Advances in Next Generation FTTH

Webinar
December 15, 2010

Building Fiber-to-the-Home Communities Together
Participants

- Neda Cvijetic, NEC Labs America
  OFDMA PON
- John Halvorsen, LG Ericsson
  Injection-Seeded WDM PON
- Leif Sandstrom, ADTRAN
  WDM PON Enabling Optical Technologies
- Shan Wey, NSN
  Ultra-Dense WDM PON with Coherent Detection

Moderator: Denis Khotimsky, PhD

Editor G.984.3, G.987.3
Neda Cvijetic received the Ph.D. degree in electrical engineering from the University of Virginia, Charlottesville, in 2008. She is currently a Research Staff Member in the Broadband and Mobile Networking Department at NEC Laboratories America, Princeton, NJ. Her research interests include advanced modulation/detection techniques for high-speed optical transmission, optical-wireless convergence, and throughput optimization in heterogeneous networks.
John Halvorsen has spent the past two years working on LG-Ericsson's Ethernet Fiber Access portfolio as a senior product marketing manager, including having a specific focus on how this technology fits into NG PON2 standardization. Prior to joining LG-Ericsson, John was a senior product manager in Nortel for the Multiservice Switch (MSS) and the Services Edge Router (SER) data portfolios, and has spent time in Nortel's wireless endeavours as well. John holds an engineering degree and an MBA, both from the University of Ottawa, and for interests sake, is a two time Olympian in Track and Field.
Leif Sandstrom has been a member of ADTRAN’s R&D team for the past 10 years with an exclusive focus on optical technologies and optical communications systems for the past 5 years. Leif holds a Master’s degree in electrical engineering and is nearing completion of his PhD in Optical communications. Leif is one of ADTRAN’s representatives to FSAN. Leif’s interests include camping, backpacking, and spending time with his family.
Shan Wey is with the Research group at Nokia Siemens Networks. Shan received her PhD on high speed optical fiber communications research from the University of Maryland, College Park. Prior to joining Siemens/NSN in 2004, she held research positions in both academia and industry focusing on optical long haul and access networks. Since joining NSN, she is also involved in IPTV product development activities. Shan currently represents NSN in standards organizations including FSAN and ATIS COAST-OAN for optical access, and ATIS IIF and MSF for IMS and IPTV integration technologies.
Q & A
Advances in Next Generation FTTH:
**OFDMA-PON for NGPON2**

Neda Cvijetic
**NEC Laboratories America Inc.**
NGPON2 Requirements and Desired Features

- **Requirements**
  - Enhanced bandwidth per user (> per-user capacity than NG-PON1)
  - Simultaneous 20 km reach and 1:32 split (class B+ or equivalent)

- **Desired Features**
  - 60 - 100 km reach (with extender if necessary)
  - Support for larger optical splits (> 1:64)
  - Colorless O/E modules
  - *Full-range dynamic bandwidth allocation*
  - *Converged platform for heterogeneous services*
Advanced Features of NGPON2

• **Full-range dynamic bandwidth allocation**
  - Adaptive re-assignment of bandwidth resources between users and/or services

• **Flexible support for heterogeneous services** over a common platform
  - Services include mix of digital, analog, circuit and packet-switched, legacy and emerging applications

• **It is critical** that future PON technologies be **highly cost-efficient** to remain attractive and practical
  - Re-use existing optical distribution network (ODN)
  - Upgrade with advanced modulation and digital signal processing (DSP)
**Orthogonal Frequency Division Multiple Access (OFDMA)**

- **Key idea:** divide total bandwidth into many narrow-band subcarriers to transmit independent data streams in parallel
- **Orthogonality:** spectra overlap without interference for high spectral efficiency
  - **Long-reach transmission:** high resistance to linear dispersion
  - **Efficient implementation:** digital signal processing (DSP) that is transparent to front end optics and can simplify them

![Diagram of OFDM Sub-carriers in frequency and time domains](image.png)
OFDMA-PON Technology

- Several candidates for future passive optical network (PON)
  - OFDMA, TDM, WDM, hybrid TDM/WDM...

- OFDMA-PON differentiator: tackle key challenges in electronic domain through digital signal processing (DSP)

- Leverage advanced DSP to achieve superior performance, rapid and robust network re-configurability, cost reduction

- OFDMA-PON: novel DSP-based platform for speed, flexibility and cost-efficiency in future high-speed PON access systems

- DSP technology becomes enabler of cost-efficiency
  - Re-use existing optical distribution network (ODN)
  - Upgrade with advanced modulation and digital signal processing (DSP)
OFDMA-PON for NGPON2 Access

OFDM sub-carriers become transparent pipes for arbitrary signal delivery (e.g. T1/E1, Ethernet, RF mobile backhaul, IPTV, VPN, etc.)

Full-range dynamic bandwidth allocation in frequency and time

Flexible, scalable system, extensible to any emerging applications
OFDMA-PON Flavors for Multi-User Access

- **OFDMA-PON**: Different users assigned different OFDM subcarriers within one OFDM band of total $N$ subcarriers.

- **OFDMA + TDMA PON**: Different users assigned different OFDM subcarriers and TDM slots within one OFDM band; *2-dimensional dynamic bandwidth allocation*.

- **OFDMA + TDMA + WDMA PON**: Different users assigned different OFDM subcarriers, and TDM slots and WDM $\lambda$. 

[Diagram showing the allocation of subcarriers and services over time and frequency.]
Practical OFDM-PON Implementation

Through advanced digital signal processing (DSP), practical implementation is simple and efficient through Fast Fourier Transform (FFT)

$$x_p[n] = \frac{1}{N} \sum_{k=0}^{N-1} X_p[k] e^{j(2\pi/N)kn}$$

Advanced DSP enables practical, cost-efficient, multi-user implementation
Key Benefits of OFDMA-PON Transmission

**SPEED**
- Up to 100 Gb/s/λ downstream transmission
- Up to 100 Gb/s/λ upstream transmission
- Long reach transmission (up to 100km)

**FLEXIBILITY**
- Dynamic bandwidth allocation in time and frequency
- Transparency to arbitrary services
- Adaptive modulation/coding on per-user basis

**COST-EFFICIENCY**
- Optically colorless ONUs
- DSP-based for simplified optics, robustness
- Non-disruptive to legacy ODN
Summary of Experimental Demonstrations

- (NEC Labs, ECOC 2007): 10 Gb/s Bi-Directional OFDMA-PON
- (NEC Labs, OFC 2008): Heterogeneous OFDMA-PON
- (NEC Labs, Paper OMV3, OFC 2009): 40 Gb/s OFDMA-PON
- (NEC Labs, Paper OTuO7, OFC 2009): 1000km OFDM-DD Transmission
- (NEC Labs, ECOC 2009): 36 Gb/s/λ OFDMA-PON over 100km
- (NEC Labs, ECOC 2009 PD 3.3): 108 Gb/s/λ Upstream OFDMA-PON
- (NEC Labs, OFC 2010): 44 Gb/s/λ Polarization Insensitive Upstream OFDMA-PON
- (NEC Labs, OFC 2010 PDPD9): 41.25 Gb/s Real-Time, Variable-Rate WDM-OFDMA-PON
DSP Component Characteristics

- **Silicon platform**
  - ADC/DAC + DSP integration, mass production, cost-efficiency

- **Low power** consumption
  - 65nm, 40nm, 28nm CMOS processes

- **Cost-efficient packaging** options
  - Component cost profile driven by volume

- **DSP complexity**: IFFT/FFT dominates, $\sim \log(N)$ scaling
  - Optimized, readily available algorithms
Summary and Conclusions

- **OFDMA-PON** very well-suited for NGPON2
  - Transparent to emerging **heterogeneous** applications
  - Highly-**flexible, dynamic** bandwidth allocation
  - **DSP-based** for simplified optics, robust operation
  - Can be **efficiently combined** with TDMA, WDMA

- Recent advances in high-speed OFDMA PON
  - **108 Gb/s/\(\lambda\)** downstream/upstream transmission
  - **41.25 Gb/s real-time**, variable-rate DSP receiver
  - NGPON2 speeds feasible on **class C+ ODN** (**30+ dB** power budget)

**Key OFDMA-PON advantages**: **high flexibility and cost-efficiency** with record transmission rates/distances
Empowered by Innovation

NEC
Appendix: Technology Trends and Next Steps

- DSP-based system cost can be significantly and rapidly reduced by **component integration** and **mass production**

- **Optimized** OFDM algorithms re-used from wireless and wireline building blocks

- Next generation **100 Gb/s** long-haul fiber transmission **will be heavily DSP-based**

- **Aggressive 100 Gb/s DSP development** expected to have **favorable effect** on OFDMA-PON cost profile

Example DSP platform for real-time OFDMA-PON implementation
(NEC Labs, Paper PDPD5, OFC 2009): 108 Gb/s OFDMA PON over 20 km SSMF + 1:32 split

Highest-speed downstream PON transmission to date

Additional 5 dB OSNR margin exists for 40 Gb/s class B+ OFDMA-PON transmission

40 Gb/s OFDMA-PON architecture extensible to 29-32 dB optical power budgets: 20 km SSMF + 1:64 split
(NEC Labs, Paper PD 3.3, ECOC 2009): Colorless 108 Gb/s/$\lambda$ Upstream OFDMA-PON

Highest-speed single-$\lambda$ upstream transmission in PON reported to date
(NEC Labs, OFC 2010 PDPD9): 41.25 Gb/s Real-Time, Variable-Rate Receiver for WDM-OFDMA-PON

Highest-speed real-time reception achieved in PON to date
Advances in Next Generation FTTH: 
Injection Seeded WDM PON

John Halvorsen
LG-Ericsson

FTTH Council Webinar
Dec 15th, 2010
WDM PON Technology Fundamentals

OLT: Optical Line Terminal
ONT: Optical Network Termination
WDM: Wavelength Division Multiplexing

CO
OLT

Single fiber strain

Passive WDM Filter

ONT
Residential

Wireless Backhaul

ONT
Business - Multi-Tenant Unit

OLT: Optical Line Terminal
ONT: Optical Network Termination
WDM: Wavelength Division Multiplexing
WDM PON Technology Fundamentals

- Symmetrical bandwidth – 100Mb or Gigabit Ethernet in both directions
- Colorless CPEs with Automatic Wavelength Selection
- Low cost optics – no expensive tunable lasers
- Optimized Outside Plant - No Outside Plant Electronics, Single Fiber Working
- Up to 20+ Km reach

Up to 32 100M / GigE λ
Higher densities in the future

OLT
CO

WDM Filter

ONT Indoor/Outdoor
Residential

ONT
Wireless Backhaul

ONT
Business - Multi-Tenant Unit

OND
WDM PON strengths

Symmetrical Bandwidth
- 100M or GigE in both directions
- Point-to-point operational model

Point to point topology
- Secure connectivity
- Physical separation

Simple deployment model:
- Automatic wavelength allocation
- No link engineering
- Configuration downloaded from OLT
- Ethernet OAM
- Universal sparing
- Simple fault isolation

Other Capabilities
- Native Ethernet
- Efficient IP multicasting
- Traffic Management
- RF-overlay option
Optical Innovations Driving New Applications with WDM PON

- A-AWG: Athermal - Array Waveguide Grating Filter
  - Suitable for OSP

- Optics: OLT / ONU Colorless Lasers

- Optics: Broadband Light Source

Cyclical - Array Waveguide Grating (AWG)
WDM PON - Ethernet Fiber Access

Injection Seeded FP-LD Enabling Technology

Automatic Wavelength Locking

- Broadband Light Source (BLS)
- Wavelength Filter
- Spectral Slicing
- Laser

Spectrum before locking: 1530nm 1560nm
Spectrum after locking: 1530nm 1560nm

Colourless ONU:
- Low inventory management cost
- Elimination of high cost wavelength-specific lasers
Injection Seeded WDM PON Fundamentals

1. Two Broadband Light Source
   - C & L-band BLS

2. Modulation for downstream (FP-LD)
   - FP-LD
   - Rx
   - Cyclic AWG

3. Downstream data detection

4. Modulation for upstream (FP-LD)
   - FP-LD
   - Rx

5. Upstream data detection

OLT (current implementation)

Commercial Components

- Laser Diode Cavity
  - Anti-Reflective Facets 1% - 10%

- Low Cost FP-LD

Cyclical Athermal Array Waveguide (AWG)

- FSR
- λα, λb, λn

Common ODN
WDM PON Applications

Residential Services
- Tipple play
- Indoor/outdoor
- Wholesale
- Local loop unbundling

Business Services
- Secure and scalable
- Redundancy
- Ethernet diagnostics
- TDM circuit extension

Backhaul Services
- Redundancy
- CESoPTN
- T1/E1 or STM1/4 termination
- Synchronization
- Reach extension

OLT
EA1100
WDM
100M/GE
SFU
MDU
SFU
WDM PON Home Run
point to point
100M/GE
small office
corporate HQ
remote branch office
campus
protected ring
GE
remote branch office
Wireless 2G/3G/4G
wireless
WiMAX
Femto
DSL local loop extension
CO consolidation
GPON & WDM PON Coexistence can occur on the same fiber.
LG-Ericsson

WDM Ethernet Access Solution

- World’s first commercially available WDM-PON solution
- 150,000 WDM-PON lines in-service today
- More than 10 customer (Tier1/PTTs) trials worldwide
- 4 trials in planning and pilot stages
- WDM PON considered by many service providers as the next generation of Access technology
- Launched WDM PON Ecosystem for Multi-vendor interoperability

Commercially Available
Incorporates new future-proof OLT:
- 240G 1+1 Ethernet Switch Fabric
- 20G backplane slot capability (40G ready)
- 80G+80G Network Interface
- Supporting WDM-PON and Pt-Pt Service Interfaces
- Comprehensive Residential, Business & Wireless Backhaul service suite
**WDM Ethernet Access Summary**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infrastructure</strong></td>
<td>Efficient fiber reutilization due to PON architecture</td>
</tr>
<tr>
<td><strong>Equipment OPEX</strong></td>
<td>Per subscriber planning and fault finding</td>
</tr>
<tr>
<td><strong>Guaranteed Bandwidth</strong></td>
<td>Dedicated and symmetrical bandwidth per user</td>
</tr>
<tr>
<td><strong>Future-Proof Scalability</strong></td>
<td>Wavelength per user scalable to 1Gig</td>
</tr>
<tr>
<td><strong>Business/Backhaul Ready</strong></td>
<td>Per wavelength unobstructed security</td>
</tr>
<tr>
<td><strong>Regulatory suitability</strong></td>
<td>Per wavelength unbundling capability</td>
</tr>
<tr>
<td><strong>Open Architecture</strong></td>
<td>Optical modules / SFP comprehensive ecosystem</td>
</tr>
<tr>
<td><strong>Protection / Availability</strong></td>
<td>1+1 equipment, E-SPRing – G.8032</td>
</tr>
</tbody>
</table>

**WDM PON Provides Deployment Model for Multi-Service Network**

**Future Proof Network as Point to Point Ethernet Network Today**
Advances in Next Generation FTTH:
WDM Enabling Optical Technologies

Leif Sandstrom
ADTRAN
• **WDM**: Business class services in the Access network
  - High Capacity
  - High Flexibility (Independent Customer Channels)
  - High Reliability (Independent Customer Channels)

• **WDM-PON**
  - Objective: Expand WDM type service to the entire Access network...Cost-Effectively
  - Formula: WDM Model + PON + “**Color-Agnostic**” Optics
WDM-PON Technologies

- Low-Cost Tunables
  - External Cavity Lasers (ECL)
  - Modulated Grating Y-branch (MG Y-branch)
WDM-PON Technologies

- **Injection seeded**
  - Separate Upstream and Downstream Bands
    - Injection-locked Fabry Perot (IL-FP)
    - Reflective Semiconductor Optical Amplifier (RSOA)
    - Reflective Electro-Absorption Modulator (REAM)
  - Wavelength Reuse (Remodulated Upstream)
    - RSOA, REAM
WDM-PON Technologies

- Injection-Locked Fabry Perot (IL-FP)
  - Long cavity
    - Consistent Power across WDM-PON channels (close mode spacing)
    - Limits modulation rate (carrier lifetime)
  - Asymmetric Facet Reflectivity
    - High back-facet reflectivity
    - Low front-facet reflectivity
      - Low enough to allow seed injection
      - High enough to preserve lasing behavior (coherence, lasing modes, etc.)
  - Asymmetric Quantum Well structure
    - Consistent Power across WDM-PON channels

WDM-PON Technologies

- Reflective Semi-conductor Optical Amplifier (RSOA)
  - Same Semiconductor Structure as IL-FP
  - High-Reflectivity Back Facet
  - No Lasing Action Allowed!
    - Zero-Reflectivity Front Facet
      - Anti-reflective coating and angled front facet
      - ASE noise (P. R. Morkel, “NOISE CHARACTERISTICS OF HIGH-POWER DOPED-FIBRE SUPERLUMINESCENT SOURCES”. ELECTRONICS LETTERS 18th January 1990 Vol. 26 No. 2)
      - Modulation speeds up to 2.5 Gbps reported
WDM-PON Technologies

- RSOA and Electro-Absorption Modulator (REAM)
  - RSOA with integrated EAM
    - External Modulation -> 10 Gbps
    - Must overcome additional loss of EAM.
# WDM-PON Technologies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RSOA</th>
<th>IL-FP</th>
<th>Tunable</th>
<th>REAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Cost</td>
<td>1.5 to 3</td>
<td>1</td>
<td>2 to 6</td>
<td>2 to 6</td>
</tr>
<tr>
<td>Max Data Rate</td>
<td>2.5 Gbps</td>
<td>1.25 Gbps</td>
<td>10 Gbps</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>Optical Channel Spacing</td>
<td>100 - 200 GHz</td>
<td>100 - 200 GHz</td>
<td>50 GHz - 200 GHz</td>
<td>100 GHz - 200 GHz</td>
</tr>
<tr>
<td>Channel Length</td>
<td>&lt; 20 km</td>
<td>&lt; 20 km</td>
<td>&lt; 40 km</td>
<td>&lt; 20 km</td>
</tr>
<tr>
<td>Seed Source</td>
<td>Required</td>
<td>Required</td>
<td>N/A</td>
<td>Required</td>
</tr>
<tr>
<td>Optical Band</td>
<td>C-band</td>
<td>C and L-band</td>
<td>C and L-band</td>
<td>C-band</td>
</tr>
<tr>
<td>Case Temp Range</td>
<td>0 - 70</td>
<td>-40 to +85</td>
<td>0-70 with TEC</td>
<td>0-70 with TEC</td>
</tr>
</tbody>
</table>
WDM-PON: Research Projects

• Objective: Remove Barriers to General WDM-PON Deployment
  – To lower Cost
  – To extend Reach
  – To increase Capacity

• Projects
  – **GigaWAM** ([http://www.gigawam.com/](http://www.gigawam.com/))
WDM-PON Research

- **GigaWAM**: focused on improving component technologies
  - Low-cost tunable lasers
  - VCSEL arrays
  - 10 Gbps

- **PIEMAN** and **SARDANA** are independent projects with similar objectives
  - Merge Access and Metro networks
  - Hybrid WDM-TDMA PON
  - 10 Gbps / $\lambda$
  - 500 to 1000 subscribers
  - 100 km reach

- **MUSE**
  - Partner Project with PIEMAN
  - Focused on Upper and MAC layers
    - End-to-End Integration
    - End User Plug and Play
    - Multi-Service / Multi-Hosting Capability

Lazaro, “Scalable Extended Reach PON” OFC/NFOEC 2008, OThL2
WDM-PON Research

- Merging Metro and Access with Hybrid WDM-TDMA PON:

![Diagram of Hybrid PON OLT and Access Node with WDM and TDMA components](image)
Wait a minute…

Don’t write off GPON just yet

• Can GPON support the FCC National Broadband Plan Goals?
  − 2015: 100 million U.S. homes have access to actual download / upload speeds 50 / 20 Mbps
  − 2020: 100 million U.S. homes have access to actual download / upload speeds 100 / 50 Mbps
• **YES:** GPON will easily provide these actual data rates
  − 95% of time a given user will be able to achieve > 1Gbps when performing a speed test at peak use times

• Assumptions:
  − “Actual rate” means can be achieved 95% of time
  − 2.5/1.25 Gbps DN/UP, 1:128 split ratio
  − Projected Average Demand 2020: 5.1 Mbps/subscriber
SUPPLEMENTAL SLIDES
GPON Capacity Modeling

• Assumptions:
  – 2.5/1.25 Gbps DN/UP, 1:128 split ratio
  – Projected Average Demand/ User in 2020: 5.1 Mbps
    • based on Cisco VNI estimates thru 2013
    • Extrapolated to 2020 using 50% Compound Annual Growth Rate

• Statistical modeling:
  – Monte Carlo with 10,000 trials
  – Demand modeled with bounded Pareto distribution.
  – User rates set using max-min fair share algorithm
  – Capacity Distribution sliced at 95% level to obtain used capacity
    • Output: max single user capacity (speed test).
Pareto (Power-Law) Distribution

- “Pareto Principle” or 80-20 rule:
  - 20% of a population controls 80% of the resources
- Pareto Distribution Model
  - Size of human settlements (cities vs. small towns)
  - Values of oil reserves in oil fields
  - Price returns on individual stocks
  - Internet traffic distribution

\[
P(x) = \frac{\alpha \beta^x}{x^{\alpha+1}} \left[ 1 - \left( \frac{\beta}{y} \right)^x \right]^{-1}
\]

\[
D(x) = \int_{\beta}^{y} P(x) \, dx
\]

95%
Advances in Next Generation FTTH: Ultra Dense WDM-PON Utilizing Coherent Detection

Jun Shan Wey
Nokia Siemens Networks

15 December 2010
Nomenclatures

Wavelength Division Multiplexing (WDM)

- Multiple wavelength channels separated by a well defined wavelength spacing. Each channel carries an independent data stream.
- WDM channel spacing – ITU grid:
  - CWDM (Coarse WDM): 20 nm
  - WDM: 100 GHz (0.8nm)
  - DWDM (Dense WDM): 50 or 25 GHz
- NSN’s Next Generation Optical Access research: 3 GHz

Optical Coherent Detection

- A weak signal is superimposed on a strong local oscillator of nearly the same frequency. A detector detects the difference frequency at base band. Both the signal and the LO are generated from narrow linewidth lasers.
- High wavelength selectivity
- High receiver sensitivity
Flat Simple Fiber Based Networks – CapEx and OpEx savings

Consolidation of Access and Metro

Consolidation of Fixed and Mobile

Home network

Access Network

Fiber

GPON

Carrier Ethernet switches

Ethernet Aggregation

Copper

DSLAM

IP edge

Video

IP Core

VoIP

ISPs

FTTH

FTTO

LTE / Femto

Enterprise

Building Fiber-to-the-Home Communities Together
Next Generation Optical Access

- **Passive optical distribution network**
- **UD-WDM**
- **OLT**
- **Photonic IP core**

**One wavelength per customer: unshared 1Gbps symmetrical**

**Up to 100 km reach and high splitting factor of ≤ 1000 - depending on splitter design**

**Reuse existing metro fibre – convergence of access and metro aggregation**

*NGOA is an NSN research project*
NGOA Technology Ingredients

Coherent Detection
- High wavelength density: no need for external filter
- High receiver sensitivity: Rx sensitivity < -45 dBm @ 1Gb/s

Electronic Signal Processing
- Relaxed tunable lasers requirements
- High flexibility in modulation concepts
- Software defined radio for carrier recovery and channel decoding

Low-cost Tunable Laser
- Linewidth < 200 kHz
- Serves as the LO for coherent detection
- Serves as the upstream signal

Photonic Integration
- Single integrated ONU optical component
- Single integrated OLT optical component
- Generation of multiple downstream wavelengths out of a single laser source
Principle of Operation

Each OTG:
- contains one laser and one/a pair of PD
- generates multiple wavelengths

- Each OTG occupies a dedicated sub-spectrum in C band
- Guard bands allow wavelength drifts without interference

OLT: Optical Line Terminal
LIC: Line Interface Card
OTG: Optical Transmission Group
ONU wavelength locking and automatic drift adjustment

- Downstream wavelengths follow a defined frequency plan
- Each ONU is locked to its respective downstream wavelength
- Each ONU generates an individual upstream wavelength with a defined and stable offset to the downstream wavelength

- If the downstream wavelength drifts, the ONU automatically adjusts the upstream wavelength to keep the defined frequency offset
NGOA Tunable Laser

External cavity laser tuned by a micromotor controlled dielectric filter:
- No complicated, fast control loops needed
- No strict temperature control needed

Characteristics:
- Linewidth: <200kHz
- Tuning range: 1520-1565 nm
- Tuning precision: a few 10 MHz
- Tuning speed: < 1 sec for full C-band
- Lock to target λ: < 500 ms (design goal)
- Tx Power: -3 dBm
- Rx Sensitivity: -46 dBm (-62 dBm theoretical limit)
Optical Power Budget

GPON
- 100bT 1000bT
- Downstream Rx Power
  - Class A: -21 dBm
  - Class B: -21 dBm
  - Class C: -28 dBm
- ODN Attenuation
  - Class A: 20 dB
  - Class B: 25 dB
  - Class C: 30 dB
- Downstream Tx Power 2.5 Gbps
  - Class A: 0 - 4 dBm
  - Class B: 5 - 9 dBm
  - Class C: 3 - 7 dBm

NGOA
- 1000bT
- Downstream Rx Power
  - 46 dBm
- ODN Attenuation
  - 43 dB
- Downstream Tx Power 2.5 Gbps
  - -3 dBm /channel

ODN Attenuation
- Class A: 20 dB
- Class B: 25 dB
- Class C: 30 dB

ODN Attenuation
- 43 dB

GPON 2.5/1.2 Gbps

20 km 80 km

Cat5/6 Fiber

Building Fiber-to-the-Home Communities Together
GPON and NGOA Coexistence Overlay for Gradual Subscriber Migration

- Re-Use of B/GPON outside plant
- ODF separation for B/GPON and NGOA
- WDM splitter in Local Office for NGOA
- Range extension with NGOA
Thank You!