NG-EPON Call for Interest

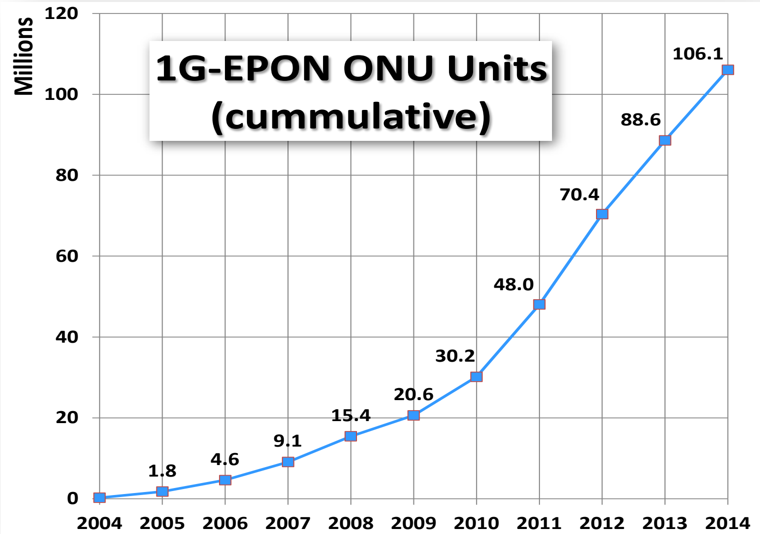
Glen Kramer, Broadcom
Marek Hajduczenia, Bright House Networks
Duane Remein, Huawei Technologies
Ed Harstead, Alcatel Lucent
Bill Powell, Alcatel-Lucent
Curtis Knittle, CableLabs

EPON is an 802.3 Success Story

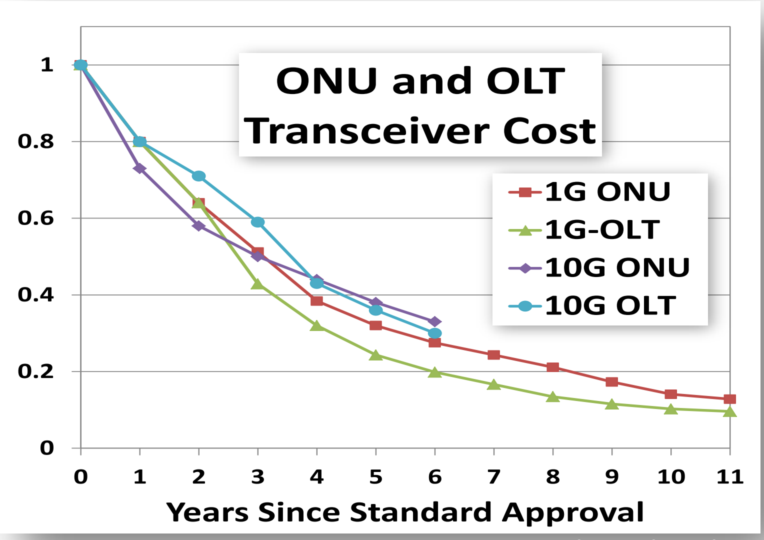
Why is EPON successful? It's simple…

- ❑ We steal!
  - – EPON utilizes many components and building blocks "borrowed" from other Ethernet standards.
  - – Relying on proven, mature, and mass-produced components leads to low-cost solutions and fast time to market.
- ❑ And we fight!
  - – Network operators, OEMs, chip vendors, and optics vendors all have different pain points. In 802.3, we argue until we find the best balance between performance, capex, and opex.

For these reasons, EPON was adopted (1) quickly, (2) worldwide, and (3) by telcos and MSOs alike.



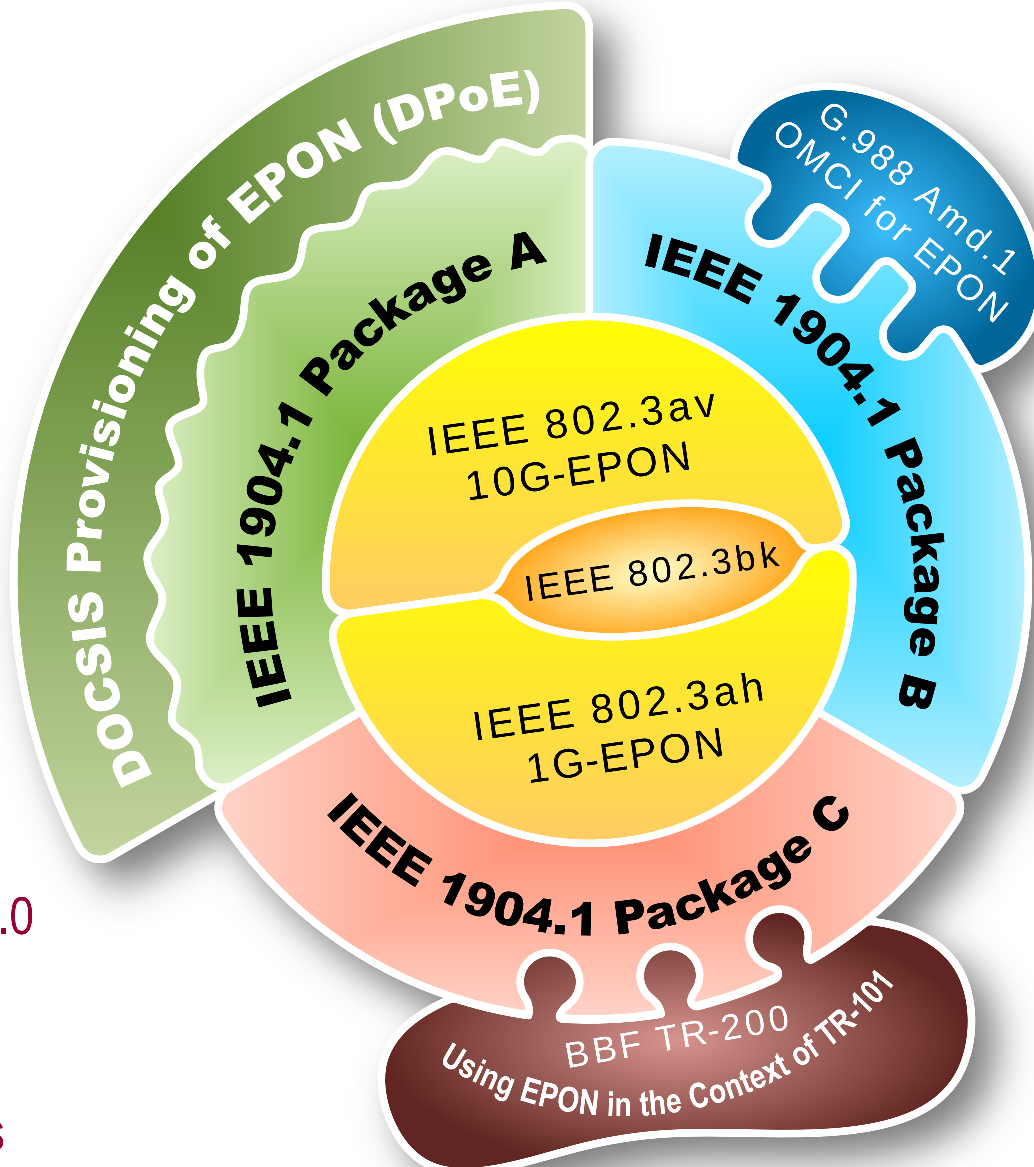
Source: Infonetics (2004-2007), Ovum (2008-2014)



Source: Ligent Photonics

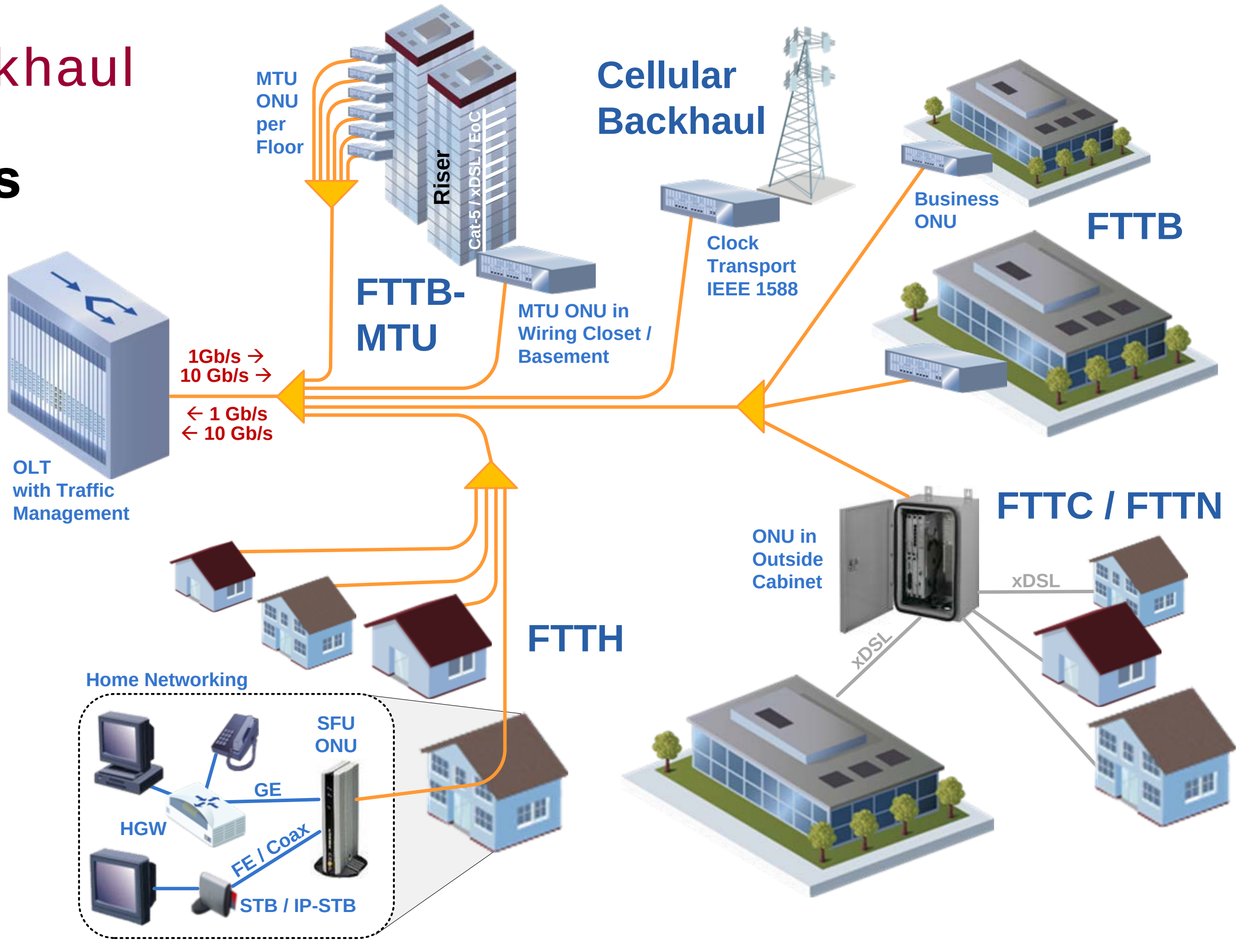
EPON is an Ecosystem

- "EPON" is not a collection of disparate technologies – it is an access ecosystem.
- 802.3ah and 802.3av have laid a foundation of EPON ecosystem that now includes multiple complementary system-level specifications
  - IEEE 802.3ah and 802.3av
  - IEEE 802.3bk
  - IEEE 1904.1 – SIEPON
  - CableLabs DPoE1.0 and DPoE2.0
  - ITU-T G.988 Amd. 1
  - BBF TR-200
  - CCSA series of EPON standards



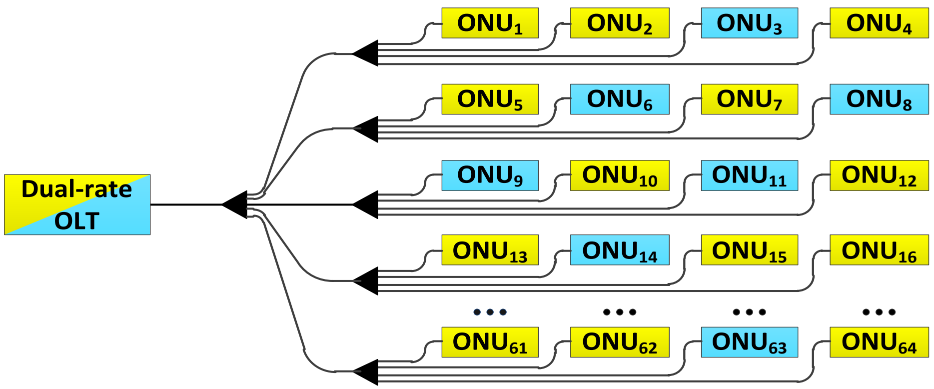
EPON is a Universal Architecture

- **All user types**
  - Residential
  - Businesses
  - Wi-Fi/Cellular backhaul
- **All configurations**
  - SFU
  - MDU/MTU
  - FTTH
  - FTTC/FTTN
- **All Data Rates**
  - 1/1 Gb/s (.3ah)
  - 10/1 Gb/s (.3av)
  - 10/10 Gb/s (.3av)
- **All supported on the same network!**



EPON is an Evolving Technology

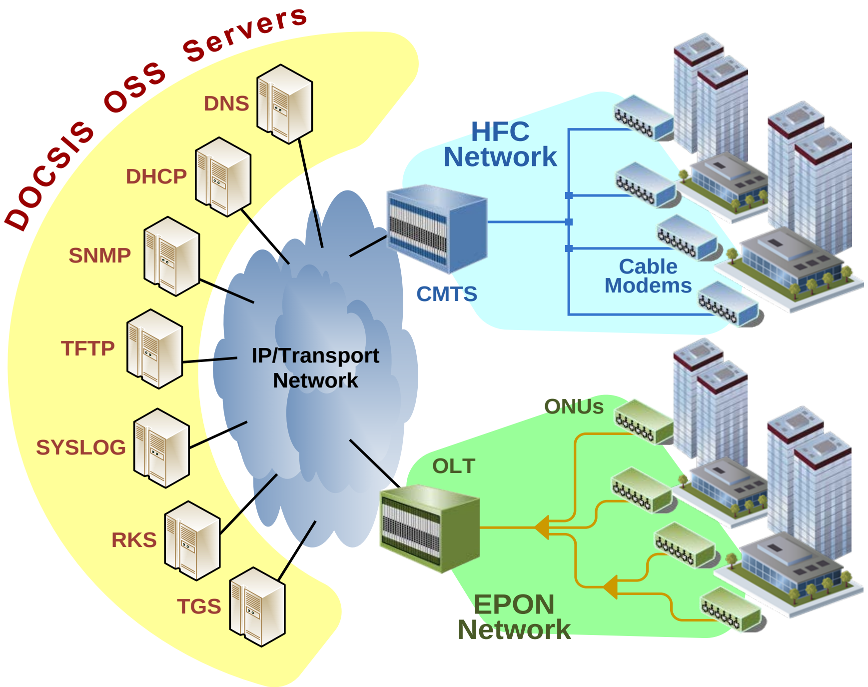
Network operators see EPON as a seamlessly-evolving technology



- Unique method for 1G-EPON and 10G-EPON coexistence allows mixed operation of two generations of EPON ONUs on the same ODN and pay-as-you-grow upgrade

- As optical technology matured, extended power budgets were added (802.3bk)

- EPON has evolved to support DOCSIS back-office functions (DPoE)



EPON must continue to evolve to meet changing requirements, to satisfy the ever-increasing demands, and to support new markets and applications.

Why are we here?

NG-EPON

- To measure the interest in starting a study group to investigate a "**Next Generation EPON**" project within 802.3.

- **You will hear:**
  - NG-EPON Market Potential
    - Marek Hajduczenia, Bright House Networks
  - NG-EPON Technical Feasibility
    - Duane Remein, Huawei Technologies
    - Bill Powell, Alcatel-Lucent
  - Concluding Remarks and Straw Polls
    - Curtis Knittle, CableLabs

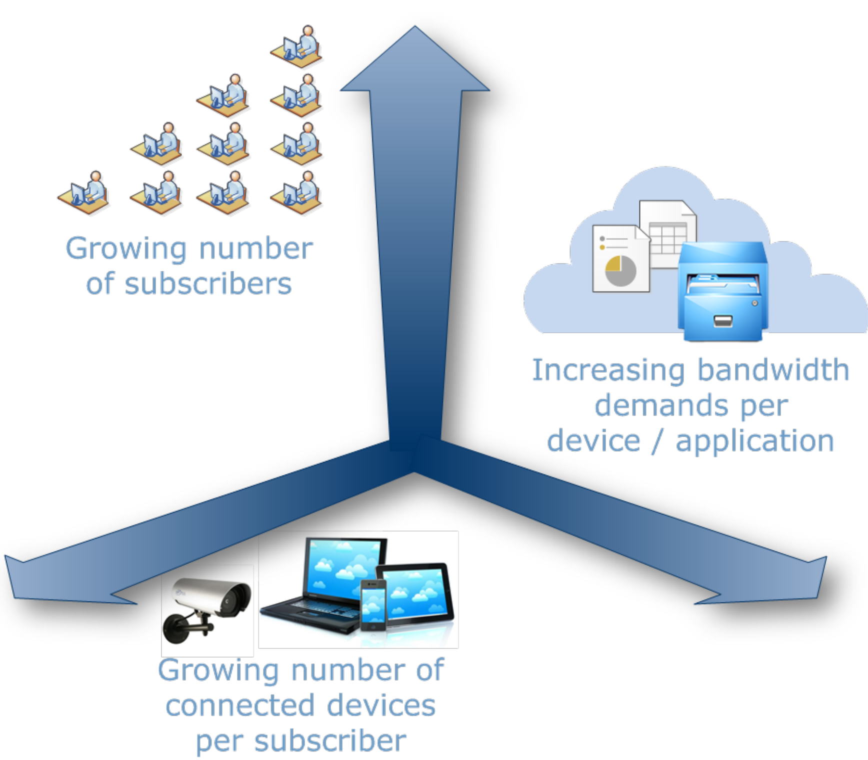
- **This meeting will NOT:**
  - Fully explore the problem
  - Debate strengths and weaknesses of solutions
  - Choose any one solution
  - Create a PAR, CSD or Objectives
  - Create a standard or specification

NG-EPON
Market Potential

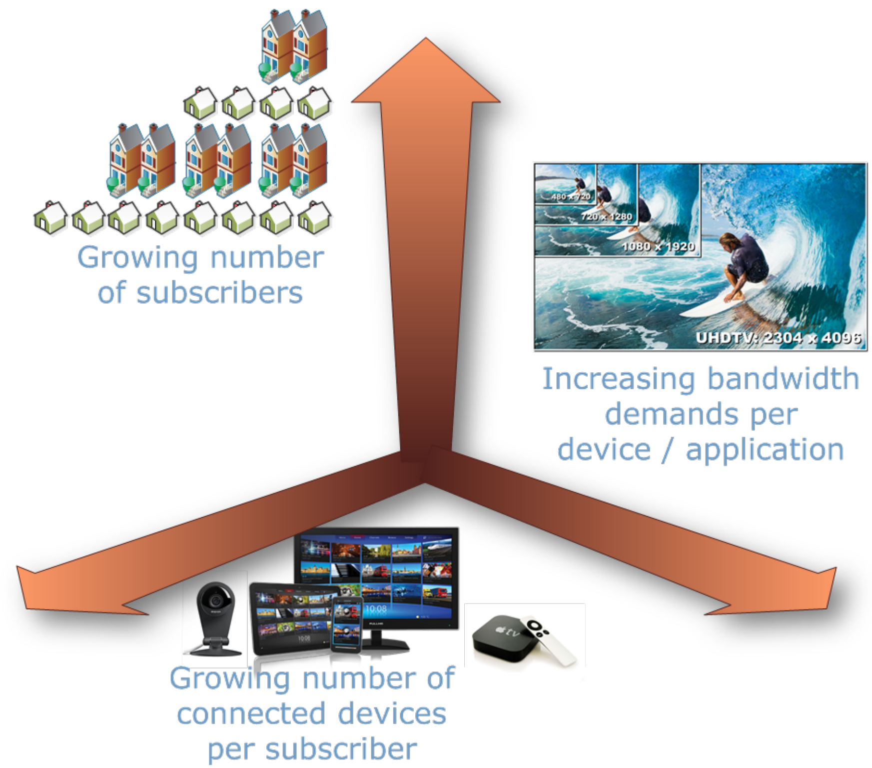
Marek Hajduczenia,
Bright House Networks

Access Bandwidth Demand

Business Access Networks



Residential Access Networks

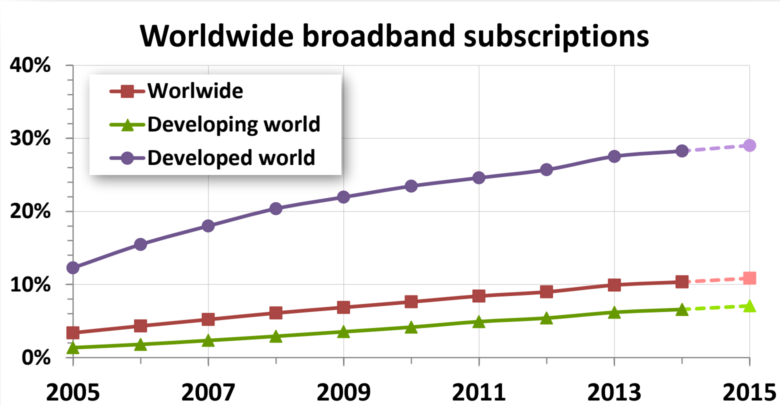


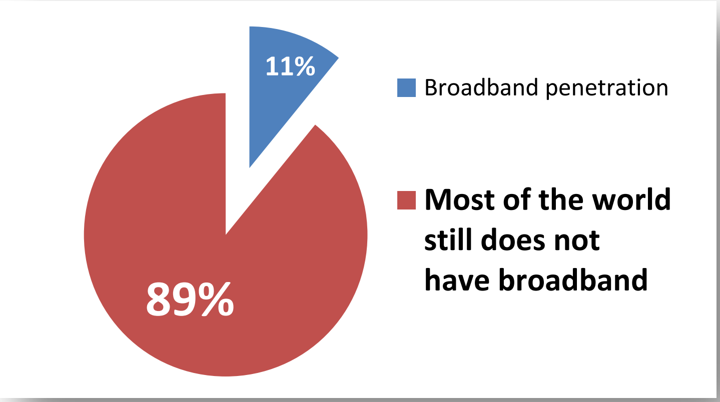
- Similar trends drive the bandwidth demand in business and residential access networks.
- Three linearly increasing bandwidth drivers lead to the exponential growth of the total bandwidth demand:

$$Total\_Bandwidth = Users \times Devices/User \times Bandwith/Device$$

Growing Number of Subscribers

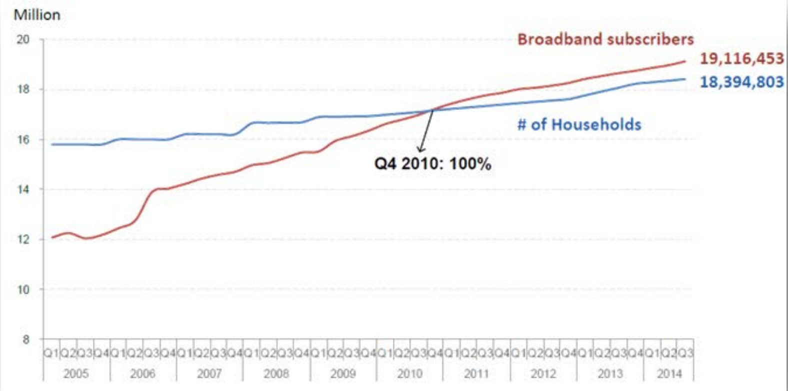
- Lots of people still do not have fixed broadband!

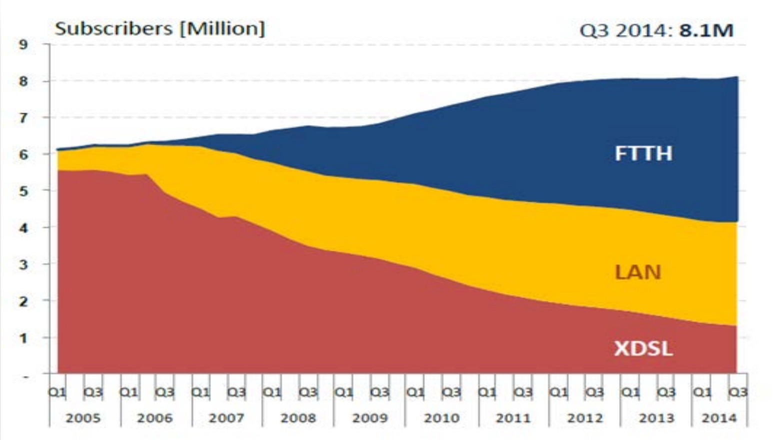




Source: www.itu.int/en/ITU-D/Statistics/Documents/statistics/2015/ITU_Key_2005-2015_ICT_data.xls

- Even in mature markets, subscriber count is still growing
  – "broadband subscribers" include residential and SOHO customers

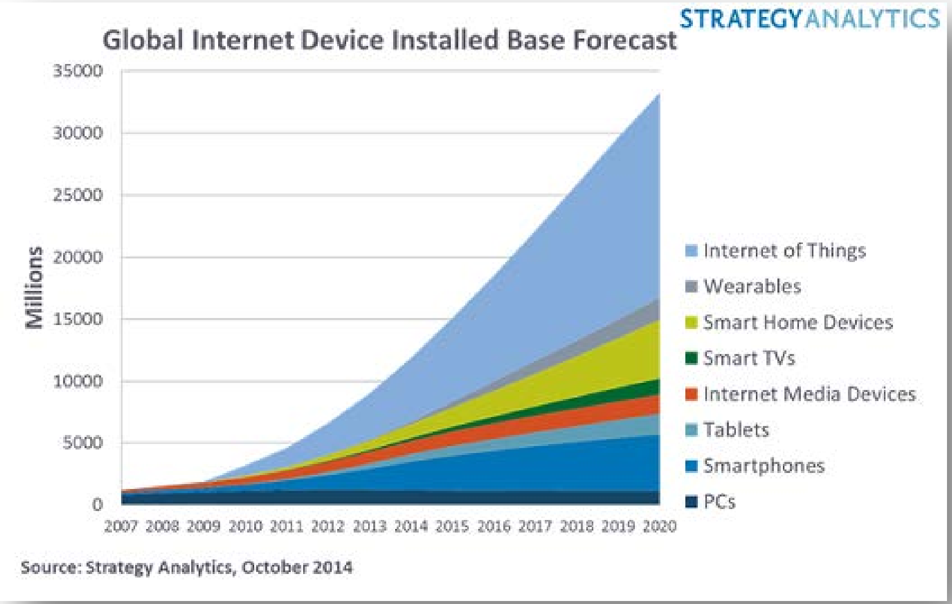


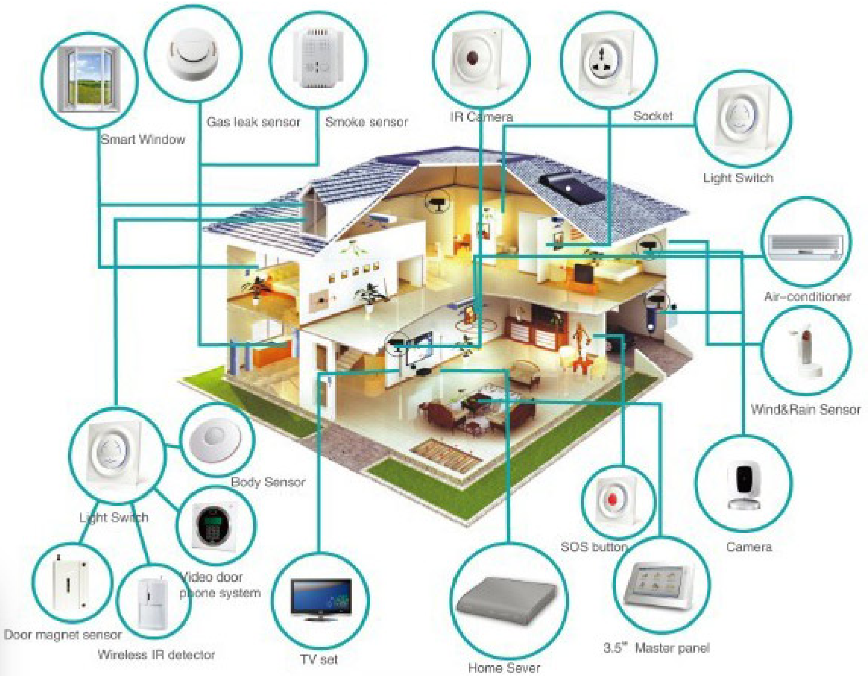


Source: Netmanias, 2015 – data for South Korea

More Devices per Subscriber

- ~12 billion internet-connected devices in 2015
  - ~1.7 devices per person
- Expecting 33+ billion devices by 2020, driven by IoT, smart home, smartphones, etc.
  - ~4.3 devices per person



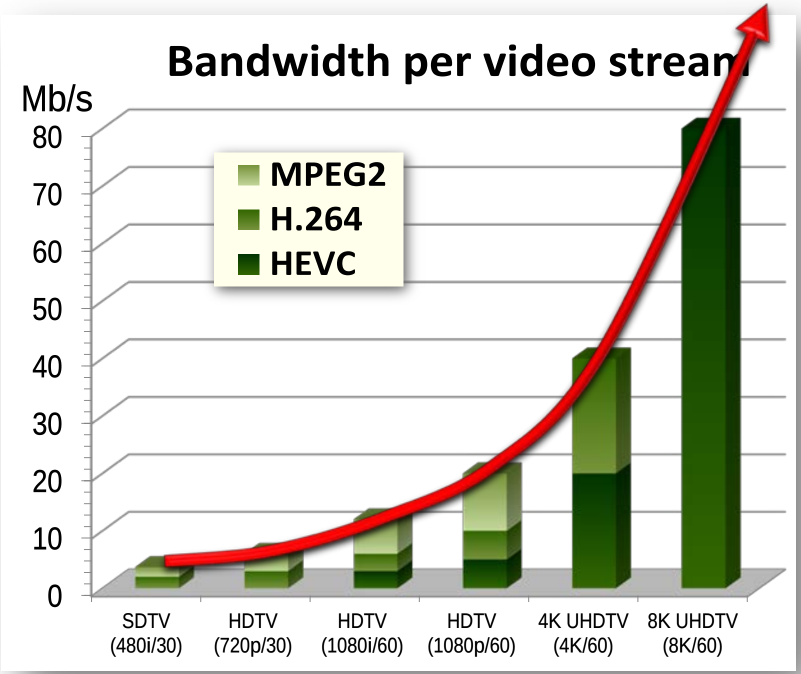


- Emerging IoT devices will dominate connected world
  - M2M
  - Smart home
  - Smart objects
  - Smart grid
  - Smart cities

Increasing Data Rates per Device / App

- **Improving quality of streaming video services**
  - HD is here
  - Next step: 4K with 60 fps
  - DisplayPort 2.1 will support 8K @ 60 fps and 4K @ 120/240 fps
- **Gaming As A Service (GaaS)**
  - Nvidia announced GaaS with full HD at 60 fps:
    - 15 Mb/s is required
    - 50 Mb/s is recommended

Source: http://www.polygon.com/2015/3/5/8146683/nvidia-shield-console



- **Telepresence, teleHealth …**
  - HD video & sound, with virtual reality in the future
  - Remote life sign monitoring, analysis, tele-radiology, virtual house calls …

Increasing Data Rates per Device/App

- **More concurrent online sessions or parallel video streams**
  - Longer online sessions, with higher peak rates per device
  - Multiple video streams for split-screen / picture-in-picture

Sky adds split-screen Formula-1 viewing

- **Content personalization**
  - More on-demand / time-shifted and less broadcast increases bandwidth consumption per sub

"Comcast customers can now live-stream videos over the Internet from their smartphone directly to the TV to share with friends and family."

Comcast press release, 4 May 2015

New Apps Require Higher Rates

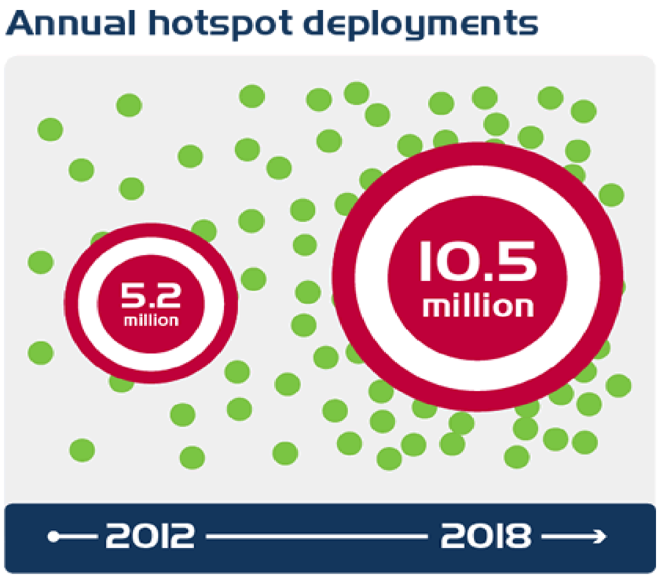
"Schools that switched from Windows-based notebooks to Chromebooks saw 700 times increase in network traffic."

http://www.slideshare.net/PrincipledTechnologies/chromebook-vs-windows-notebook-network-traffic-analysis

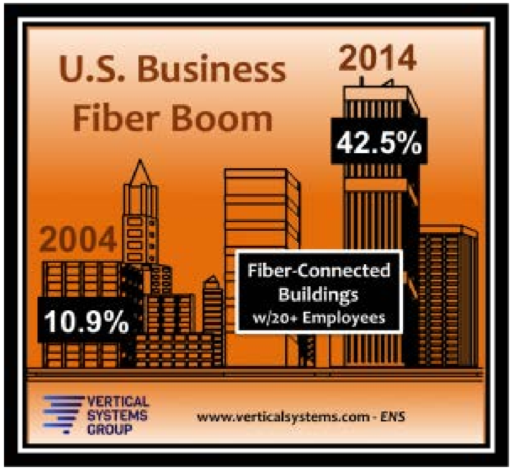
- **Faster-Than-Real-Time**
  - Prefetching digital content onto your device to combat network impairments (loss, latency, etc.)
- **Download-To-Go**
  - Downloading digital content (movies, music) to a tablet or car entertainment system before travel
- **Cloud services integrated into all major operating systems**
  - Access content anywhere, on any device, at any time, with no lags
  - Cloud compute and storage increase access bandwidth consumption

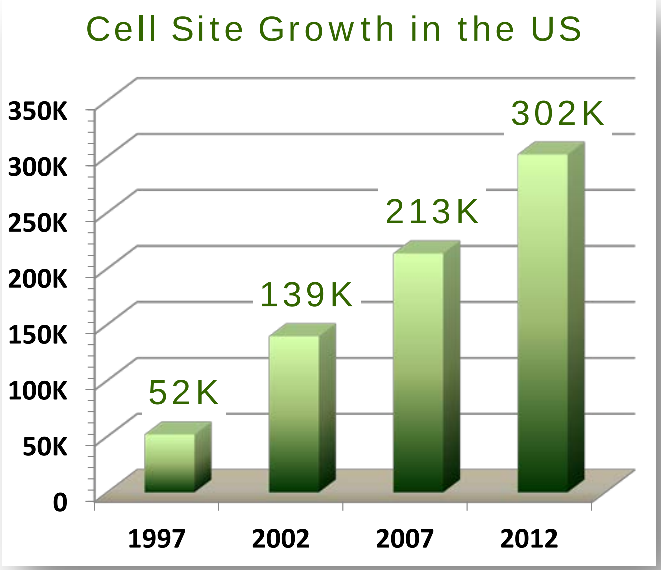
Growing Number of Business Subs

- **Major trends:**
  - Continued high rate of deployment of new cell towers and public Wi-Fi APs
  - Existing businesses move from mobile to fixed broadband for better SLA and higher data rates
  - Growing number of small businesses and home offices switching to business-grade access: Doctor's offices, home offices, etc.
- **High-speed, high-reliability access is now considered fundamental to successful business!**



Source: Wireless Broadband Alliance, 2015



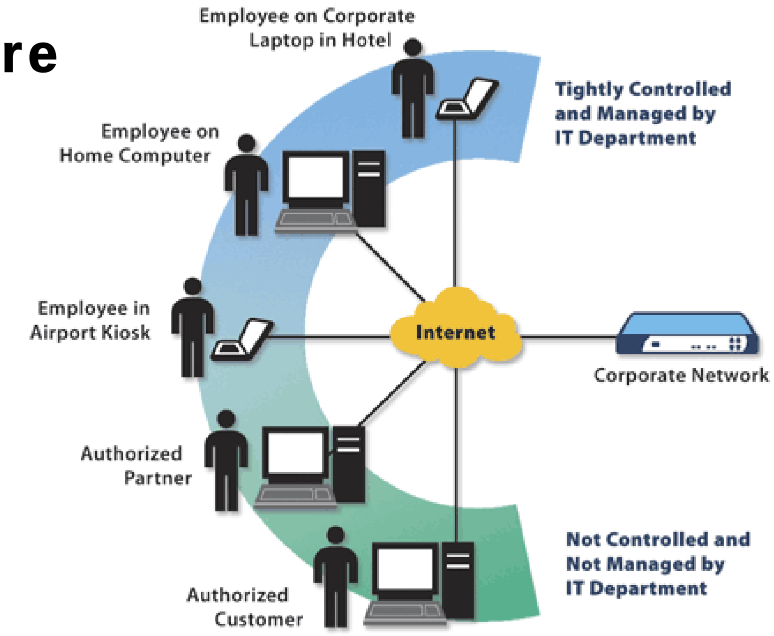


Source: DXX Report, March 2013

BW Intensive Business Apps

- Cloud and SAN solutions drive bandwidth demand
  - For enterprises with demand for secure “big data” storage

- Advanced “remote office” solutions for telecommuting
  - Access to corporate networks via VPN
  - No local data storage for security
- Outsourced IT staff / infrastructure
  - Managed firewall
  - Intrusion detection
  - DDoS mitigation
  - Other security solutions
  - Remote (cloud) compute & storage
- Rapid increase in number of connected devices per business
  - Laptops, tablets, smartphones, etc.

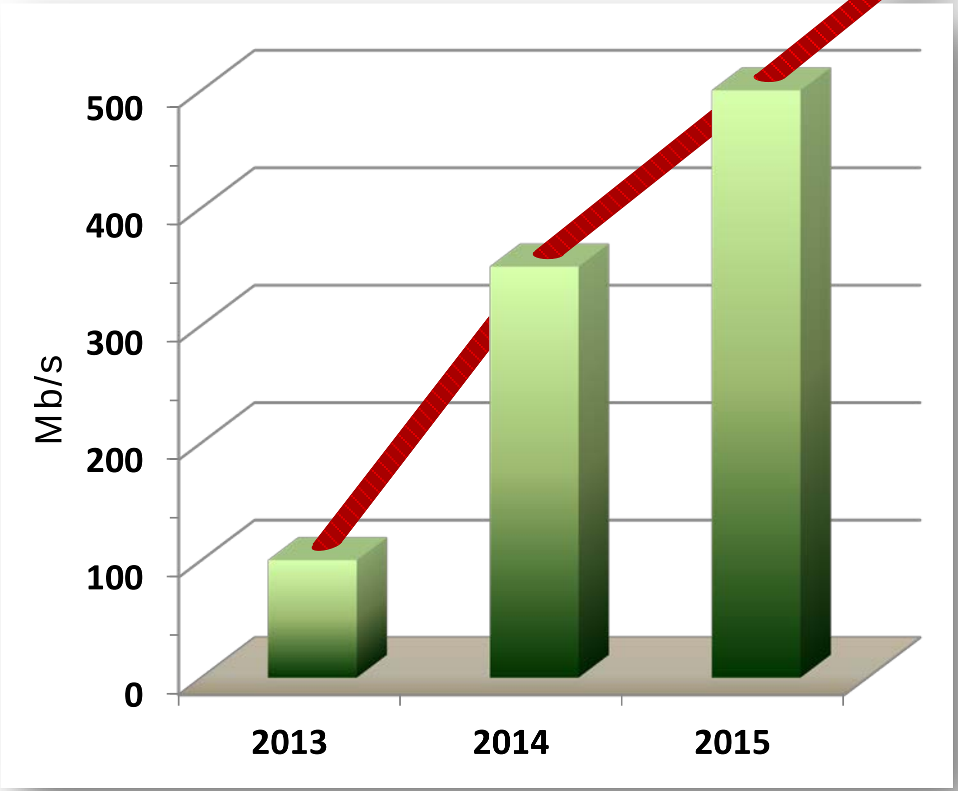


Cellular Backhaul Bandwidth

- Assuming the current growth rate continues, 1 Gb/s per cell tower in urban areas will be required by end of 2016

- Similar bandwidth growth trend is visible in all cell towers in all locations, though on different time scales.

Bandwidth demand per cell tower



2013: 100 Mb/s – mostly 3G and little 4G traffic

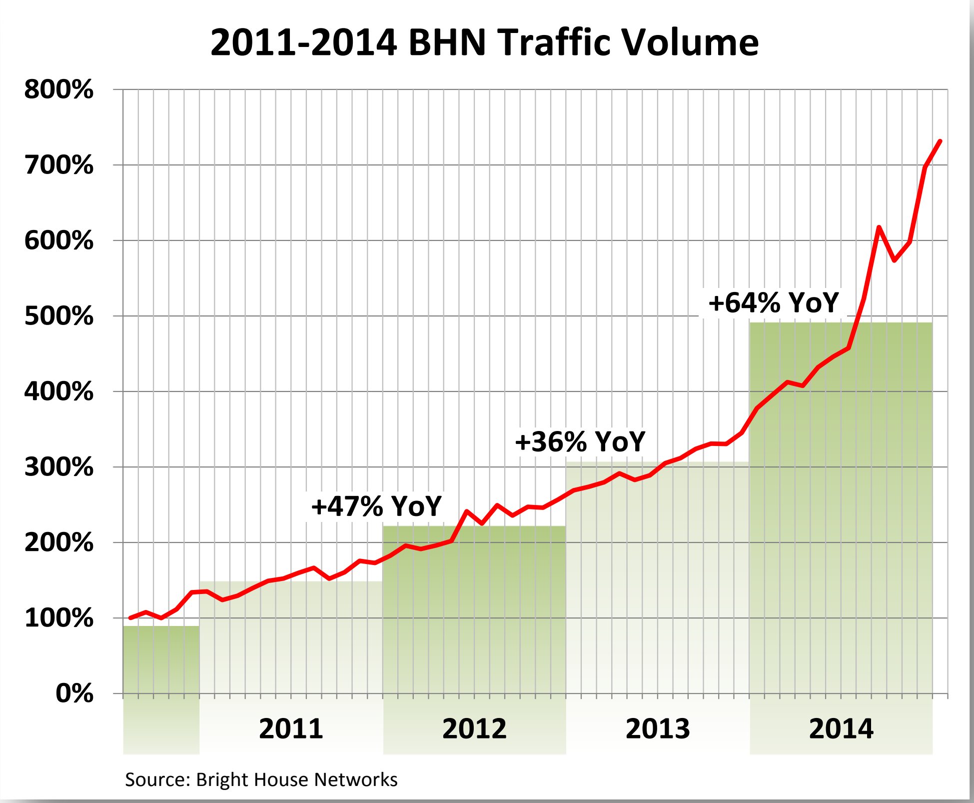
2014: ~350 Mb/s – broader adoption of 4G devices (single channel).

2015: ~500 Mb/s (projected demand) – proliferation of 4G channel bonding.

Source: internal analysis of Bright House Networks

Unabated Bandwidth Growth

- **Bandwidth CAGR above 20% across industry for the last 5+ years**
  - Some operators see CAGR of 64% for last 4 years!
- **Business services deployed without oversubscription**
  - Operators run out of bandwidth on OLT ports before running out of power budget



- **Residential access bandwidth demand closely follows the evolution of wired and wireless home networks**
  - In 3-5 years, home network speeds will increase to 2.5/5G
  - Last month Comcast started deployments of 2 Gb/s symmetric residential service (15th speed increase in 13 years)

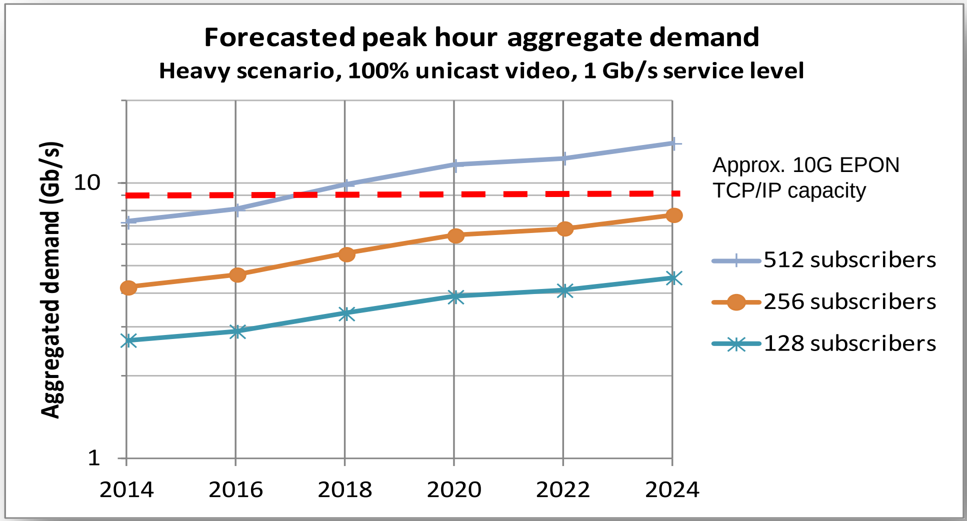
Residential demand can break 10G-EPON

- A large fraction of broadband users live in Multi-Dwelling Units (MDUs)

MDU ONUs

- Fiber-to-the-Building (MDU) aggregates hundreds of subscribers on a single PON

- In dense MDU environments, the 10G-EPON capacity is predicted to be insufficient



E. Harstead, R. Sharpe, "Forecasting of Access Network Bandwidth Demands for Aggregated Subscribers using Monte Carlo Methods", IEEE Comm. Mag., Mar. 2015.

Bandwidth Targets (Business Access)

- In a typical business access scenario, the NG-EPON is expected to serve a combination of small, medium, and large businesses, and to provide backhaul connectivity for cellular towers.

Subscriber Type	Guaranteed Access Bandwidth Range (2018-2025)
Small Business	0.1–1 Gbps
Medium Business	1–2.5 Gbps
Large Business	5–10 Gbps
Cellular Backhaul	1–5 Gbps

Typical Combinations of Subscribers				Required PON Capacity
Small Business	Medium Business	Large Business	Cellular Tower	
24	8	-	-	~ 30 Gbps
16	8	-	8	~ 32 Gbps
-	16	1	8	~ 38 Gbps
16	8	2	4	~ 40 Gbps

Market Demands

NG•EPON

- Capacity of existing access solutions will be exhausted in several years
- New solutions are needed that would achieve
  - 25+ Gb/s per PON for residential and
  - 40+ Gb/s per PON for businesses
- The new solution has to be able to
  - Operate over existing ODNs
  - Support mixed business and residential access
  - Coexist with previous generation(s)

Now is the time to start working on the new standard.

NG-EPON
Technical Feasibility

Duane Remein, Huawei
Ed Harstead, Alcatel-Lucent
Bill Powell, Alcatel-Lucent

Technology Advancements

- The last time 802.3 considered technology selection for optical access was in 2006-2007, during the early stages of the 10G-EPON project (802.3av)

- Since that time, new technologies have emerged and/or matured enough to become feasible candidates for the next generation of optical access
  - **Optical component advances may allow use of WDM in EPON**
    - Optical Arrays
    - Tunable Lasers
    - Tunable Optical Receivers
  - **Advanced optical modulation may allow 25 Gb/s serial transmission using 10 Gb/s optical components**
    - Duobinary
    - PAM4
  - **802.3 optical 25 Gb/s ecosystem**

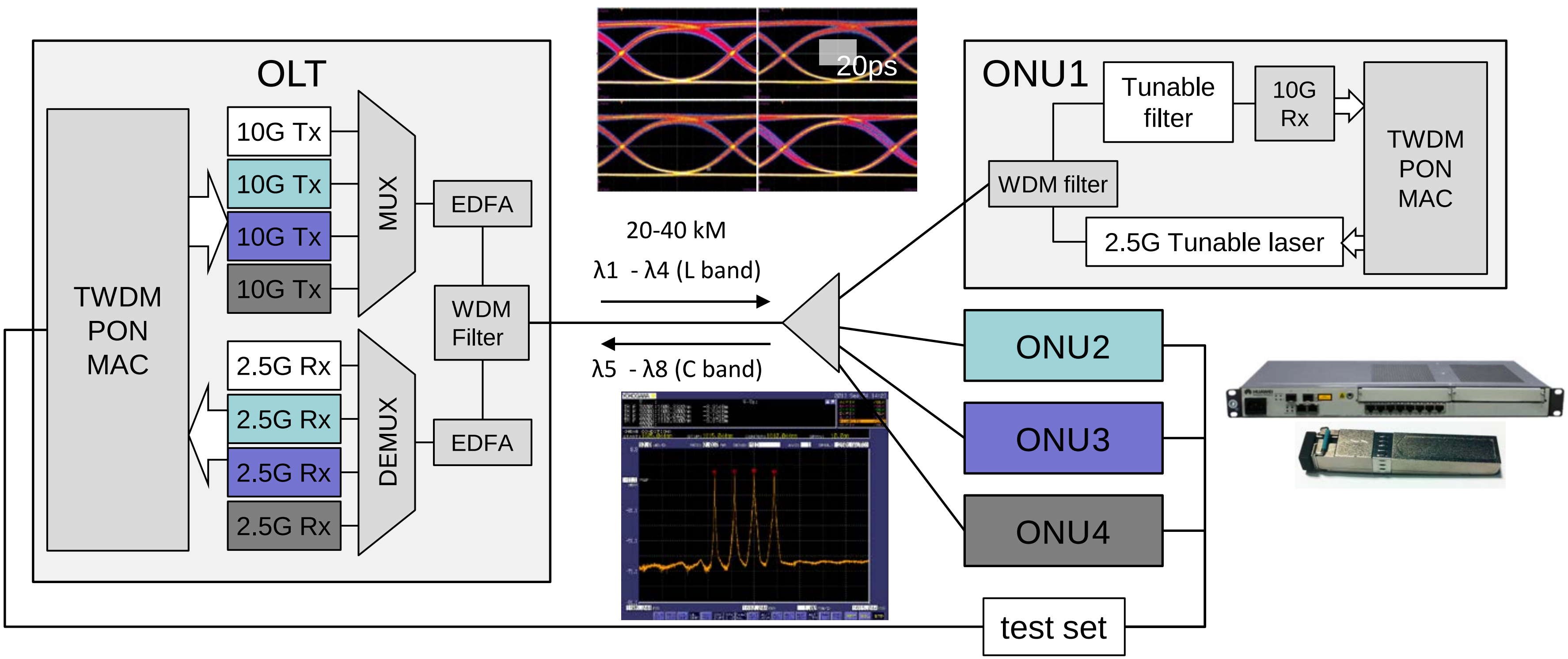
Recent TWDM Breakthroughs

- **World's First Demonstration of Pluggable Optical Transceiver Modules for Flexible TWDM PONs** (Huawei, presented at ECOC 2013, *details on next slide*)
- **100-ns λ-selective Burst-Mode Transceiver for 40-km Reach Symmetric 40-Gbit/s WDM/TDM-PON** (NTT, presented at ECOC 2013)
- **Low Cost TWDM by Wavelength-Set Division Multiplexing** (Alcatel Lucent, published in Bell Labs Technical Journal, December 2013.)
- **Demonstration of 10G Burst-Mode DML and EDC in Symmetric 40Gbit/s TWDM-PON over 40km Passive Reach** (ZTE, presented at OFC 2014)
- **First Field Trial of 40-km Reach and 1024-Split Symmetric-Rate 40-Gbit/s λ-tunable WDM/TDM-PON** (NTT, presented at OFC 2015.)
- **Demonstration of a Symmetric 40 Gbit/s TWDM-PON Over 40 km Passive Reach Using 10 G Burst-Mode DML and EDC for Upstream Transmission** (ZTE, published in Journal of Optical Communications and Networking, 2015)

TWDM System Demo

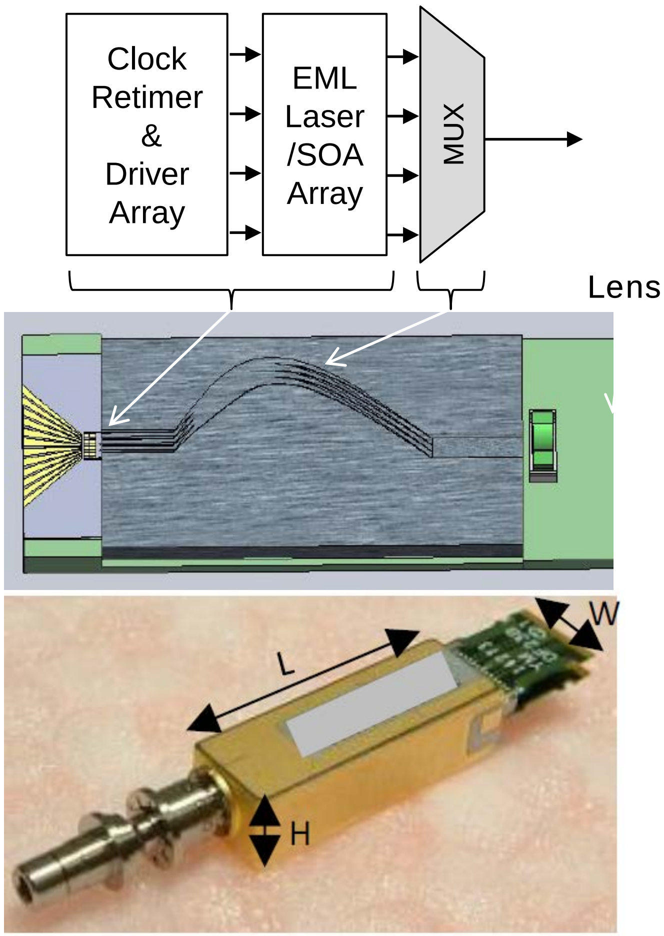
- Downstream: 4 λ's @ 10Gb/s each
- Upstream: 4 λ's @ 2.5 Gb/s each
- 20 km with 1:64 split

- 4 ONUs with pluggable optics
  - Tunable optical filter
  - Tunable laser with thermal control



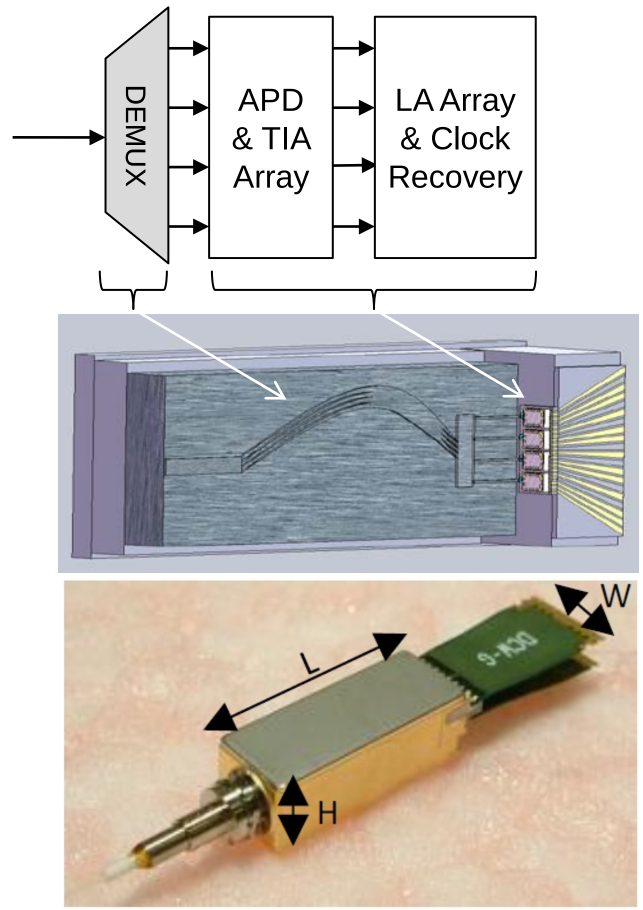
Optical Arrays

❑ 4 Channel EML Array



W5.3xH6.3xL19.6 mm

❑ 4 Channel APD Array



W6.8xH5.8xL17.3 mm

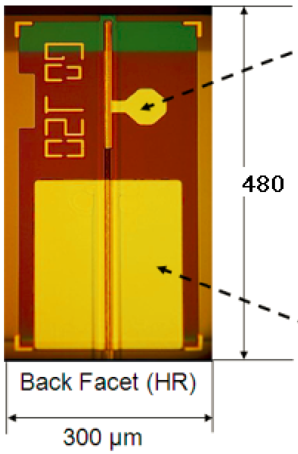
K. Taguchi, K. Asaka, M. Fujiwara, S. Kaneko, T.i Yoshida, Y. Fujita, H. Iwamura, M. Kashima, S. Furusawa, M. Sarashina, H.Tamai, A. Suzuki, T. Mukojima, S. Kimura, K. Suzuki and A. Otaka, "First Field Trial of 40-km Reach and 1024-Split Symmetric-Rate 40-Gbit/s-tunable WDM/TDM-PON", OFC 2015.

Tunable Optics

Tunable Transmitter Options

	Tuning Range	Tuning Time
Distributed Feedback (DFB) laser		
– Thermal tuning (λ changes with ΔT)	3-4 nm	ms
Distributed Bragg Reflector (DBR)		
– Grating Current (λ changes with ΔI at grating)	8 nm	ns

Jinglei, "Tunable optics technology and relative cost trends," http://www.ieee802.org/3/ad_hoc/ngepon/public/mar14/jinglei_ngepon_01_0314.pdf, March 2014, Beijing, PRC.



DFB laser with an electro-absorption (EA) modulator

Source: Archcom Technology

Tunable Receiver Options

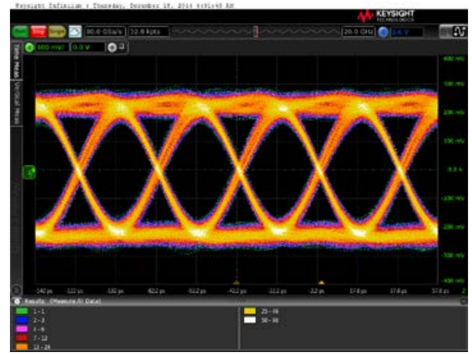
	Tuning Range	Tuning Time
Fabry-Perot Filters		
– Thermo-optical	40 nm	s
– Liquid Crystal	30 nm	ms
– MEMS	221 nm	ms
Waveguide filters		
– MZI	15 nm	μs
– Micro Ring	20 nm	ms
Micro-motor filters		
– Angle Adjustment	80 nm	ms
– Linear Variable	380 nm	ms
– Cavity Length Adjustment	60 nm	ms

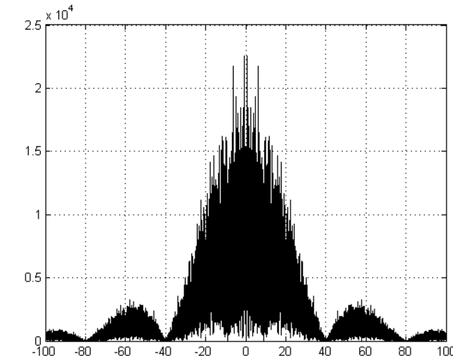
Minghui Tao, Zhicheng Ye, "Tunable Receiver Technologies", http://www.ieee802.org/3/ad_hoc/ngepon/public/sep14/tao_ngepon_01a_0914.pdf, September 2014, Kanata, Ontario.

Modulation Options for NG-EPON

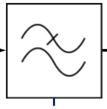
NRZ OOK

NRZ {0,1}

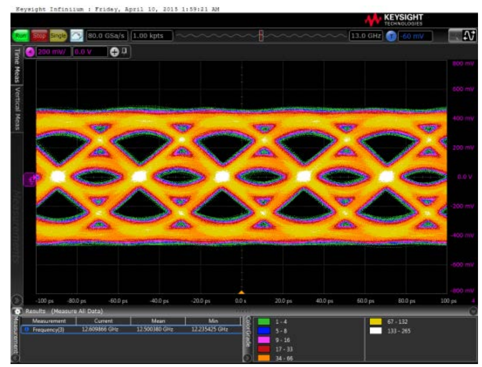


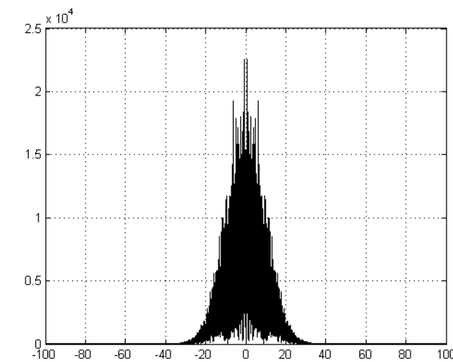


Duobinary (electrical): low pass filter approximation

NRZ {0,1} →  → {0,1,2}

Low pass filter bandwidth ≈ 40% of NRZ

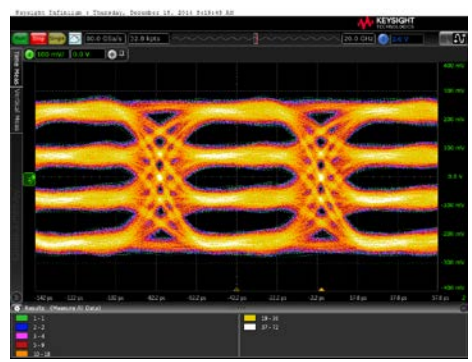


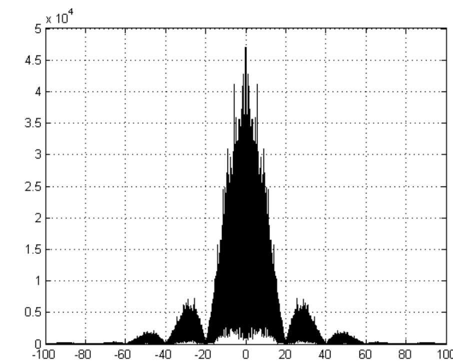


PAM4

MSB {0,1} →
LSB {0,1} →
4-level encoder → {0,1,2,3}

Possible re-use of PAM4 from 100GBASE-KP4, 802.3bs CDAUI-8 and 8x50G 10 km SMF



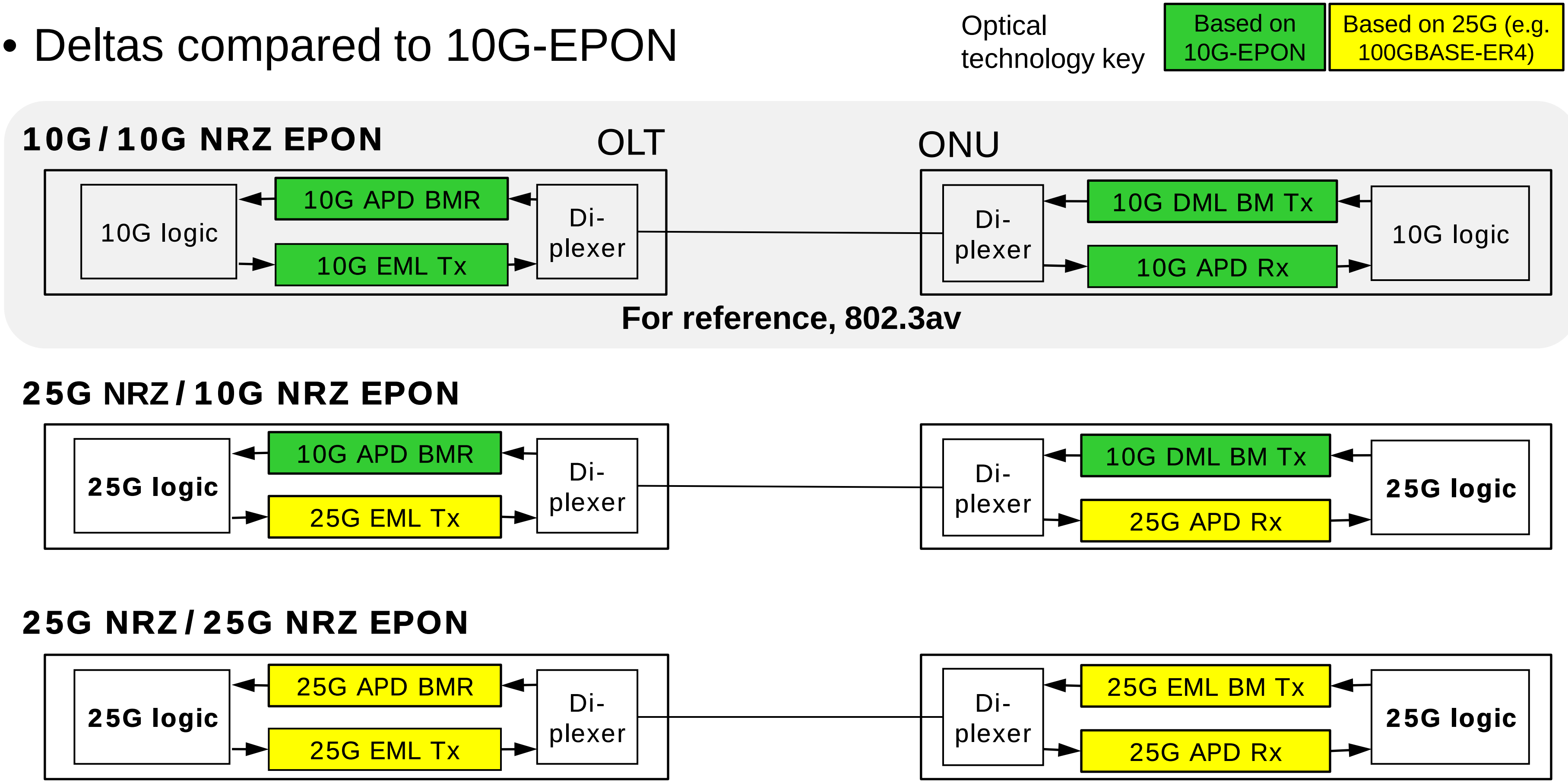


Time

Frequency

25 Gb/s TDM PON: NRZ Modulation

- Deltas compared to 10G-EPON

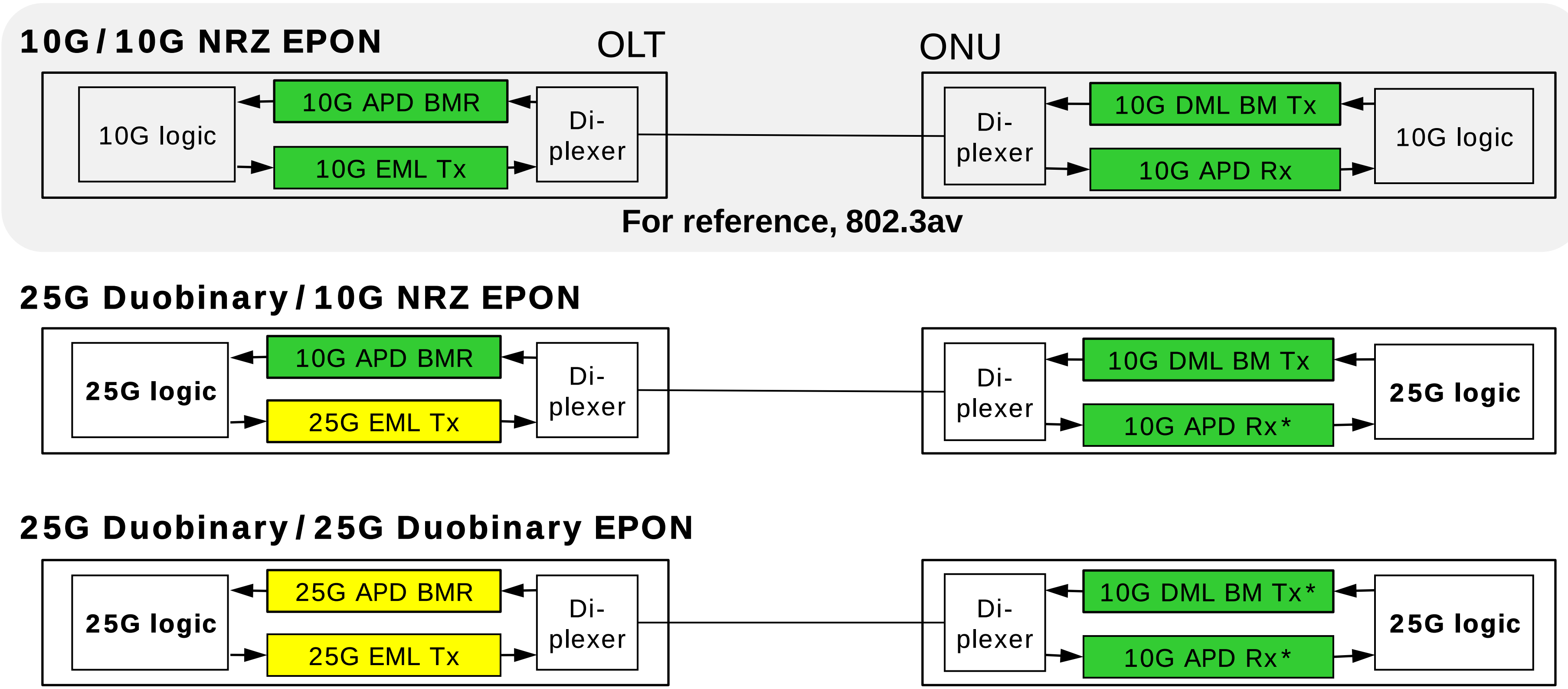


- 25 Gb/s optics required in the ONU and OLT
  - Potential re-use of 25 Gb/s 100GBASE-ER4 optics

25 Gb/s TDM PON: Duobinary Modulation

- Deltas compared to 10G-EPON

Optical technology key: Based on 10G-EPON | Based on 25G (e.g. 100GBASE-ER4)

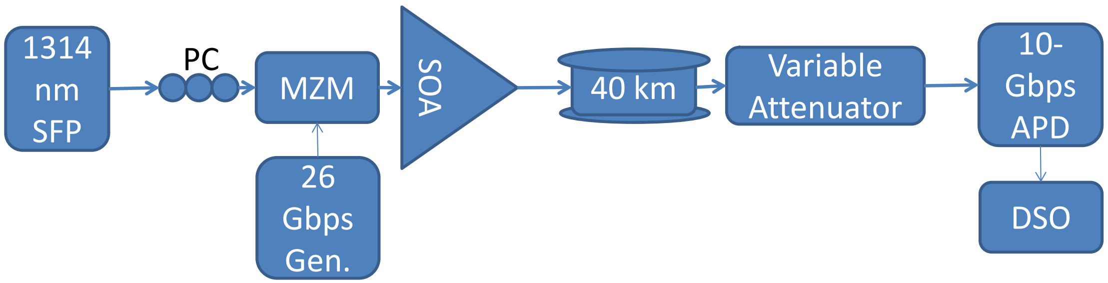


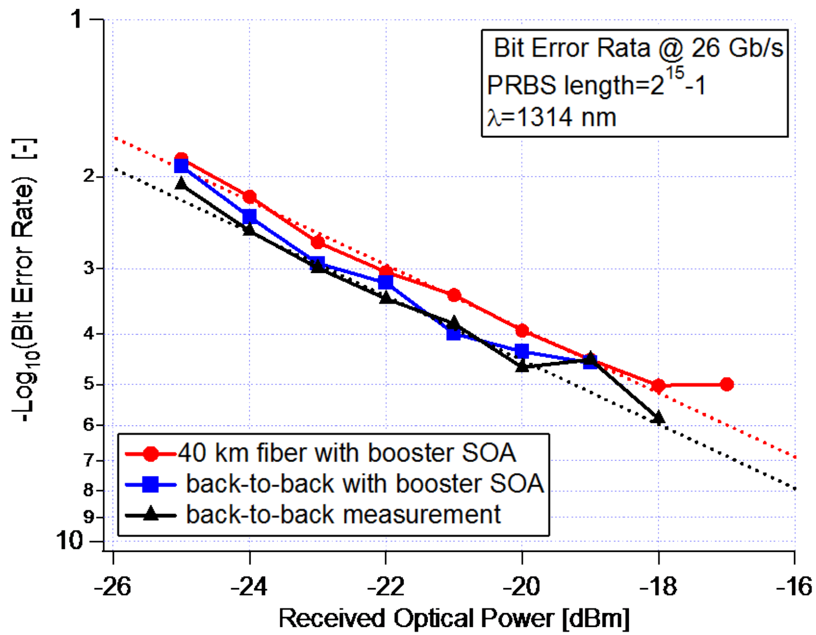
*Low pass filter function

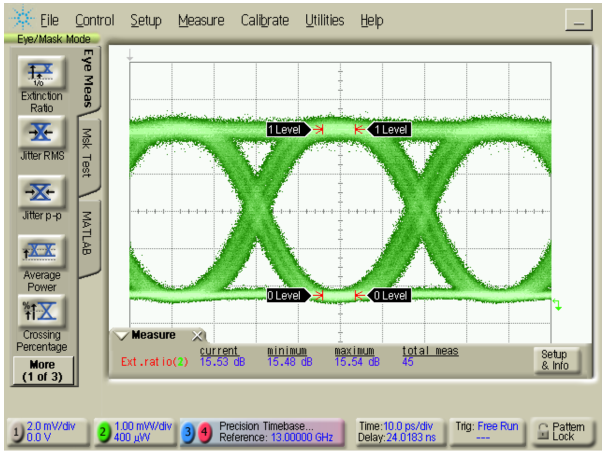
- In the ONU, same 10G optics as 10G-EPON
- Potential re-use of 25 Gb/s 100GBASE-ER4 optics in the OLT

Duobinary Modulation Demo

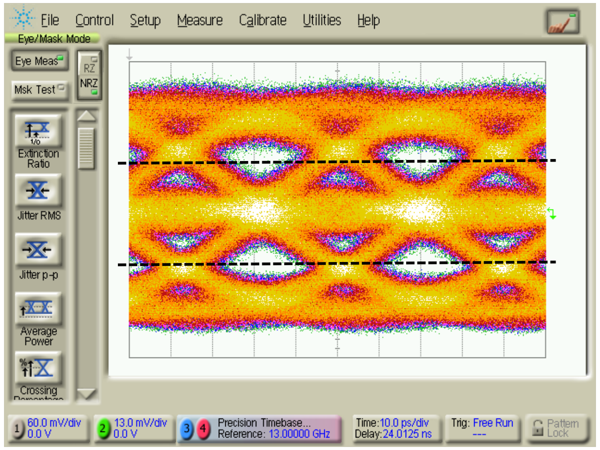
26 Gb/s downstream, with 10 Gb/s receiver







Transmitted NRZ-OOK eye

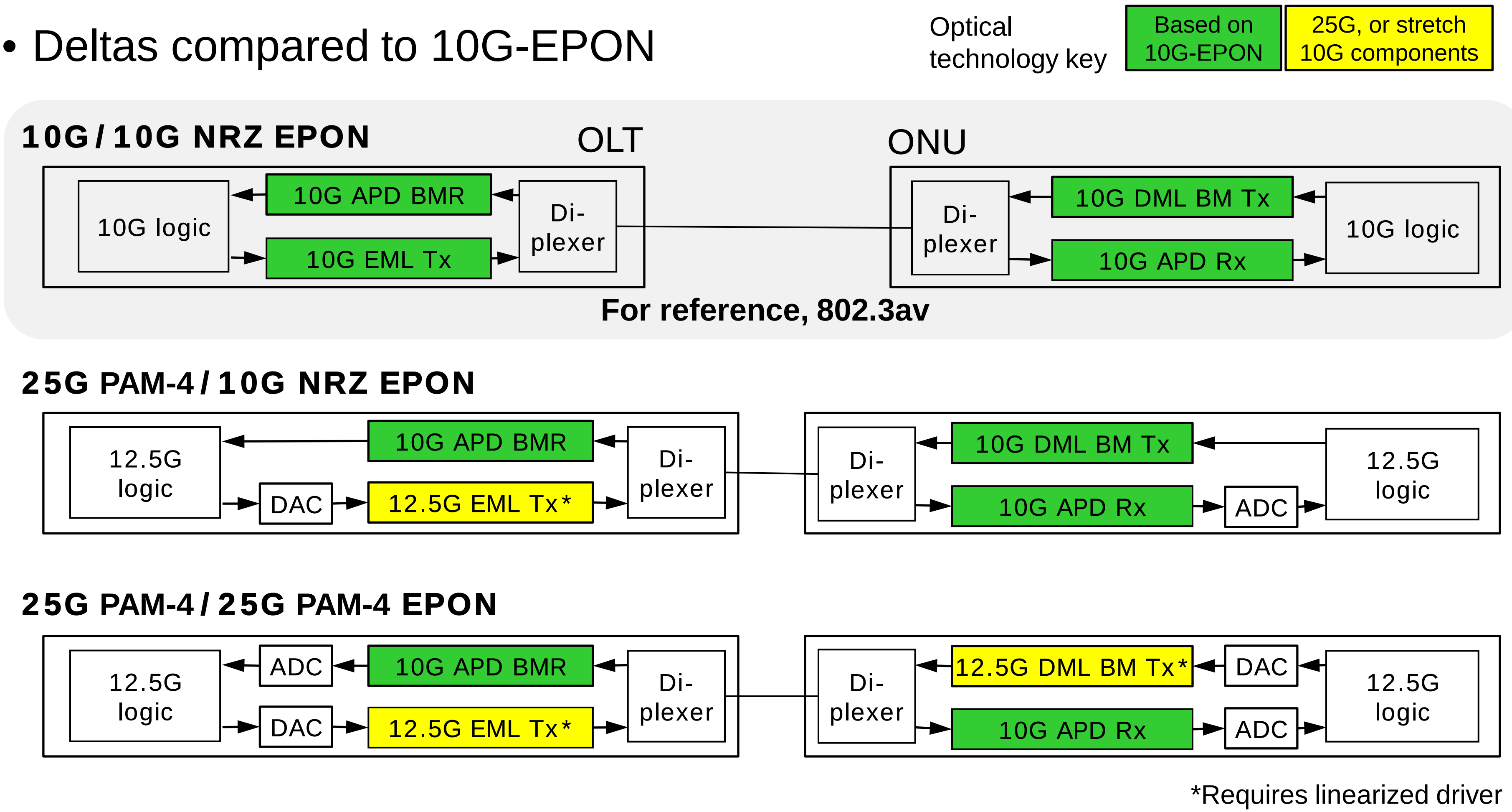


Received duobinary eye
(with decision threshold levels indicated)

D. van Veen, V. Houtsma, P. Winzer, and P. Vetter (Bell Labs), "26-Gbps PON Transmission over 40-km using Duobinary Detection with a Low Cost 7-GHz APD-Based Receiver," ECOC 2012 OSA Technical Digest, Tu.3.B.1

25 Gb/s TDM PON: PAM4 Modulation

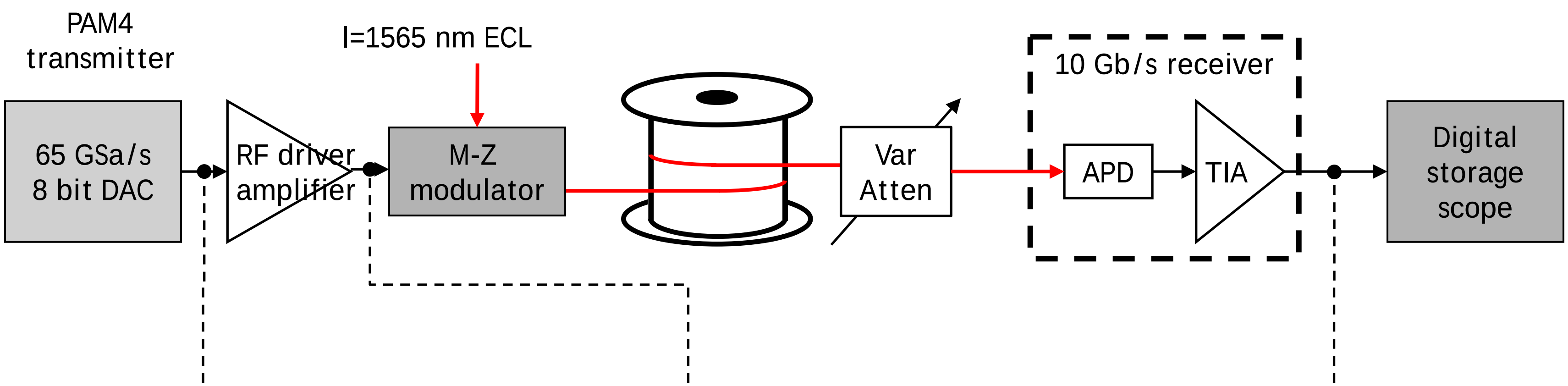
- Deltas compared to 10G-EPON

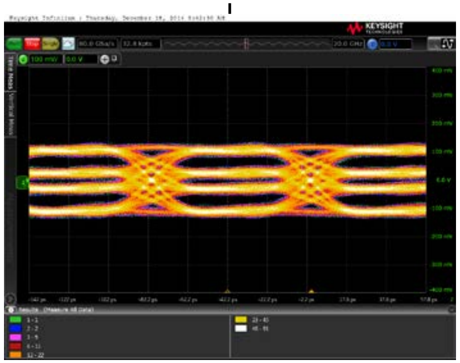


- Target = same optics as 10G-EPON
  - Might be possible to stretch 10 Gb/s components (to be confirmed)

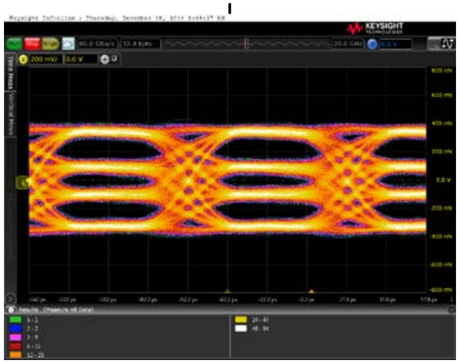
PAM4 Modulation Demo

25 Gb/s downstream, with 10 Gb/s receiver

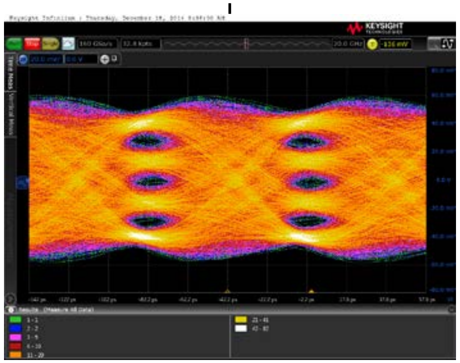




Pre-distortion



Linearized transmitted signal



Back-to-back receiver sensitivity @10^{-3} BER = -21.5 dBm

V. Houtsma, D. van Veen, E. Harstead, “PAM-4 vs. duobinary modulation @25 Gb/s”, ngepon_0115_houtsma_01, Jan. 2015.

Future Decisions

NG-EPON

- **MAC rate**
  - 10 Gb/s, 25 Gb/s, 40 Gb/s, 100 Gb/s?

- **One or multiple wavelengths in each direction? If multiple wavelengths to be used …**
  - How many wavelengths?
  - Reuse ITU-T G.989.2 NG-PON2 wavelength plan or define a new one?
  - Optics in the ONU: fixed or tunable? Or develop a protocol that allows for either?
  - Specify multi-lane PHYs, channel bonding, or none.

- **Line rate per wavelength**
  - 10 Gb/s, 25 Gb/s, 40 Gb/s, other?
  - Modulation scheme: NRZ OOK, duobinary, PAM4?

Summary

Curtis Knittle, CableLabs

Marketing Recap

Increasing bandwidth

- Number of subscribers is still growing
- Applications becoming more bandwidth-hungry
- More Internet-connected devices per subscriber
- **Demand for access capacity is growing exponentially**

10G-EPON will reach its limits soon

- Bit rates greater than 10 Gb/s will be needed by 2018 for some applications
- **Now is the time to start working on next gen. access**

What is needed

- 25+ Gb/s for residential and 40+ Gb/s for business access
- Converged access platform for business and residential
- Coexistence with previous generation(s) and gradual upgrade capability

Technology Recap

Potential technologies prototyped

- WDM stacking of multiple TDM PON systems
- Optical receiver and/or transmitter arrays
- Tunable burst mode transmitters and receivers
- Advanced modulations schemes (duobinary, PAM4) for balancing the cost of optics with the cost of electronics

Future technology decisions

- Single or multiple wavelengths in each direction
  - Number of wavelengths
  - Wavelength plan
  - Tunability
  - Channel bonding or multi-lane PHY
- Bit rate per wavelength
  - 10 Gb/s, 25 Gb/s, 40Gb/s
  - Modulation scheme: Duobinary, PAM4, NRZ

Summary

NG-EPON

1. Market demands the next generation access solution
2. There exist technologies that would allow the next generation of access systems to achieve the required performance at a reasonable cost
3. Presenters and supporters recommend formation of a Study Group to develop PAR, objectives, and CSD

Supporters

Alan M. Brown, CommScope	Curtis Donahue, UNH IOL
Alan Tipper, Semtech	Curtis Knittle, CableLabs
Bill Powell, Alcatel-Lucent	David Li, Hisense-Ligent
Bharat Tailor, Semtech	Dawit Asfaha, Shaw Communications
Bruce Chow, Corning	Denis Beaudoin, Texas Instruments
Craig Hrycoy, Shaw Communications	Duane Remein, Huawei

Wait, more supporters!

Ed Harstead,	Alcatel-Lucent	Mark Laubach,	Broadcom
Ed Mallette,	Bright House Networks	Matt Petersen,	Charter Communications
Eugene Dai,	Cox Communications	Mehmet Toy,	Comcast
Frank Effenberger,	Huawei	Michael Emmendorfer,	Arris
Glen Kramer,	Broadcom	Michael Peters,	Sumitomo
Guo Yong,	ZTE	Raz Gabe,	PMC-Sierra
Hanhyub Lee,	ETRI	Rick Li,	Cortina Systems
Hesham Elbakoury,	Huawei	Robin Lavoie,	Cogeco
Hossam Salib,	Comcast	Ryan Hirth,	Broadcom
Hussam Tarazi,	Shaw Communications	Ryan Tucker,	Charter Communications
HwanSeok Chung,	ETRI	Saifur Rahman,	Comcast
Ivan Lamoureux,	Suddenlink	Shane Woodard ,	Suddenlink
Joe Solomon,	Comcast	Shen Chengbin,	China Telecom
John Dickinson,	Bright House Networks	Steve Gorshe,	PMC-Sierra
Jorge Salinger,	Comcast	Toshihiko Kusano,	Oliver Solutions
Kevin Noll,	Time Warner Cable	Victor Blake,	Independent consultant
Liu Qian,	RITT	Yuan Liquan,	ZTE
Lu Yang,	RITT	Zhigang Gong,	O-Net
Marek Hajduczenia,	Bright House Networks	Zhou Zhen,	Fiberhome Technologies

Straw Poll – SG Formation

- Should a study group be formed to develop PAR, CSD, and Objectives for ***Next Generation EPON***?

	All in the room	802.3 voters
Yes		
No		
Abstain		
Room Count		

Straw Poll - Participation

- **I would participate in a “Next Generation EPON” study group in IEEE 802.3**

  Count: __________

- **My company would participate in a “Next Generation EPON” study group**

  Count : __________

Acronyms

ADC	Analog to Digital Converter
APD	Avalanche Photodiode
BM	Burst Mode
BMR	Burst Mode Receiver
DAC	Digital to Analog Converter
DBR	Distributed Bragg Reflector
DFB	Distributed Feedback
DML	Directly Modulated Laser
ECL	External Cavity Laser
EML	Electro-absorptive Modulated Laser
LC	Liquid Crystal
LSB	Least significant bit
MEMS	Micro Electro Mechanical Systems
MSB	Most significant bit
MZ	Mach-Zehnder
MZI	Mach-Zehnder Interferometer
MZM	Mach-Zehnder Modulator
NRZ	Non-return to zero
OOK	On-Off Keying
PAM	Pulse amplitude modulation
PC	Polarization Controller
TWDM	Time and wavelength division multiplexing
UNI	User Network Interface