intelligent PON Node Controller, which registers the IPN on one of the connected EPONs, enables the remote management and performance monitoring functions, and controls an attached FPGA. The FPGA (with an image supplied by Teknovus with the TK3401) provides crossbar connectivity between the trunk fiber OLT communications and the downstream PONs and ONUs.



The TK3401 is a System-on-Chip, with integrated processor and memory, supporting -40°C to +85°C, and consumes ~700mW. It is provided in an 11mm x 11mm TFBGA package.

In comparison with amplifiers and remote OLTs, the Intelligent PON Node offers substantially more performance, flexibility and functionality:

	Amplifier	Remote OLT	Intelligent PON Node
Service Reach	< 50km	~50-60km, depending on optics	Up to 100km (80km to IPN, 20km EPON)
Service Density	No impact	Potentially high; limited by form factor	IPN could support up to 1,000 subscribers, with single trunk fiber using WDM
Functionality	Very basic: amplification only	Potentially as high as a CO OLT; depends on form factor & remote management support	Highest: protection switching, remote mgmt, signal re-timing

	Amplifier	Remote OLT	Intelligent PON Node
Transparency	Sometimes requires a mating system in CO	Requires trunk communications system, adding cost, complexity, and two more points of failure.	Completely transparent: may be inserted into fiber plant without affecting OLTs or ONUs
Remote Management	Likely little or none. Needs additional mgmt system in CO	Requires additional management communication system and integration into EMS/NMS.	Remotely managed via OLT, full statistics, diagnostics, and loopback
Form Factor (Size, Power)	Small, low-power	Large and power-hungry. May have limited support for field-replaceable modules.	Small, low-power. SFP optics.
Cost/Subscriber	Probably lowest cost, but also lowest performance and functionality.	Highest cost: involves putting an entire OLT out into the field, likely requiring industrial temp operation.	May be same or lower than amplifier solution, due to ability to serve larger number of subscribers.

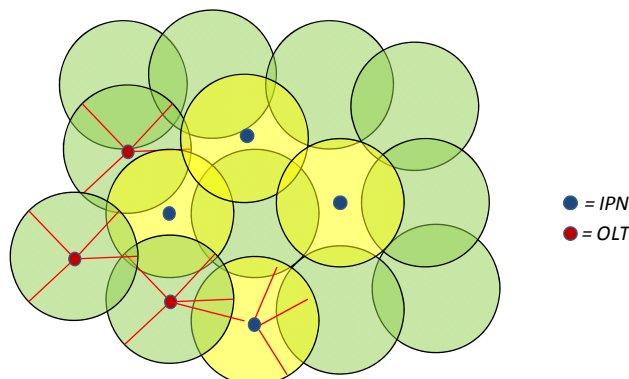
4. Example Intelligent PON Node Use Cases

This section provides several deployment examples and use cases of the Intelligent PON Node.

- **Service Gap-Filling and/or Central Office Reduction**

Low cost IPNs (represented in the diagram by blue circles) may be deployed to remote pole- or curb-side locations, fed by OLTs located in central offices up to 80km away. Service areas that had previously been unreachable may now be connected via a remotely-managed Intelligent PON Node with significant advantages:

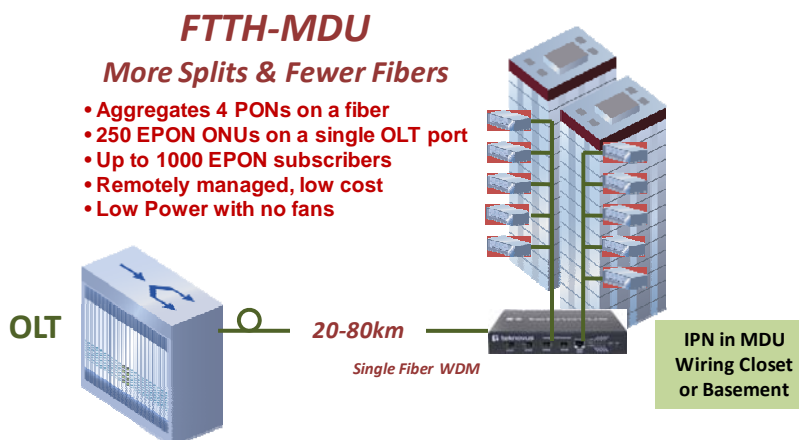
- ✓ Supports elimination/consolidation of central offices
- ✓ Increases subscriber population
- ✓ Supports multiple PONs via WDM
- ✓ Avoids costly (and power-hungry) remote OLTs



- **Multiple Dwelling Units (MDU)**

As described earlier, FTTH-MDU deployments are often complicated by the large number of potential subscribers exhausting available trunk fiber assets between the OLT and MDU. Since typical PON OLTs support 32-64 ONUs per network, several fibers may be needed to support hundreds of homes even if the splitter is located in the basement. An alternative solution would employ a remote OLT installed in the basement, which would have a large enough quantity of ports to support the MDU homes. This would require, however, development of a sophisticated remote management function over the trunk fiber point-to-point link, additional cost for environmental conditioning and security, as well as the cost for the WDM point-to-point communication systems.

Teknovus' OLT chips (e.g., TK3723) support up to 250 ONUs per PON. With the IPN supporting up to 4 PONs per unit, 1,000 subscribers may be conveniently supported via a small system without fans or special conditioning.



But how far would a 1:250 split actually reach from the IPN? Below is a link budget calculation to help answer this question:

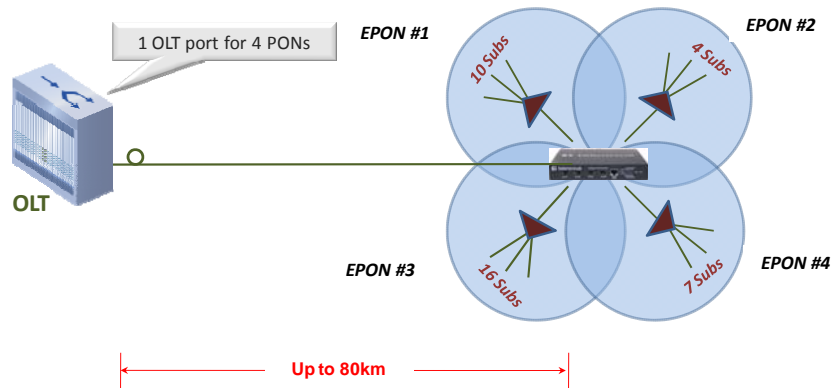
Item	Optical Budget	Comments
PX20+ Link Budget	28.0 dB	
8 splits @ 3.1dB/split	-24.8 dB	A 1:250 ODN requires 8 splits: ($2^8 = 256$)
3 pairs of connectors	-1.5 dB	
Design margin	-1.0 dB	
Remaining loss budget	0.7 dB	

At 0.35dB/km, 0.70dB supports up to 2km from the IPN to the ONU, which should be plenty for a basement-located IPN serving FTTH in an MDU.

- **OLT:ONU Split Ratio Optimization, Subscriber Load Balancing**

The early-life economics of networks are depressed because the cost of the OLT and ODN are amortized over a small number of subscribers: OLTs must be installed first in new deployments to support future connected customers. This may lead to carriers having numbers of PONs with a variety of subscriber

loading conditions whose split ratios gradually increase over time. The IPN can aggregate up to 4 PONs into a single OLT port, thus load-balancing and optimizing the split ratio economics of early deployments:

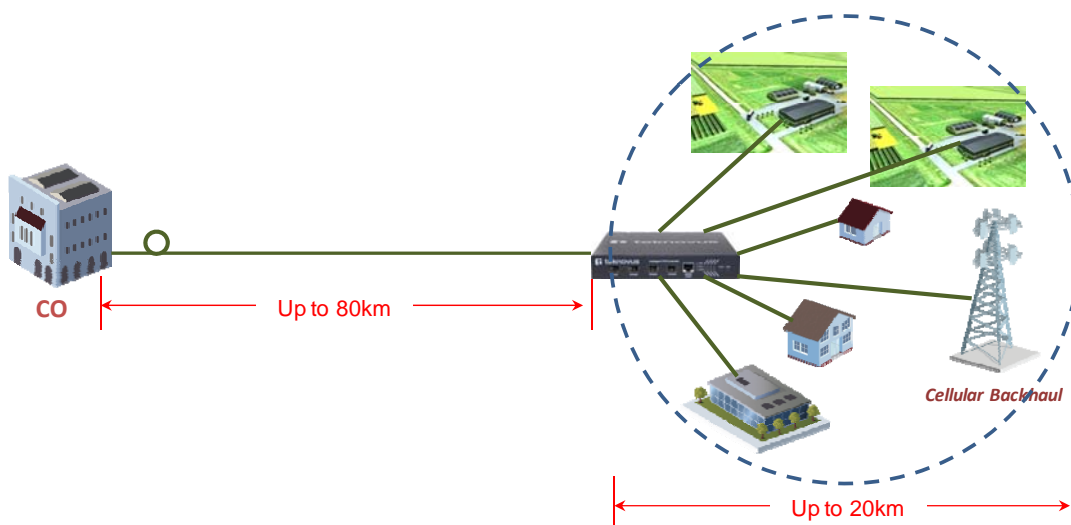


As subscribers are added to the PONs, more central office OLT ports may be added as needed to the OLT-to-IPN fiber (multiplexed using WDM), with network reconfiguration accomplished remotely without truck-rolling a technician to the IPN or subscriber sites.

- **Rural Deployments**

Deployments to rural areas are often economically challenged due to extended service distance and lack of subscriber density. The increasing value of service offerings to rural businesses and cell-towers – let alone residential customers – make them increasingly attractive. Use of the IPN in this application provides the following benefits:

- The only change to central office OLT ports is the optics. The IPN uses P2P optics between the OLT and the IPN.
- Use of the IPN doesn't change any service characteristics, such as SLAs or synchronization signaling for mobile-provider base stations.
- The IPN supports a rich set of remote monitoring, reconfiguring functionality, and protection switching – enabling rapid and low-cost problem diagnosis and service restoration.



5. Economics

The bottom line, of course, is the economics of the solution: its impact on revenue, capital expenditures, and operational costs. Every service provider's situation is different and their economic models will be affected by local costs, codes, and service conventions. The tables below provide an outline of the macro-effects anticipated through use of the IPN.

- **Revenue**

Category/Service	Discussion	Affect on Revenue
Rural Services	Valuable business, backhaul, and residential subscribers become available when the service reach is increased.	Positive
Business Services	The business services market is growing – probably faster than residential – while fiber resources are becoming scarce. EPON, with WDM enabled via the IPN, offers a practical high-payoff strategy to increase exposure in this important segment.	Positive
Service Gaps	Subscribers that fall into service gaps will either have to wait for alternative services or be costly to support. The IPN enables “virtual OLT” deployment, creating flexible service islands in areas that were previously unreachable.	Positive

- **CapEx**

Capital Expense	Discussion	Affect on CapEx
OLT Ports	The ability to optimize OLT:ONU split ratio leads to fewer OLT ports needed, even for multiple PONs.	Reduced
Remote OLTs	The IPN is considerably less complicated (and therefore less expensive) than a remote OLT.	Reduced
New Fiber	The cost and time required to install new fiber is substantially higher than increasing fiber capacity and utilization with an IPN.	Reduced

- **OpEx**

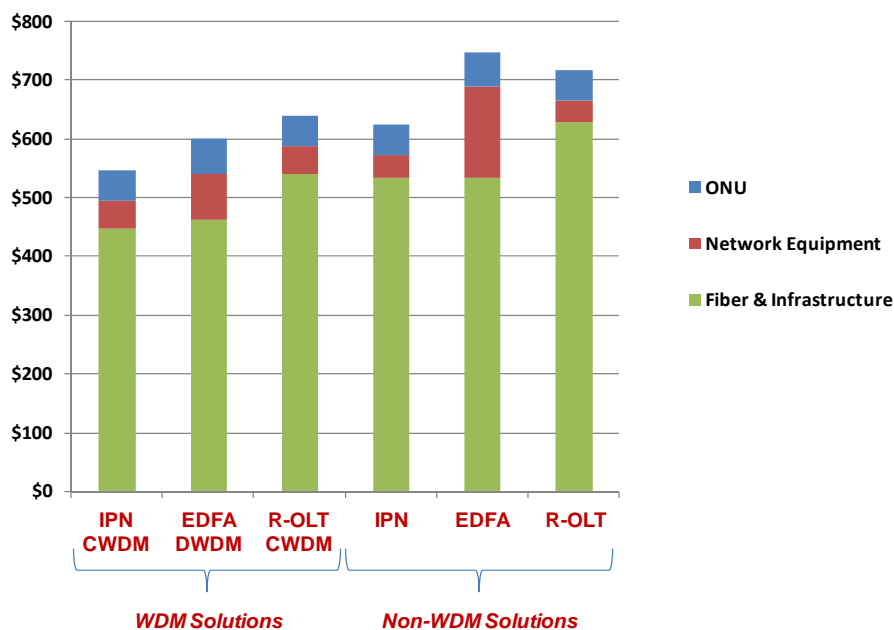
Operating Expense	Discussion	Affect on OpEx
Truck Rolls	Remote management, configuration, diagnosis, and fault recovery, dramatically reduce the need for sending technicians into the field. Customer satisfaction is higher due to fewer service disruptions and faster repair time.	Reduced
Central Office (power, real estate, personnel)	The consolidation of service operator facilities always leads to substantial expense reductions.	Reduced
Inventory	Trunk/feeder fibers to the IPN employ commodity P2P WDM optics to support multiple OLT ports.	Reduced

- **North American CapEx Economic Models**

We modeled the CapEx economics of WDM and non-WDM solutions for North American deployments. For each, we compared the three alternatives: 1) Intelligent PON Node, 2) Amplifier, and 3) Remote-OLT. For the optical amplifiers we modeled the use of EDFAs rather than SOAs because of the EDFA's maturity and well-understood economics, even though EDFA's currently lack support for burst-mode upstream operation. EDFA's narrow operating range dictated our use of DWDM optics in the WDM model.

Assumptions:

- Maximize distance from central office/head-end to subscribers
- Maximize number of subscribers, over 4 PONs
- The PONs are loaded with 32 ONUs (subscribers) per OLT port



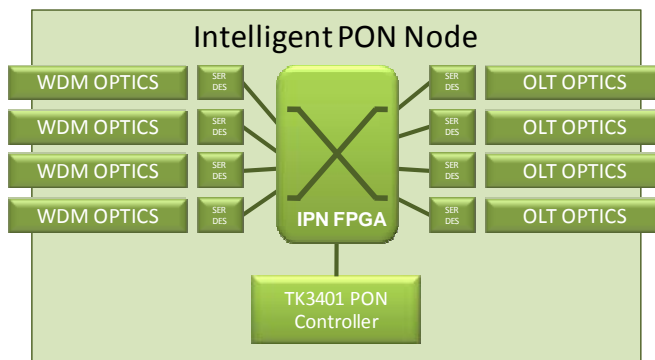
Some conclusions from the models:

- WDM offers CapEx cost savings over non-WDM.
- In either case, the IPN reduces CapEx/subscriber by ~\$100 to \$125 over Amplifier or Remote-OLT alternatives.

6. The Future

There are other deployment issues that may be encountered. Perhaps there are networks that would be well served by cascading multiple IPNs, enabling even more flexibility in configuration and subscriber locations. Or perhaps use in a ring architecture, similar to SONET?

New applications and requirements are continually explored. The TK3401 and its attached FPGA may be remotely updated, enabling feature enhancements and bug fixes without field technician support.



7. Summary

Teknovus' Intelligent PON Node (IPN) provides a comprehensive solution to a wide variety of common deployment situations that impact the economics and feasibility of service offerings to businesses, cell-tower backhaul, and residential subscribers. The IPN employs commonly-available components in a dense and low-power form factor that addresses all of these situations, enabling valuable Revenue, CapEx, OpEx, and service-enhancing opportunities for global access network service providers.