Latest Developments in Ethernet Passive Optical Networks

Glen Kramer, Teknovus, Inc.

PON Architecture

- Evolution of Optical Access
- PON Flavors
- EPON Timeline

Evolution of the First Mile

Point-to-point links

– *N* fiber lines

– 2*N* transceivers

Concentration switch in the neighborhood

+ *1* fiber line

– Power in the field

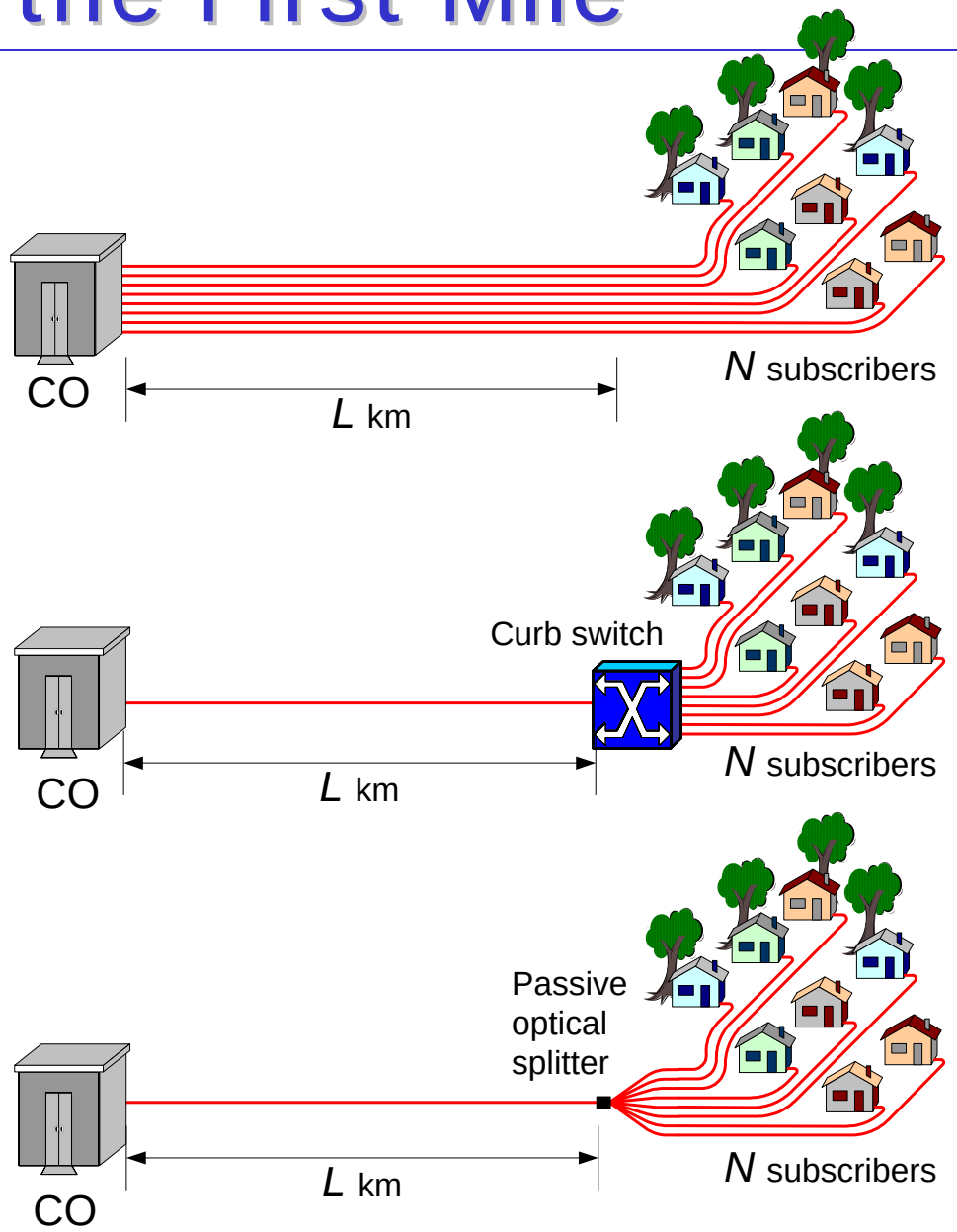
– 2*N* + 2 transceivers

PON – a distributed switch

+ *1* fiber line

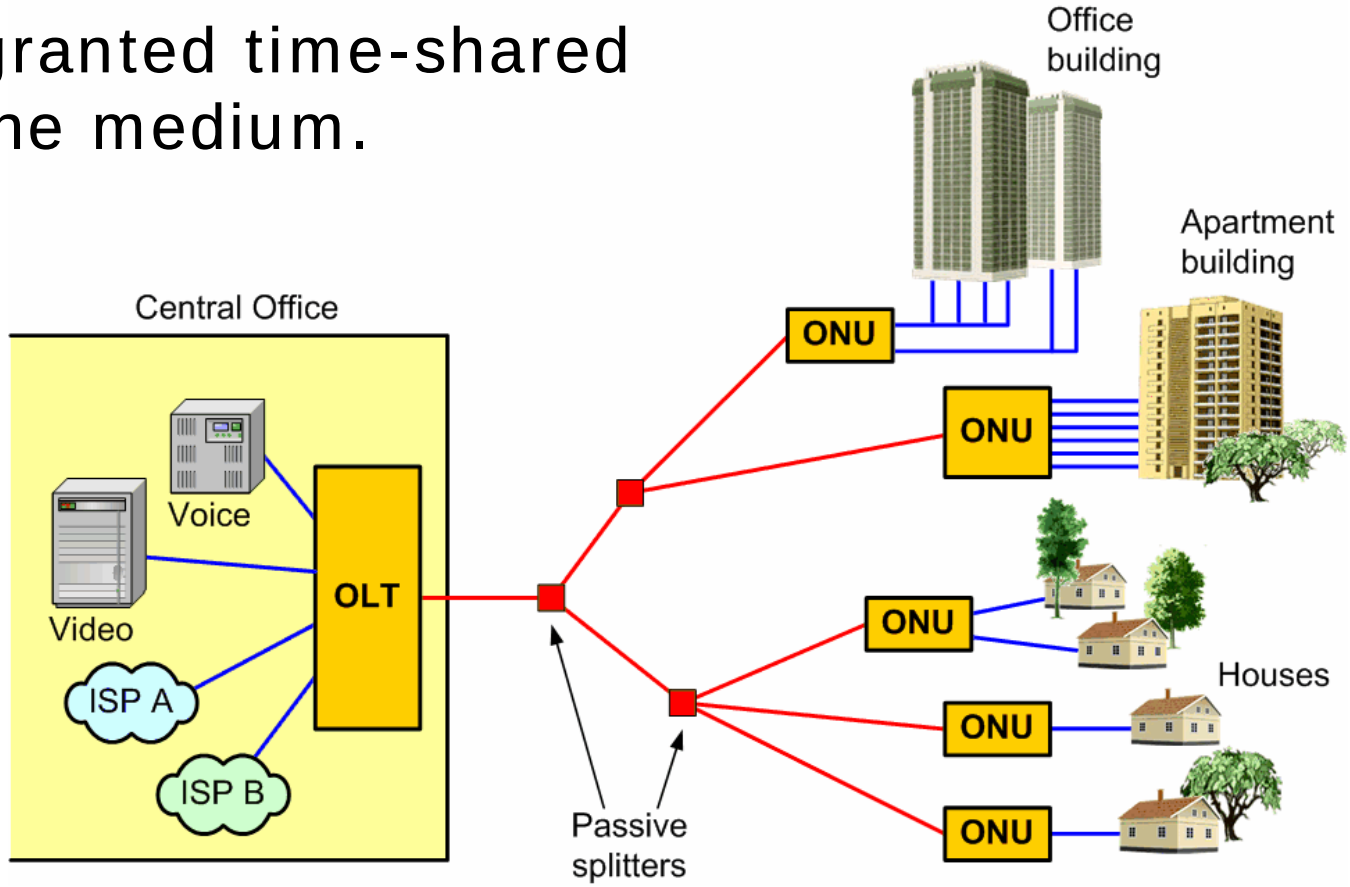
+ *N* + 1 transceivers

+ Path transparency



PON Architecture

- All transmissions are performed between **Optical Line Terminal (OLT)** located in CO and **Optical Network Units (ONUs).**
- ONUs are granted time-shared access to the medium.



Flavors of PON

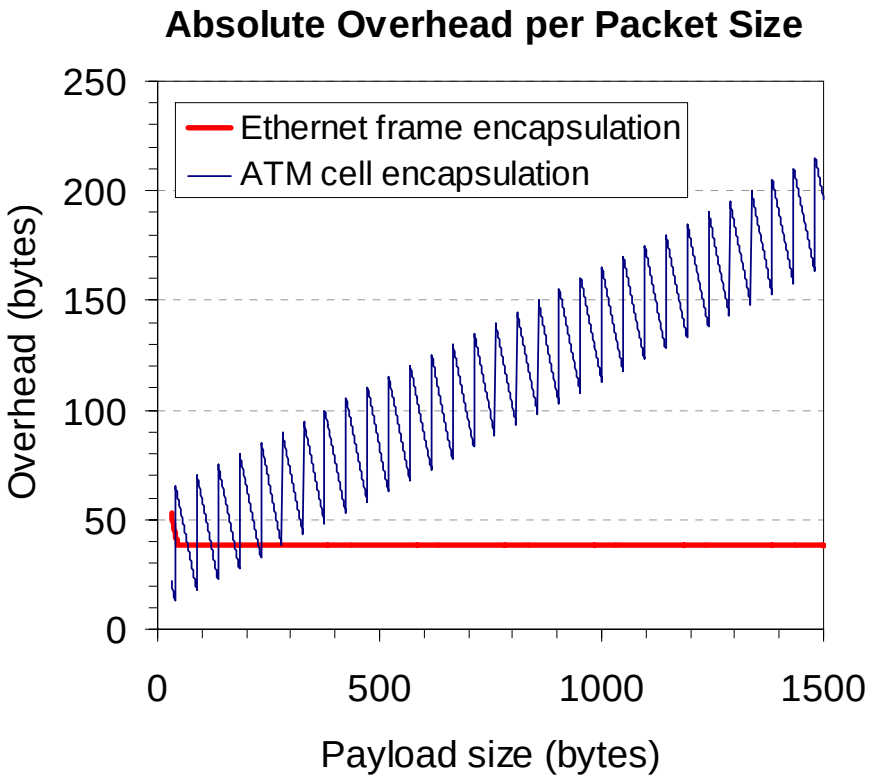
- **APON/BPON**: ATM/Broadband PON (ITU-T G.983)
  - Uses ATM as bearer protocol
  - Developed in FSAN
  - Standardized in 1998-2003
- **GPON**: Gigabit-Capable PON (ITU-T G.984)
  - Based on *Generic Framing Procedure* (G.7041)
  - Developed in FSAN
  - Standardized in 2003-2004
- **EPON**: Ethernet PON (IEEE 802.3ah-2004)
  - Uses Ethernet and *Multi-Point Control Protocol*
  - Developed by IEEE
  - Standardized in June 2004

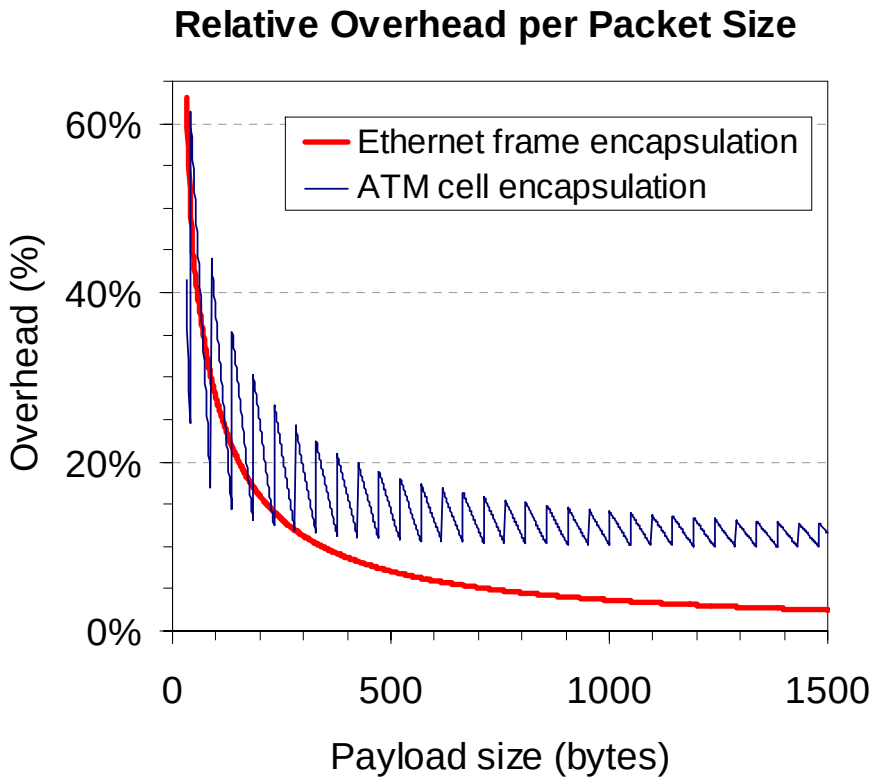
PON Optical Specifications

	APON / BPON	GPON	EPON
Laser on/off	≈ 154 ns *	≈ 13 ns	512 ns
AGC		44 ns *	≤ 400 ns
CDR			≤ 400 ns

* Short AGC intervals in APON/BPON and GPON require optical power leveling
  - Additional protocol to negotiate power level
  - Digital interface to transceiver to set the values
- Short laser on/off times in APON/BPON and GPON require high-speed laser drivers
- Relaxed specification parameters in EPON allow less expensive devices to be built

ATM Encapsulation Overhead





- Ethernet framing adds overhead of 38 bytes per IP payload
- ATM cell tax is dependent on payload size
- For an empirical packet size distribution, Ethernet framing overhead is 7.42%, ATM encapsulation overhead is 13.22%

GPON Protocol Limitations

- Current PON constraints are from optical components
- Optical components are continuously improving
- Protocol should be future-proof and should not limit PON performance
  - KDDI has demonstrated EPON with 1x64 physical split and 1x192 logical split. K. Tanaka et. al., "*Demonstration and Performance Analysis of Gigabit-Ethernet PON System Accommodating 64 ONUs*", OFC'2005, Anaheim, March 2005.

	GPON	EPON
Max Logical Reach (km)	60	unlimited
Max Logical Range (km)	20	unlimited
Max Logical Split	128	32767

GPON Upstream Architecture

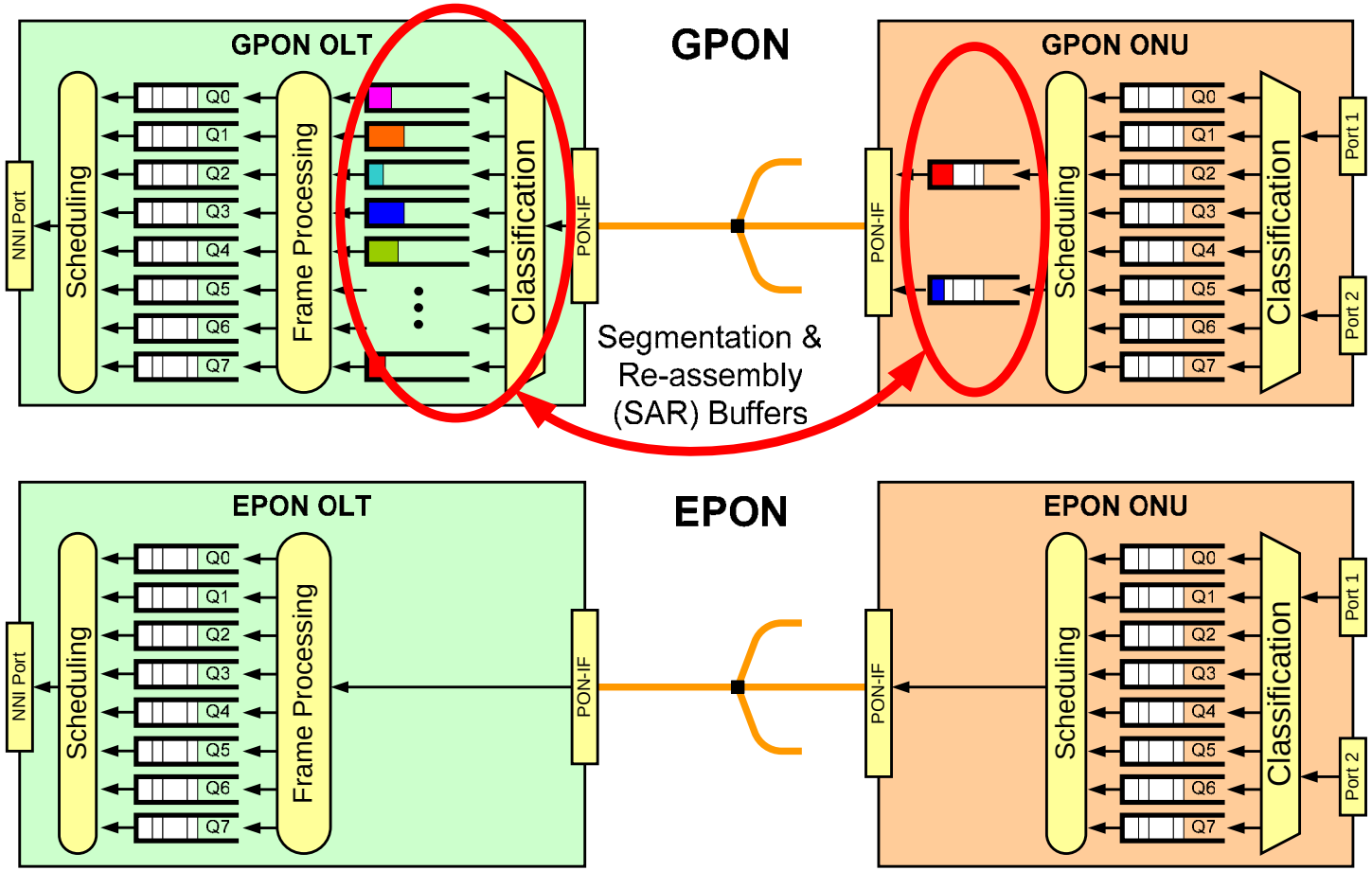
- GPON uses GEM to **Segment and Reassemble** Ethernet frames
- Each connection (Port-ID) requires a separate SAR buffer

GPON OLT

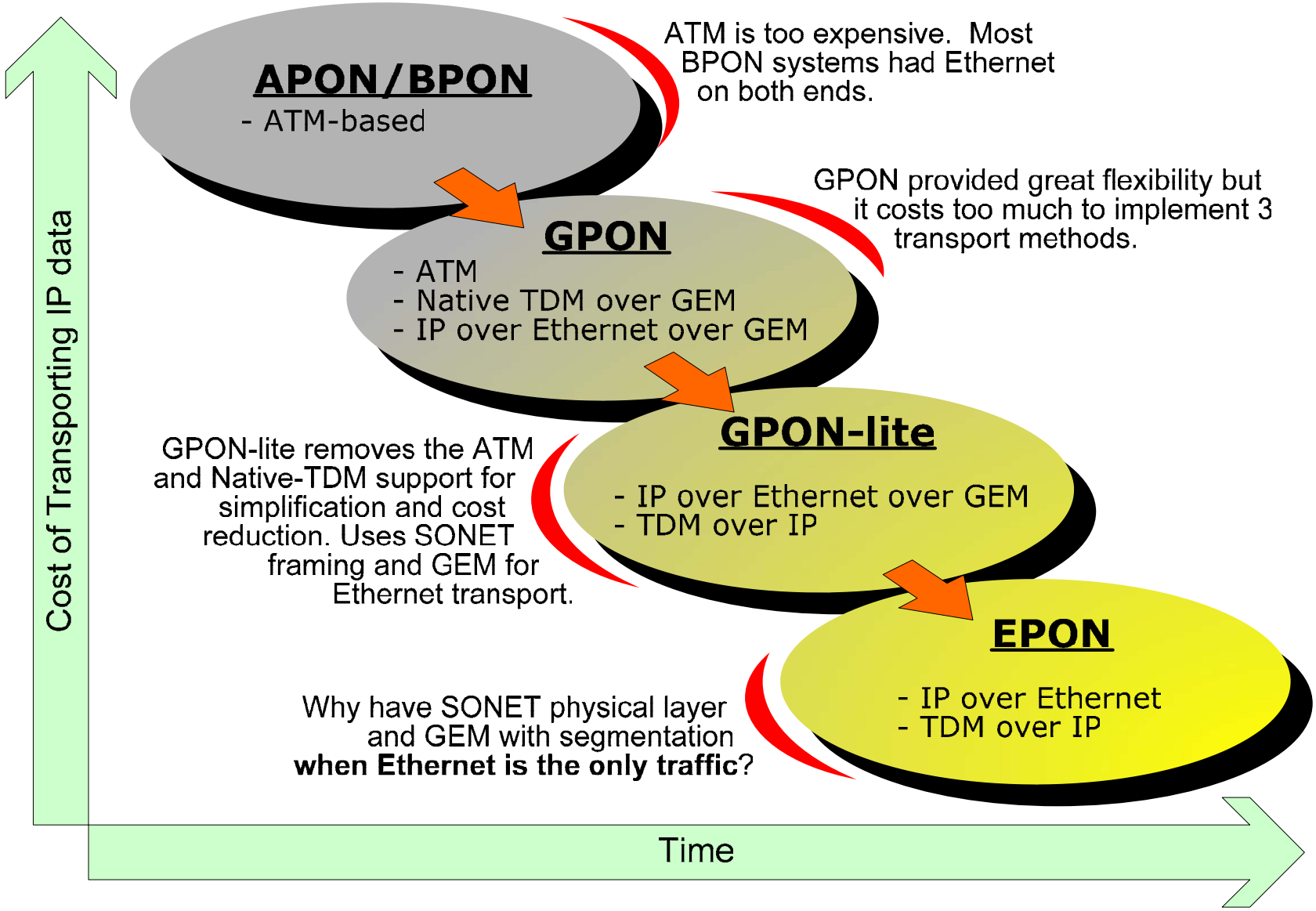
- 100's to 1000's of SAR buffers
- Frame from ONU must wait until all bytes are received upstream from ONU before it can be processed.

GPON ONU

- Segmentation buffers for every Port Id

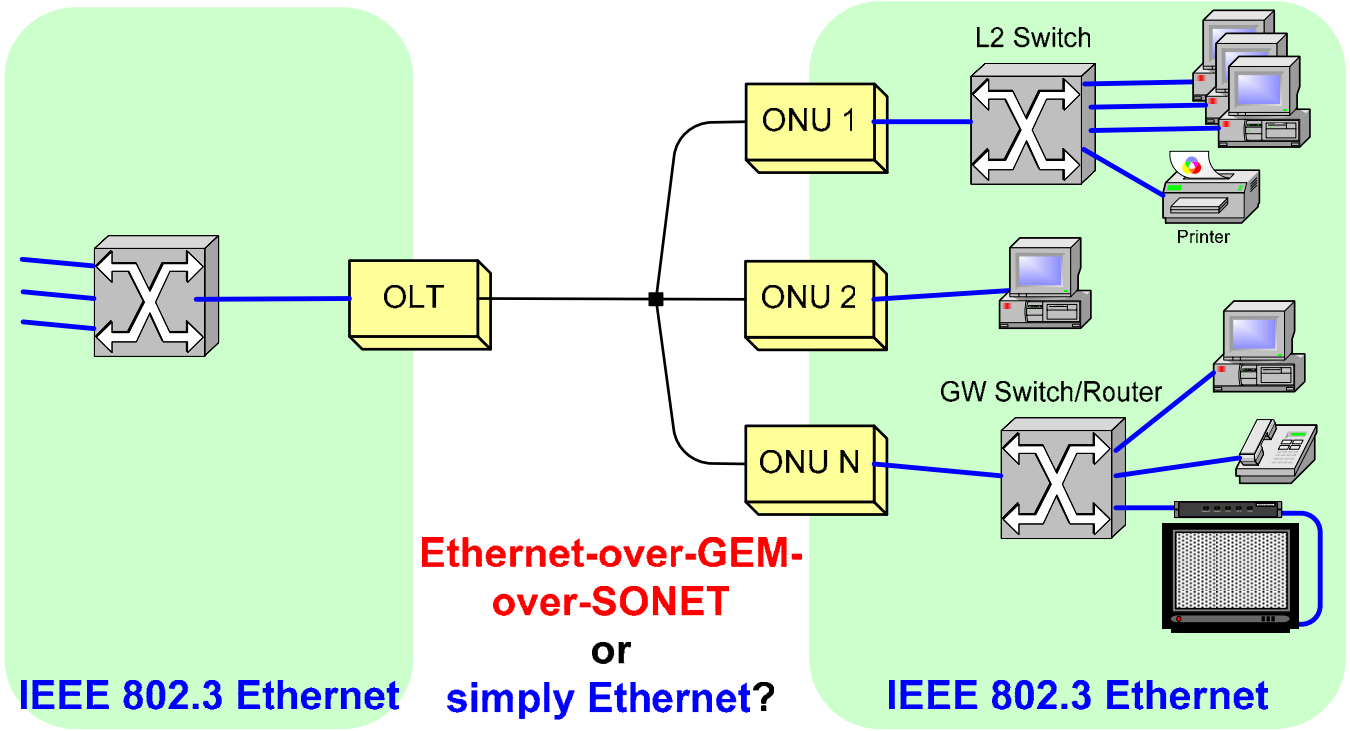


Layer Convergence...



Ethernet All the Way

- An End-to-End Ethernet solution is the lowest cost and simplest to manage.
- Why pay for unnecessary translations and speeds that don't match the Ethernet links on both sides?



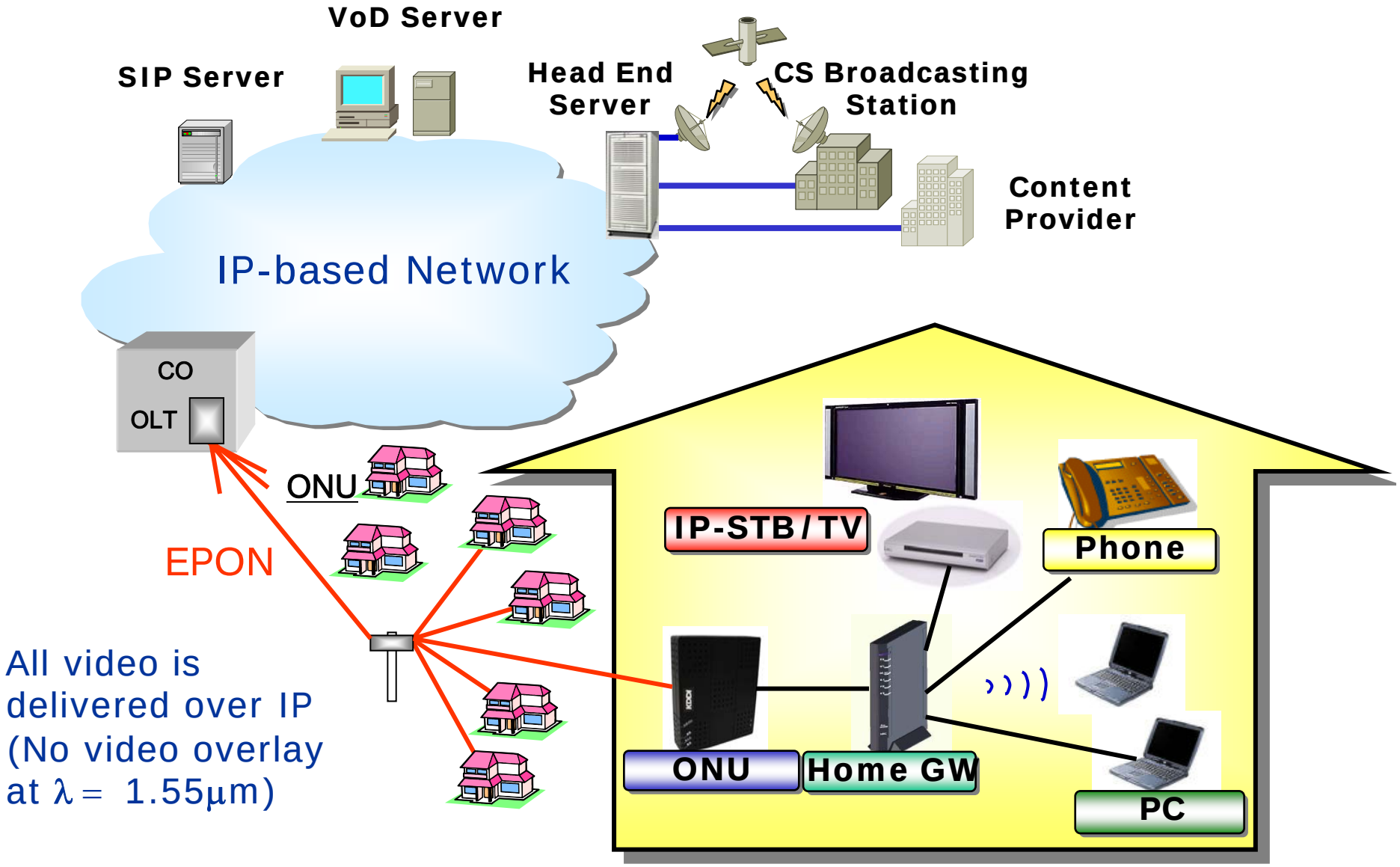
"Two types of giga-bit PON systems have been standardized: G-PON by ITU-T and GE-PON by IEEE. Now the question is which one is more promising? ... In Japan, we have seen a drastic price reduction of media converters which could be realized by sharing the technology and products of the LAN market. For services, high quality IP Telephone and IP video are becoming critical basic FTTH services. And for the core network, in NTT we have a full IP backbone network for the FLET's service. Switches and routers in the network employ Ethernet interfaces. Given these factors, we decided to develop GE-PON as the next-generation FTTH system."

Hiromichi Shinohara, Director of NTT Access Labs
(IEEE Communications Magazine, September 2005)

Advanced Services in EPON

- IPTV (Broadcast and VoD)
- VoIP

Network Architecture – KDDI case –



All video is delivered over IP (No video overlay at $\lambda = 1.55\mu m$)

KDDI Broadband Service: "**Hikari-Plus Home**"

IP Telephony

- Equivalent to existing phone service:
  - High-quality
  - Multi-functionality
  - Emergency call handling

- No need to change the current phone number

IP Video

- DVD-quality video
- 30 Broadcasting TV channels
  - MTV, ESPN, etc.
- ~4,000 VoD items
  - Hollywood movies, dramas, etc.

Data

- High-speed Internet Access

Other

- ~3,000 Karaoke tracks
- Rich set of functionalities through mobile phone
  - VoD reservation, TV program guide, etc.

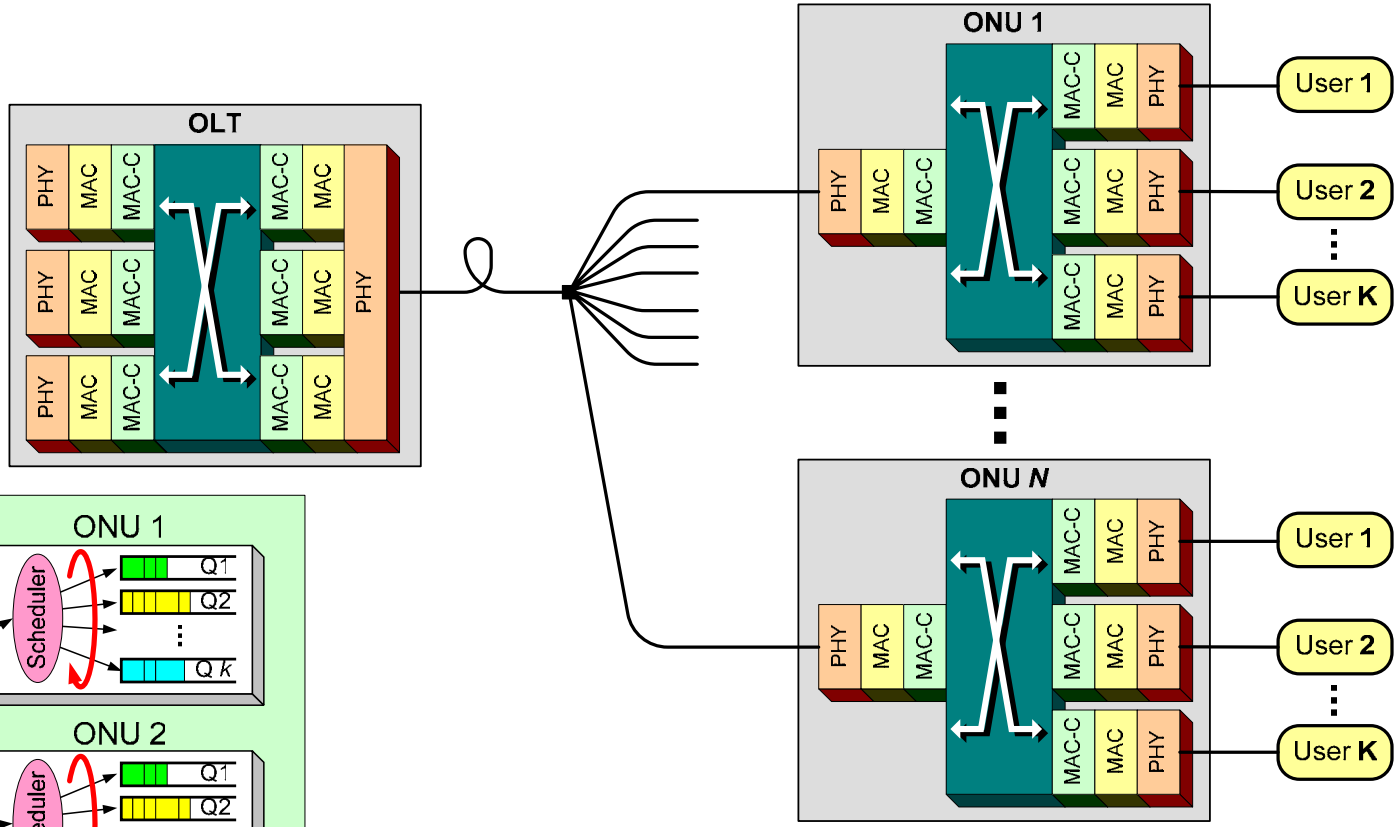
KDDI Hikari-Plus TV Screen Menu

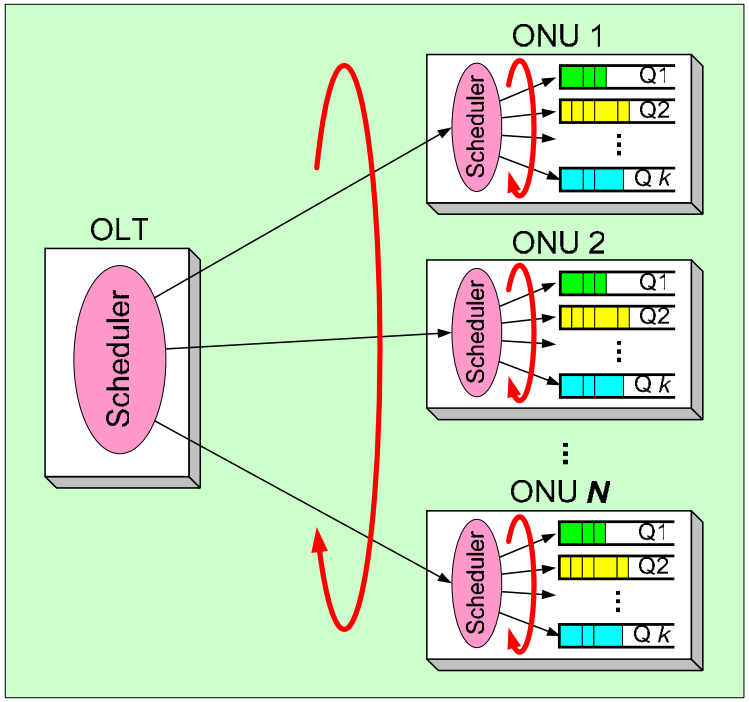
Under-Specified System-Level Issues

- Number of LLIDs per Subscriber
- Encryption
- Firmware Download
- Extended OAM

EPON with Single LLID/ONU

A single virtual link is provided per subscriber

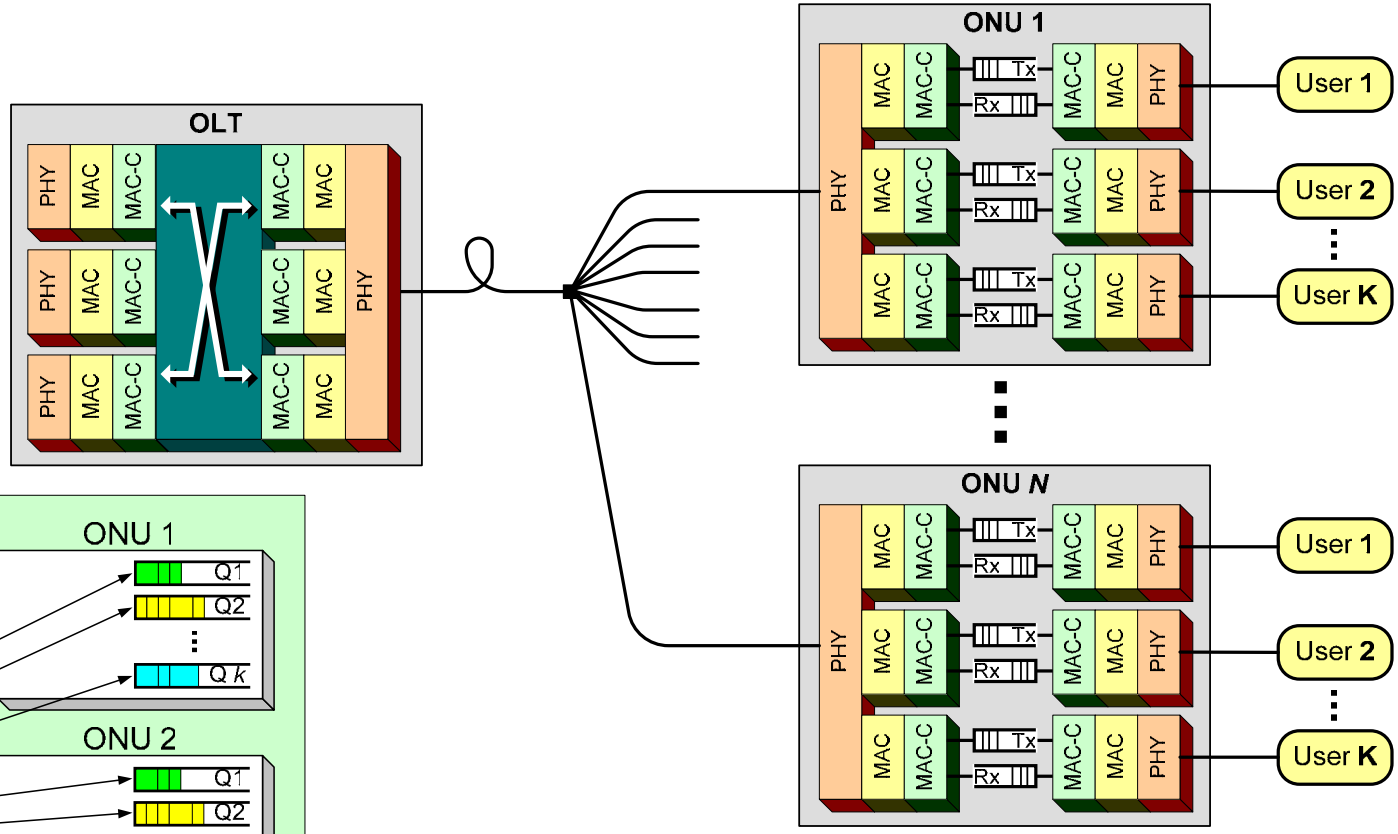


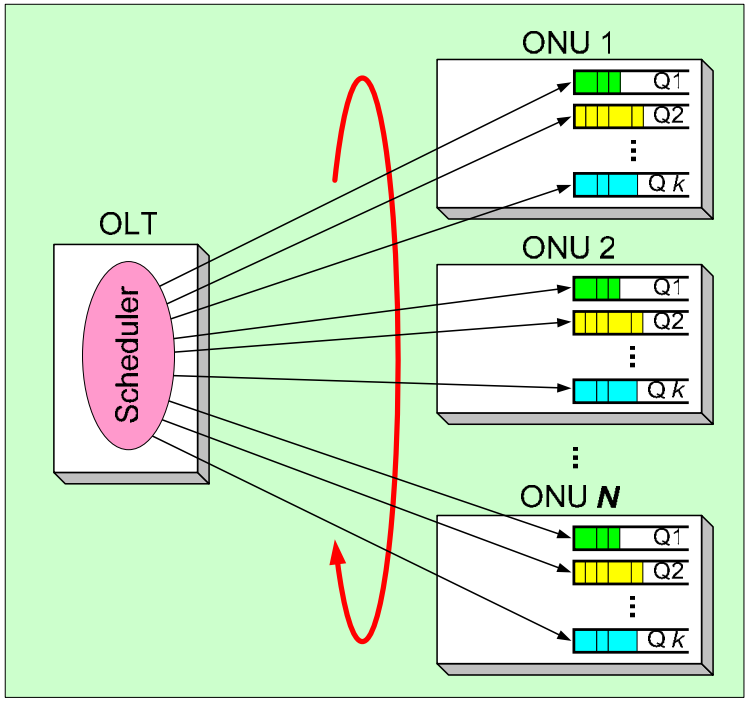


- ONU is given one aggregated grant for all queues
- ONU uses internal scheduler

EPON with Multiple LLIDs/ONU

A single virtual link is provided to each service of each subscriber

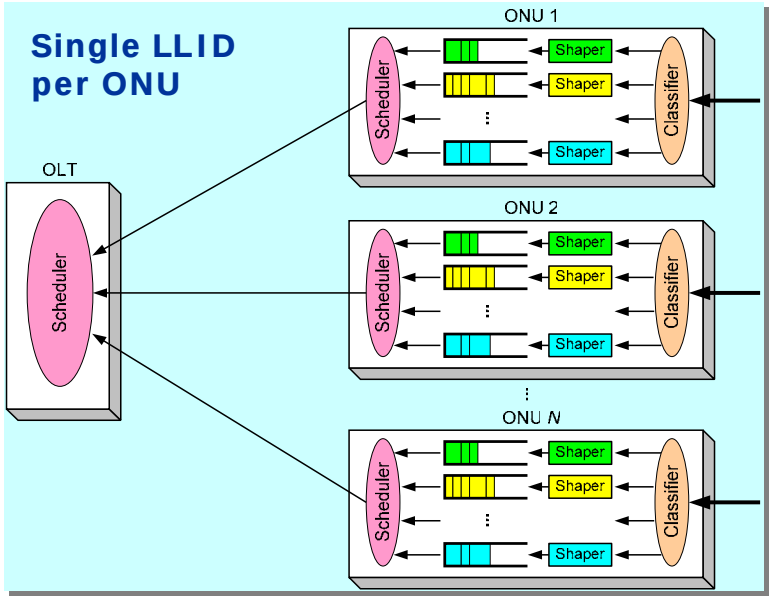


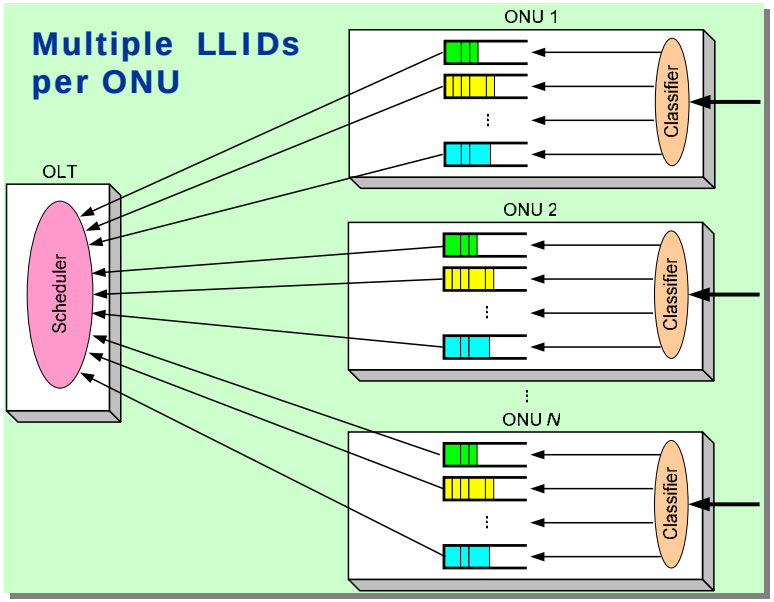


- Central scheduler schedules each queue independently
- No internal scheduler in ONU

Why single LLID per ONU doesn't work (I)

- With single LLID, ONU receives one grant for all the queues
- ONU must use priority scheduling to schedule multiple queues into a single grant.
  - **802.3ah, section 64.3.4.5:** "The index of the array [of queue lengths] is meant to reflect the same numbered priority queue in the 802.1P nomenclature."
- It is well known that priority scheduling does not satisfy carriers' requirements because no guarantees can be provided for individual queues, except the highest priority queue.
- **To prevent starvation of lower priority queues, ONU must apply ingress shapers**
- The ONU ingress shapers only know the state (load) of their local ONU, but not the states of all other ONUs. Thus, the shapers must trim all incoming traffic to their guaranteed minimum, even if extra bandwidth is available in EPON.





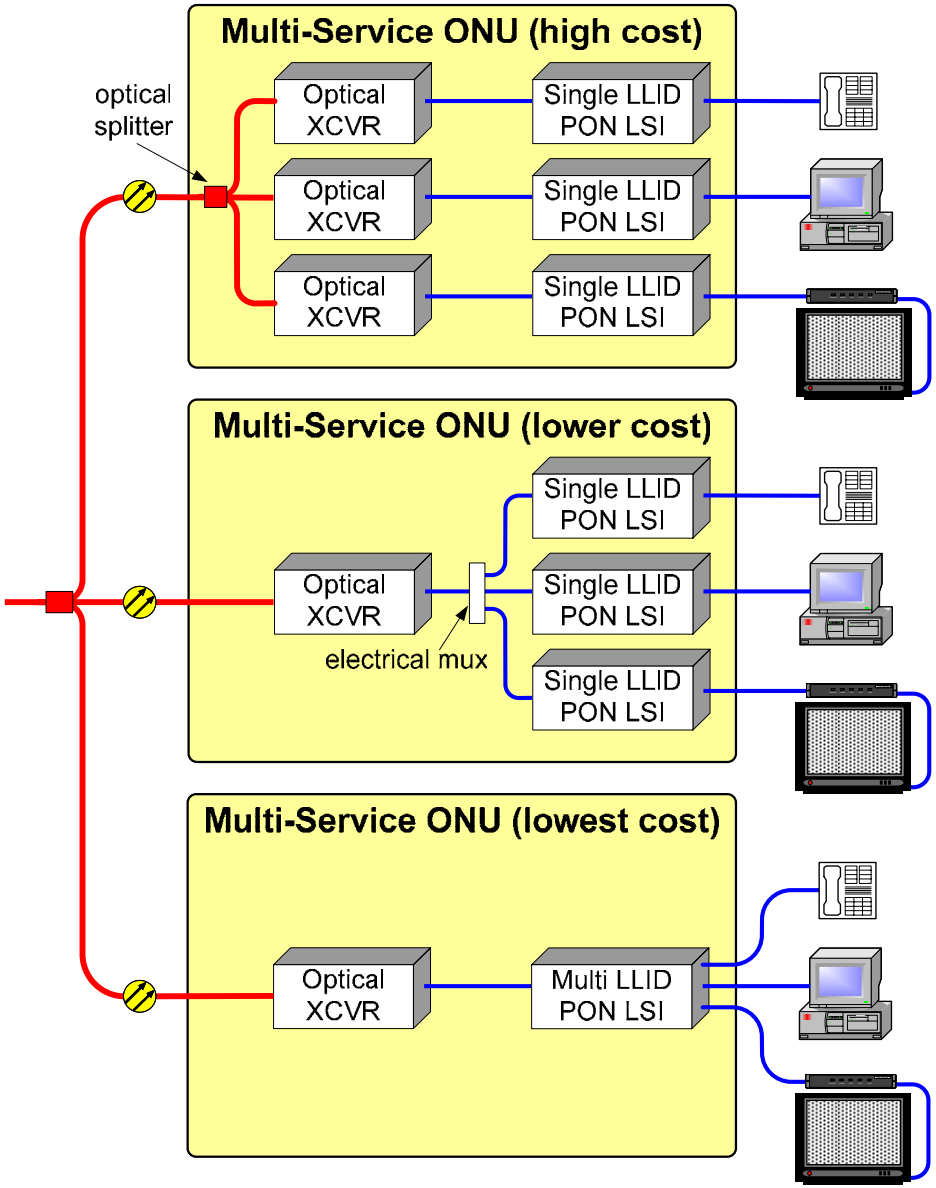
Why single LLID per ONU doesn't work (II)

- **Statistics**
  - According to IEEE Std 802.3ah, statistics is gathered per LLID
  - With single LLID, alarms and statistics gathering are done per ONU
  - If ONU reports 10% frame loss, the network operator will not be able to determine whether these were voice frames, video frames, or data frames.
- **Loopback**
  - Loopback is per LLID. With single LLID per ONU, if network operator wants to loopback data traffic, the voice and video will be disrupted as well.

Why single LLID per ONU doesn't work (III)

- With single LLID, if network operator wants to disable voice traffic for one user, but keep her video and data, the ONU should be programmed to do so.
- If ONU is owned by customer, it may not be able to drop such traffic, or may be configured not to drop it.
- With single LLID per ONU, user (or ONU) controls what is transmitted upstream, depending on ONU configuration.
- With multiple LLIDs per ONU, network operator (or OLT) controls what is transmitted upstream by giving or not giving grants for each service independently.

What is “Multiple LLIDs per ONU”



“Multiple LLIDs per ONU”
means
“Multiple ONUs per IC”

- **Example:** Carrier specifies ONU which provides 3 channels for 3 services.
- For all designs, each service / SLA can be managed & controlled independently by the OLT.
- Either single-LLID ASICs or multi-LLID ASICs can be used.

Standards Compliance & Interoperability

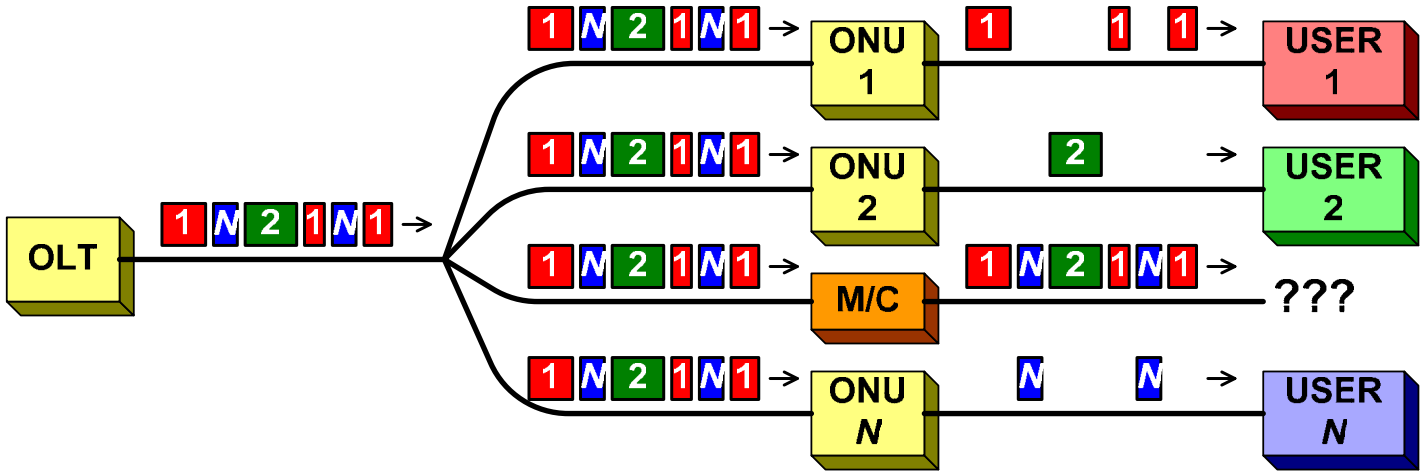
- **ONUs with multiple LLIDs are interoperable with any standard-compliant OLT**
  - The OLT always thinks there is a single LLID per ONU.
    Example: If each of 32 physical ONUs can support 3 LLIDs, the OLT will think that it has 32×3 = 96 ONUs
- **All EPON state machines in the IEEE 802.3ah standard remain unchanged for "Multiple LLIDs" solution**
  - An ONU with multiple LLIDs registers each LLID separately
  - Each LLID sends a separate REPORT; OLT grants each LLID separately
- **"Multiple LLIDs" solution facilitates interoperability**
  - Eliminates the need for proprietary scheduler at ONUs (Priority? Double-stage? Fair-weighted?)
  - Eliminates the need for proprietary protocol to control ONU ingress shapers

Multiple LLIDs per ONU

- **User isolation**
  - Independent SLA per user per service
  - Statistics monitoring per user per service
  - Protection from abusive users or misbehaving applications
- **Service isolation**
  - Independent QoS for different services (different polling intervals for different CoS)
  - Independent monitoring and billing of different services
- **Separate networks to different ISPs, voice carriers, video providers (Open Access)**
- **Fairness among users and among services**

Security Problem in EPON

- Malicious user can eavesdrop on downstream traffic from home
  - Can steal service
  - Can analyze neighbors traffic
  - Can cause Denial of Service to a specific neighbor (deregister a specific LLID)



Which Encryption Method to Use?

- **IEEE 802.1AE (MacSec)**
  - Designed for multi-hop operation, not optimal for EPON
    - Leaves MAC SA/DA in the clear
    - Leaves entire MPCPDU in the clear
    - Leaves entire OAMPDU in the clear
- **Vendor-Specific Methods**
  - Covers entire frame, including DA/SA
  - Interoperability is difficult
  - Intellectual Property Rights
- **Multiple vendors and carriers should agree on EPON encryption method**
  - Publish open specification
  - License-Free

System-Level Specification

System-Level specification is required

- Number of LLIDs
- Encryption Mechanism
  - Key Exchange
  - Authentication
- Firmware Download Mechanism
  - Protocol
  - Message Format
- Extended OAM
  - Port configuration
  - VLAN modes configuration

Next-Generation EPON

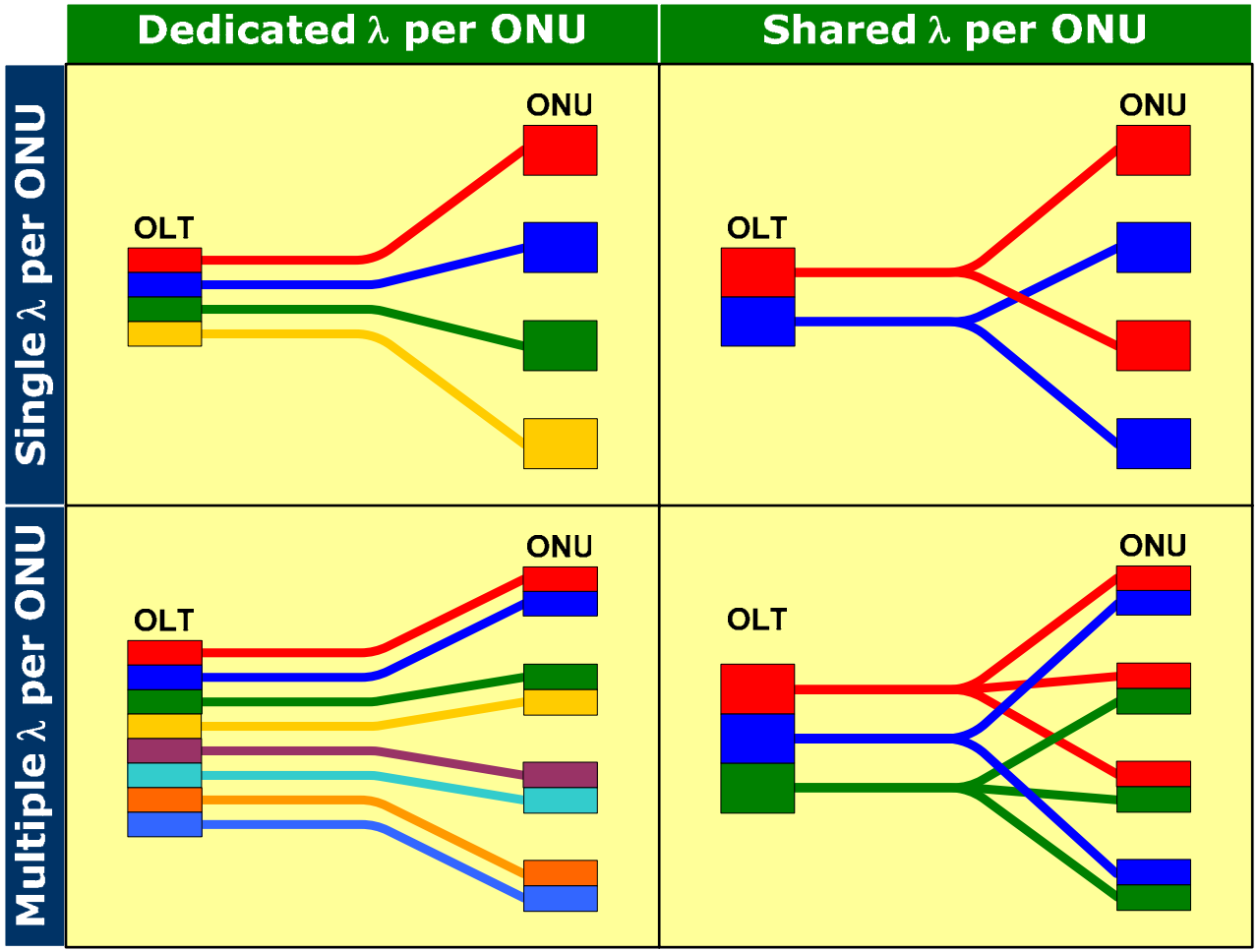
- WDM PON
- High-Speed EPON
- Spatial Upgrade

Upgrade Scenarios

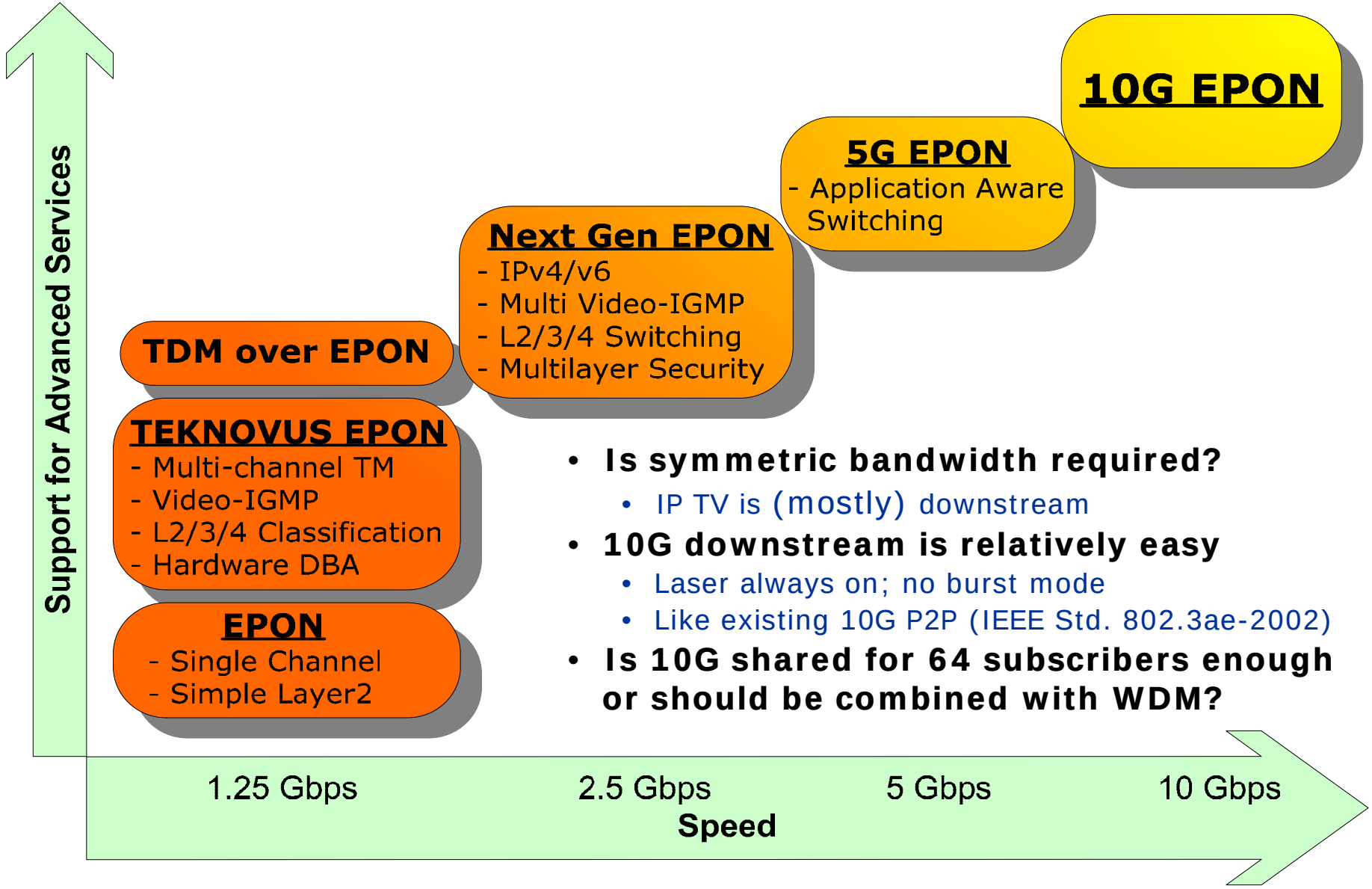
- Wavelength upgrade
  - Move premium ONUs to separate wavelengths
  - Less ONUs per $\lambda \Rightarrow$ more bandwidth per ONU
  - Inventory problem (ONUs are different or tunable lasers)
- Rate upgrade
  - Increase rate of EPON (1 Gbps -> 10 Gbps)
  - OLT should support new rate (for premium ONUs) and old rate (for non-premium ONUs)
- Spatial upgrade
  - Split 32-user EPON into two 16-user EPONs
  - Deploy multiple trunks or put splitter in the CO
  - Eventually becomes point-to-point topology

WDM-PON

- **Dedicated λ per ONU**
  - Which L2 P2P protocol to use?
    - ATM
    - SONET
    - Ethernet
- **Shared λ per ONU**
  - Which L2 P2MP protocol to use?
    - APON/BPON
    - GPON
    - EPON
- **Static or dynamic wavelength assignment?**
- **λ load balancing**



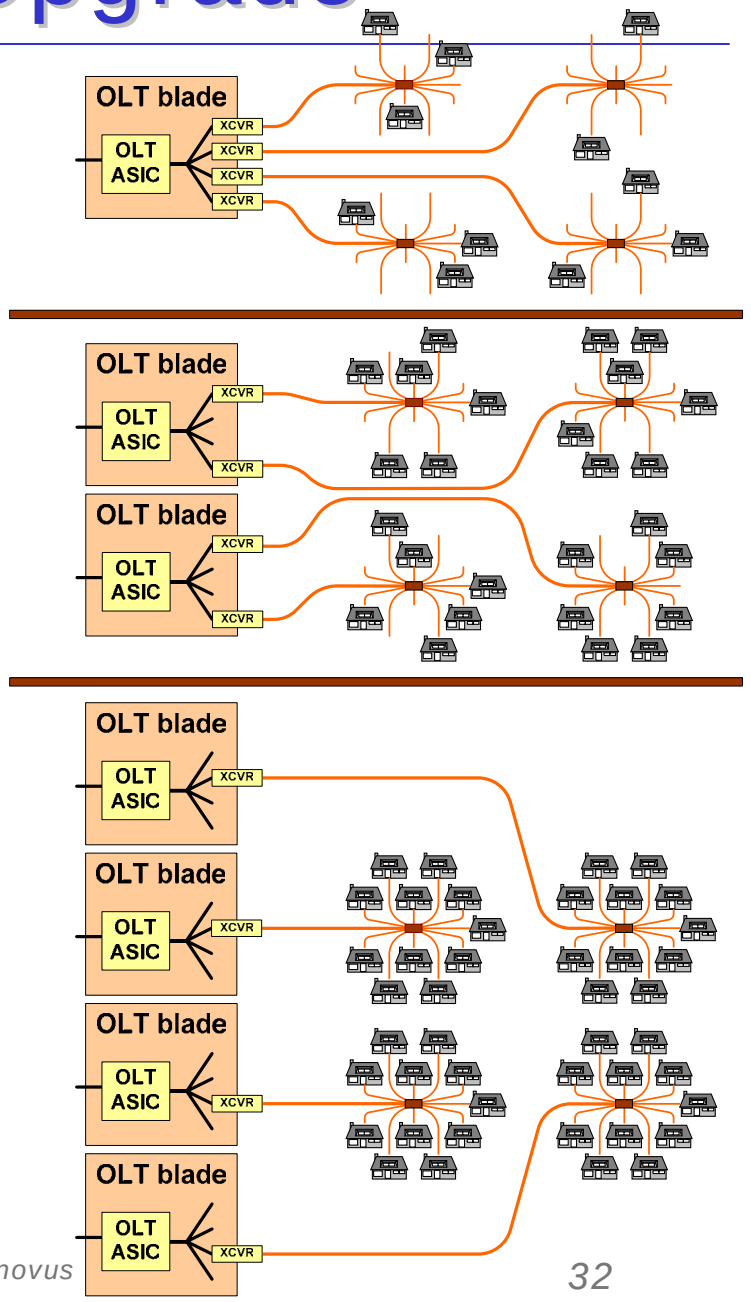
The EPON Evolution – Rate Increase



- **Is symmetric bandwidth required?**
  - IP TV is (mostly) downstream
- **10G downstream is relatively easy**
  - Laser always on; no burst mode
  - Like existing 10G P2P (IEEE Std. 802.3ae-2002)
- **Is 10G shared for 64 subscribers enough or should be combined with WDM?**

EPON Spatial Upgrade

- EPON protocol does not distinguish whether a split is done in optical or electrical domain
- Electrical splitter does not limit PON's power budget
- Using electrical splitter, one OLT can serve multiple PONs (during initial deployment)
- As take rate increases or more bandwidth is required the trunks would migrate to separate OLTs



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