Advances in Optical Access Networks

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Outline

- Evolution of the first mile
- Flavors of PON: APON/BPON, GPON, EPON
- Services
- Open issues in EPON
  - One or multiple logical links per ONU?
  - Downstream DBA
  - Open access
  - Variable capacity and CO-wide fairness
  - Upgradeability

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

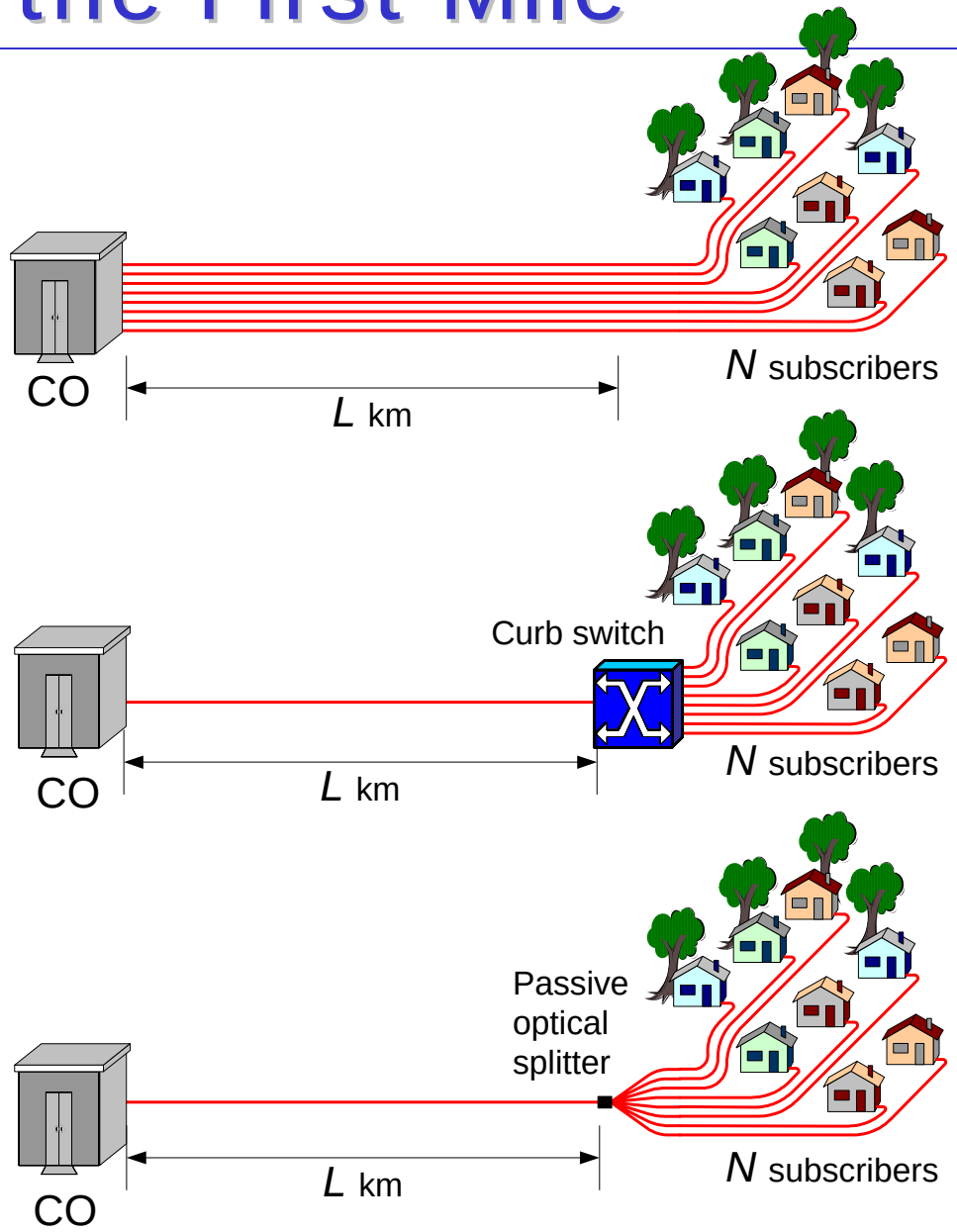
– 2*N* + 2 transceivers

PON – a distributed switch

+ *1* fiber line

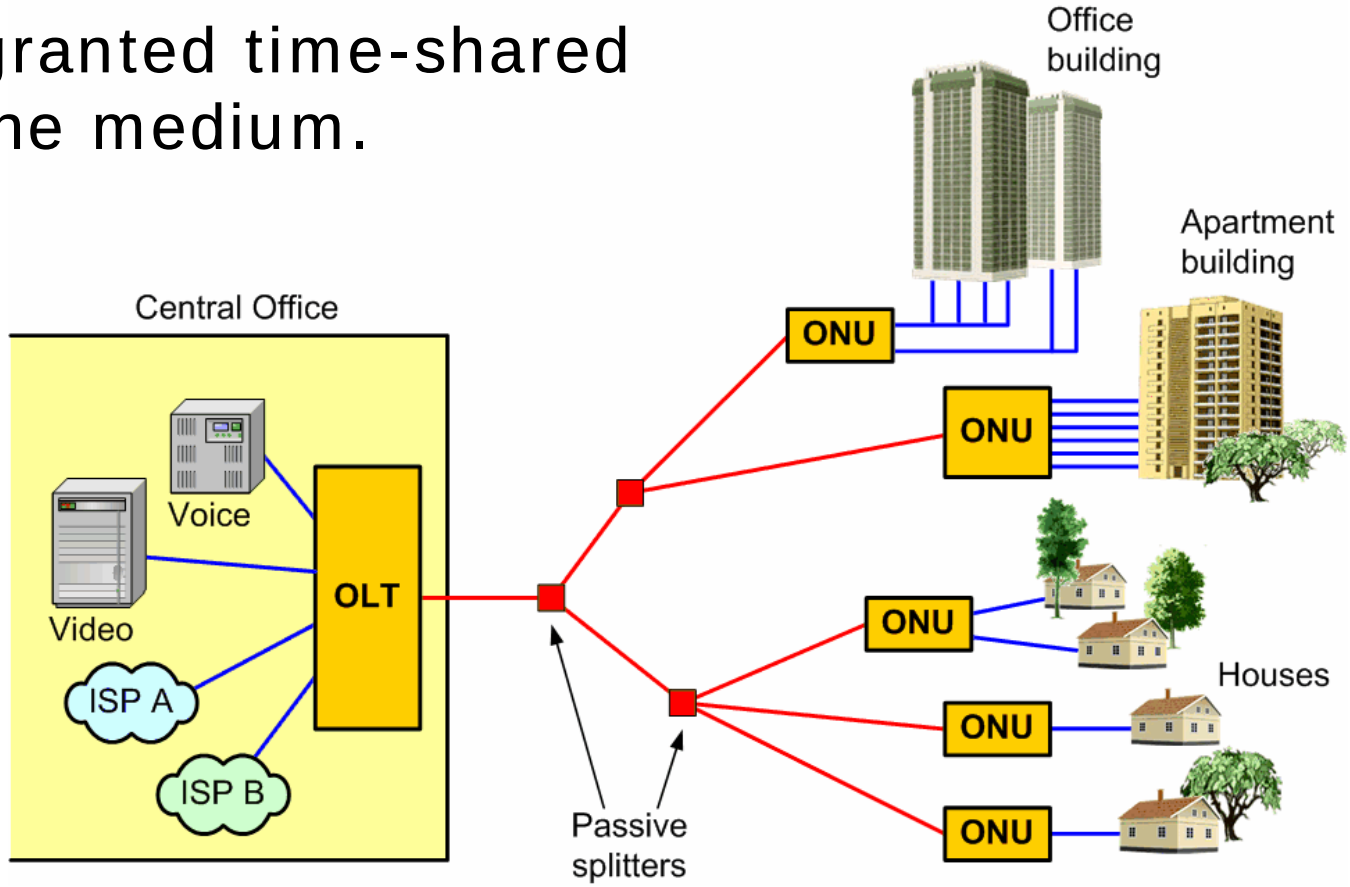
+ *N* + 1 transceivers

+ 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

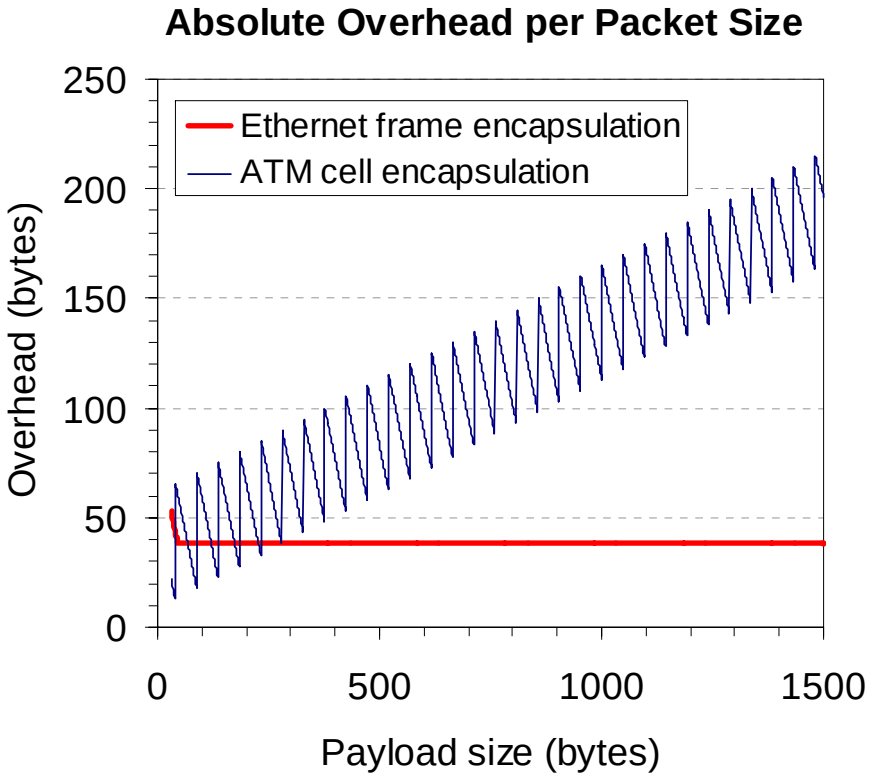
- **APON/BPON**: ATM/Broadband PON (ITU-T G.983)
  - Uses ATM as bearer protocol
  - Developed in FSAN
  - Standardized in 1998-2003
- **GPON**: Gigabit-Capable PON (ITU-T G.984)
  - Based on *Generic Framing Procedure* (G.7041)
  - Developed in FSAN
  - Standardized in 2003-2004
- **EPON**: Ethernet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

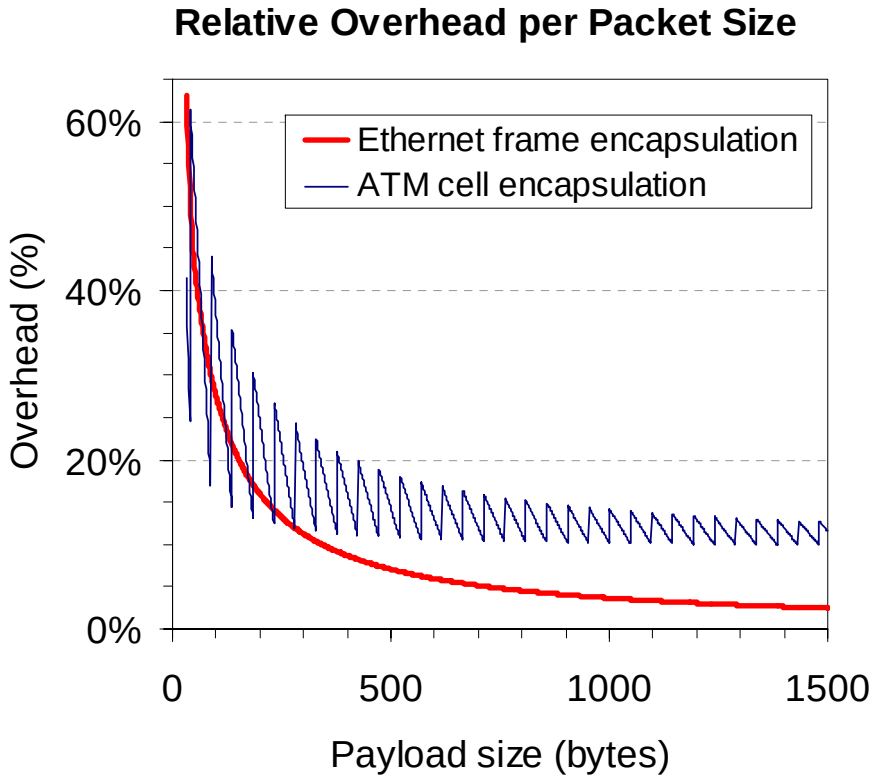
PONs At a Glance

	APON / BPON	GPON	EPON
Downstream data rate (Mbps)	155 or 622	1244 or 2488	1000
Upstream data rate (Mbps)	155 or 622	155, 622, 1244, or 2488	1000
Payload encapsulation	ATM AAL5	GPON Encapsu-lation Method	Ethernet framing
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

Encapsulation Overhead



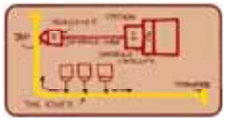


- Ethernet framing adds overhead of 38 bytes per IP payload
- ATM cell tax is dependent on payload size
- For an empirical packet size distribution, Ethernet framing overhead is 7.42%, ATM encapsulation overhead is 13.22%

EPON Timeline

- Ethernet is 30+ years old
- PON is around since 1987
- They met only in 1999…

1973 Bob Metcalfe draws the famous memo



1976 Paper "*Ethernet: Distributed Packet Switching for Local Computer Networks*" is published in Communications of the ACM

1983 Ethernet standard is approved by IEEE 802.3 Working Group

1987 First paper describing PON is published by BT researchers

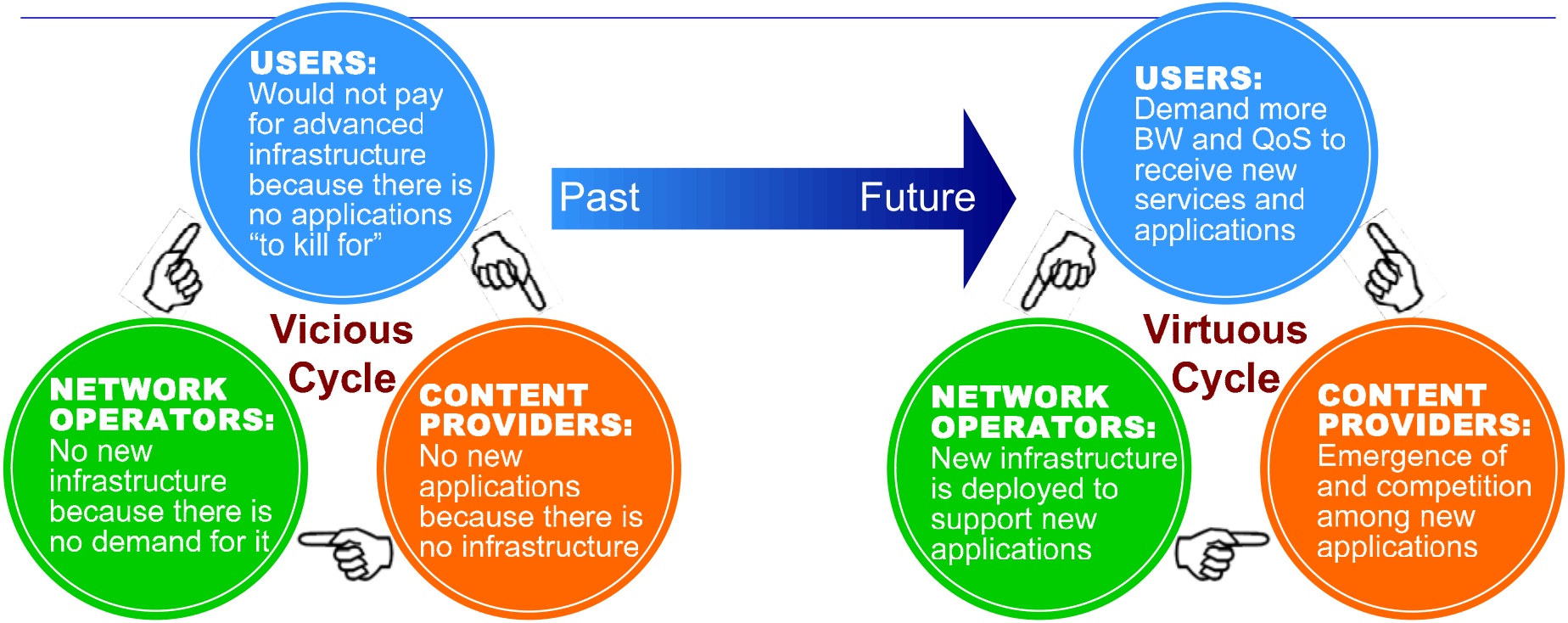
1999 Start-up Alloptic begins design of EPON system

2001 IEEE 802.3 issues call for interest for Ethernet in the First Mile study group

2004 IEEE Std 802.3ah - 2004 is approved. EPON is part of this standard

Services

Broadband Service Situation



Factors breaking vicious cycle:

- Reduction of broadband infrastructure cost and service fees
  - Shift from Media Converter and APON/BPON to EPON
- Emergence of digital home AV appliances
- Deployment plans
  - **NTT** : US$ 48B investment to reach 30 M subscribers by 2010
  - **SBC** : US$ 6B investment to FTTP in three years

Key Technologies for Triple-Play Services

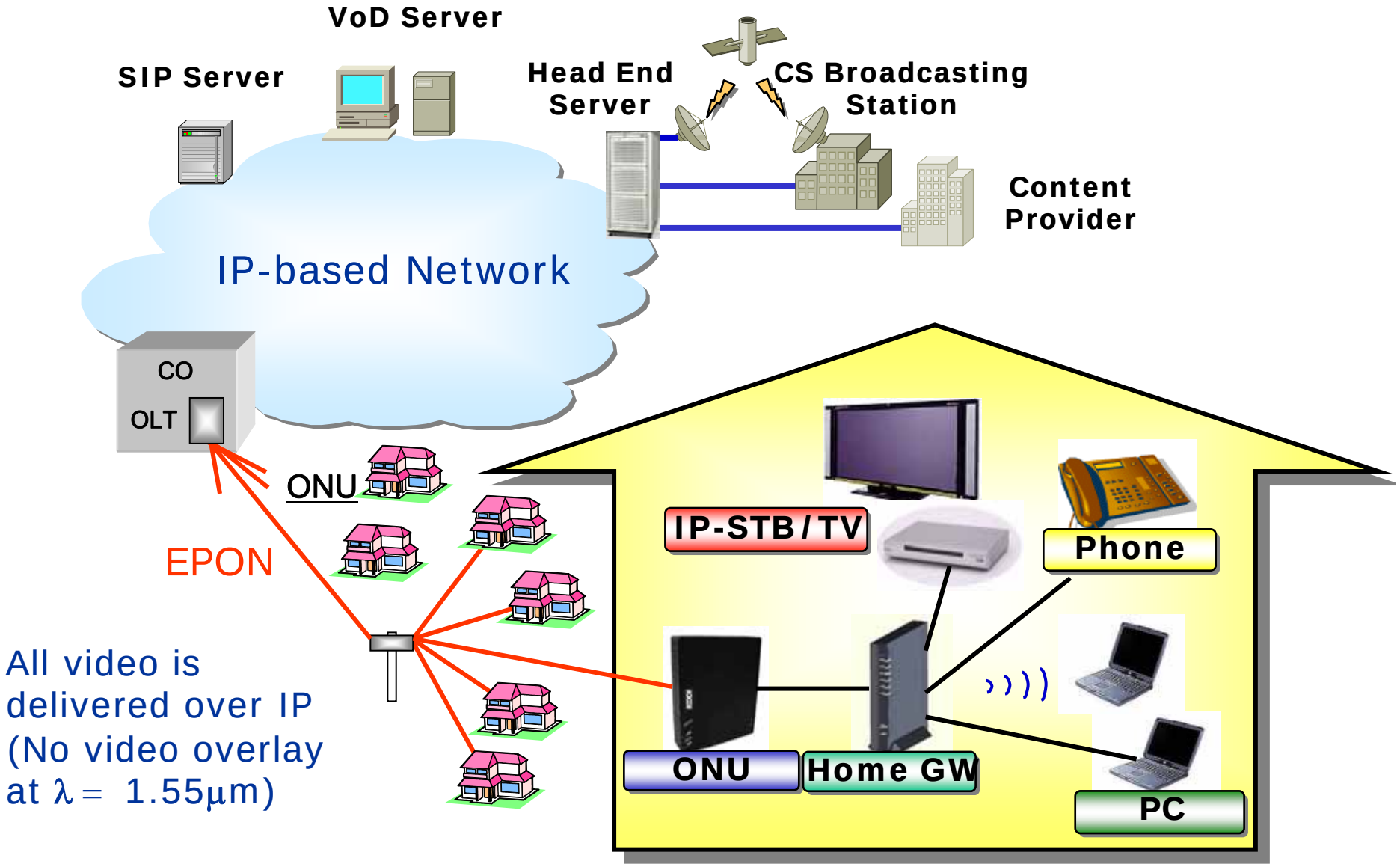
What is needed for commercial triple-play services?

- Satisfying the bandwidth and latency demands for each application
  - Detailed provisioning of bandwidth and latency; no packet loss and low latency provisioning for VoIP and Video
  - Efficient usage of the transmission capacity

Key technologies to achieve the above requirements:

- QoS/SLA
  - High-quality VoIP equivalent to the wired phone
  - DVD-quality Video (VoD and broadcasting)
- IP multicast
  - Multi-channel broadcasting video with minimum bandwidth consumption

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.

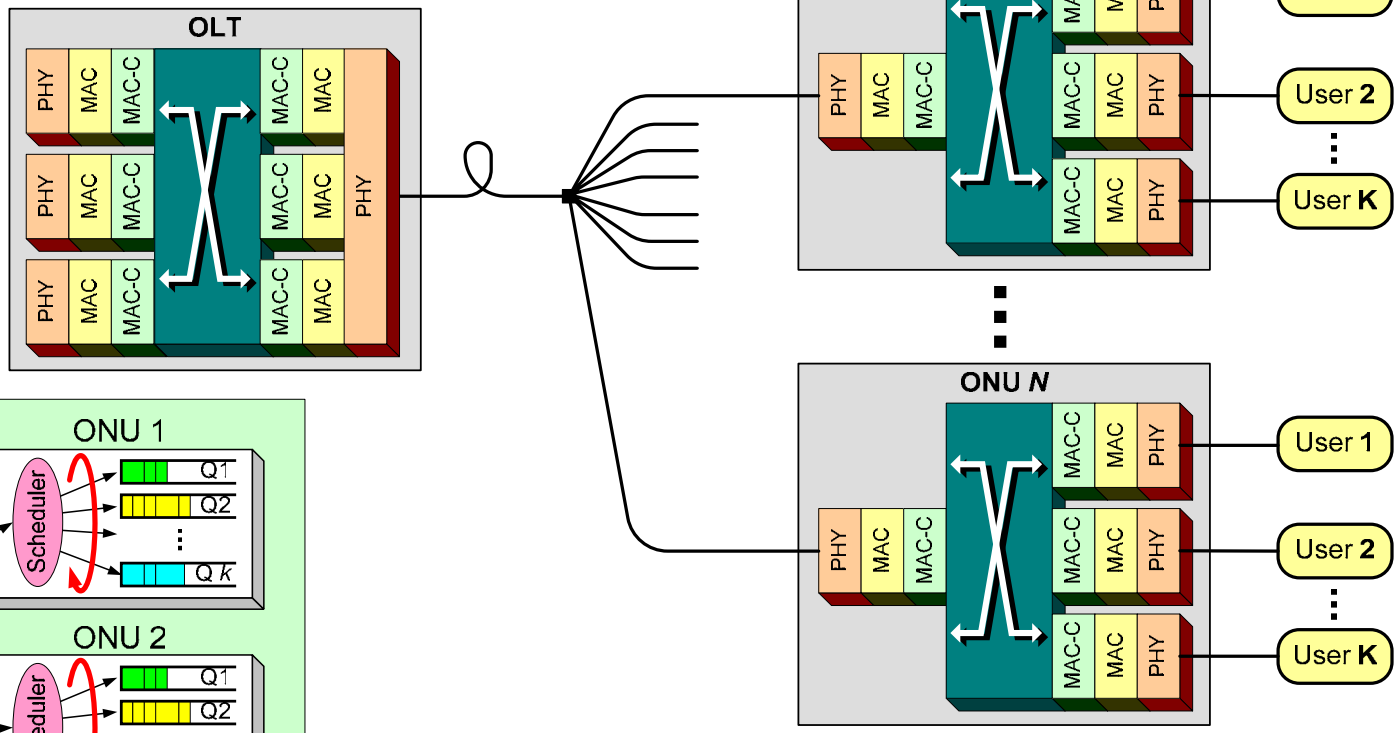
KDDI Hikari-Plus TV Screen Menu

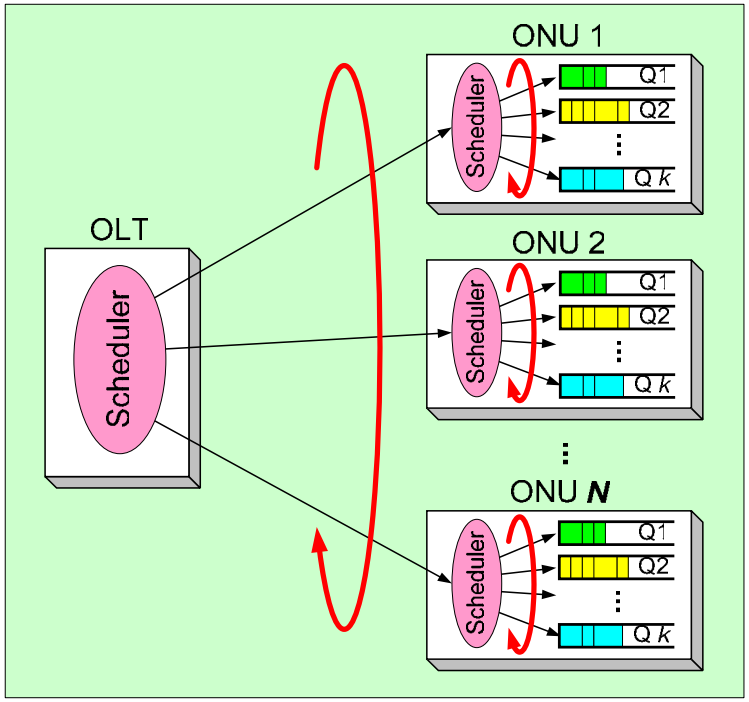
Open Issues in EPON

- **One or multiple logical links per ONU?**
  - Downstream DBA
  - Open Access
  - Variable capacity and CO-wide fairness
  - Upgradeability

EPON with Single LLID/ONU

A single virtual link is provided to an ONU

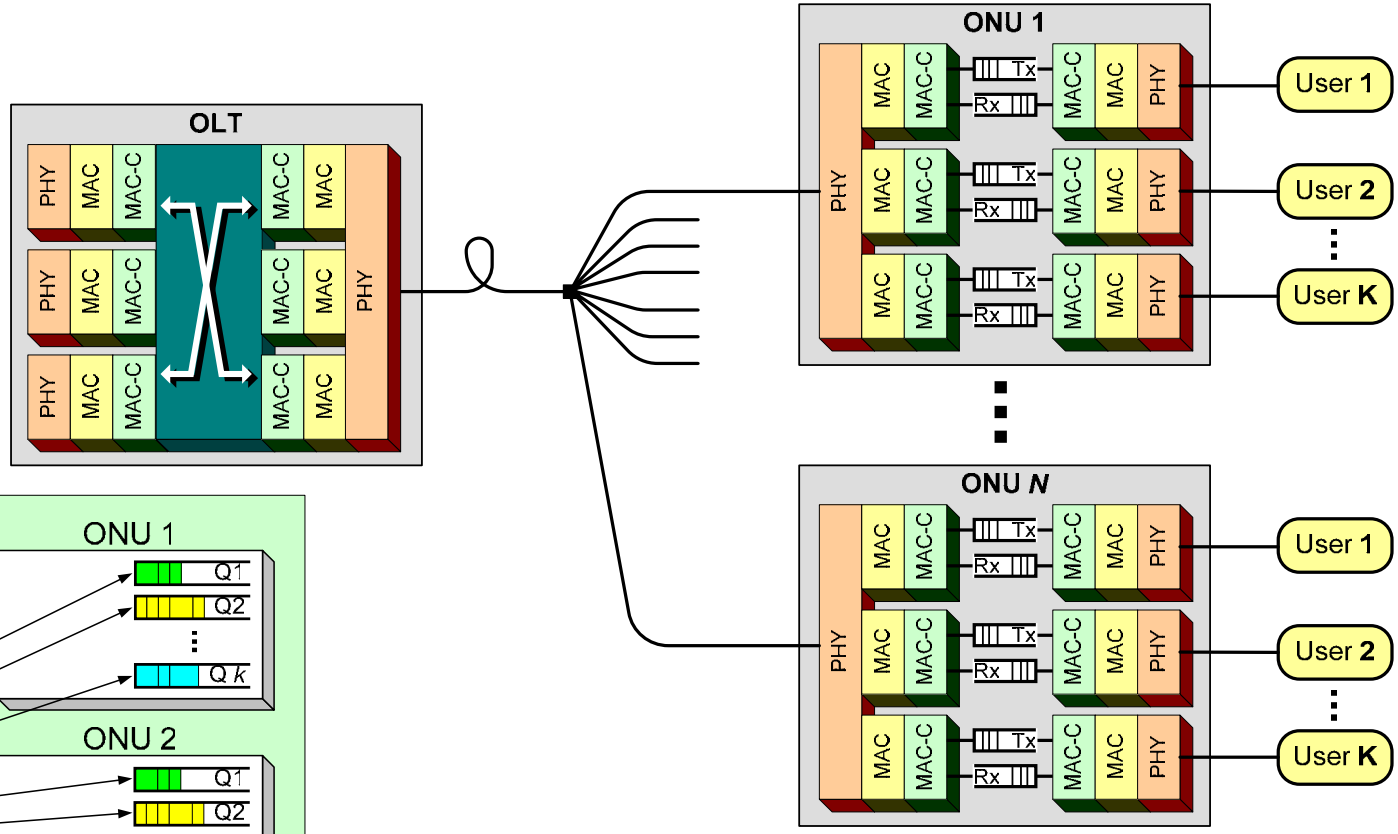


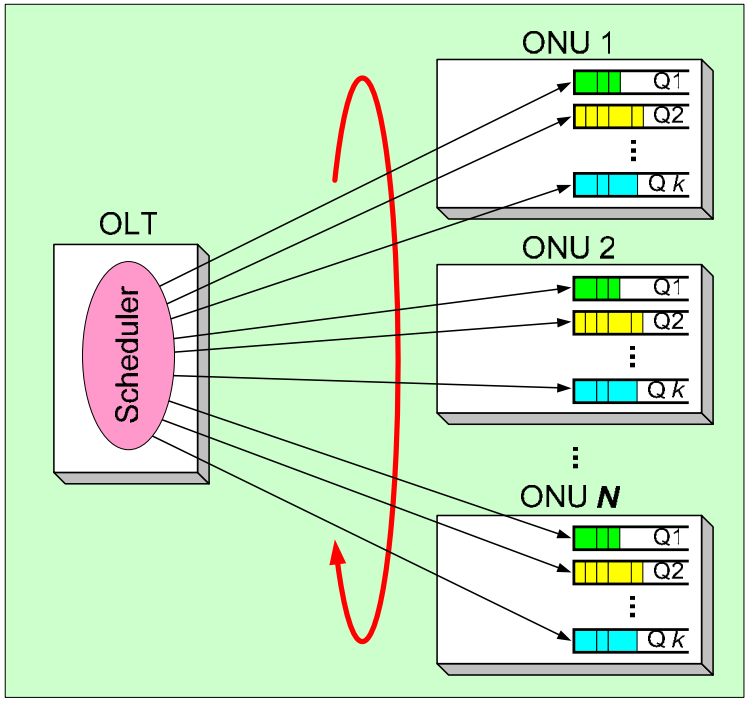


- ONU is given one aggregated grant for all queues
- ONU uses internal scheduler

EPON with Multiple LLIDs/ONU

A single virtual link is provided to each user and each class of service





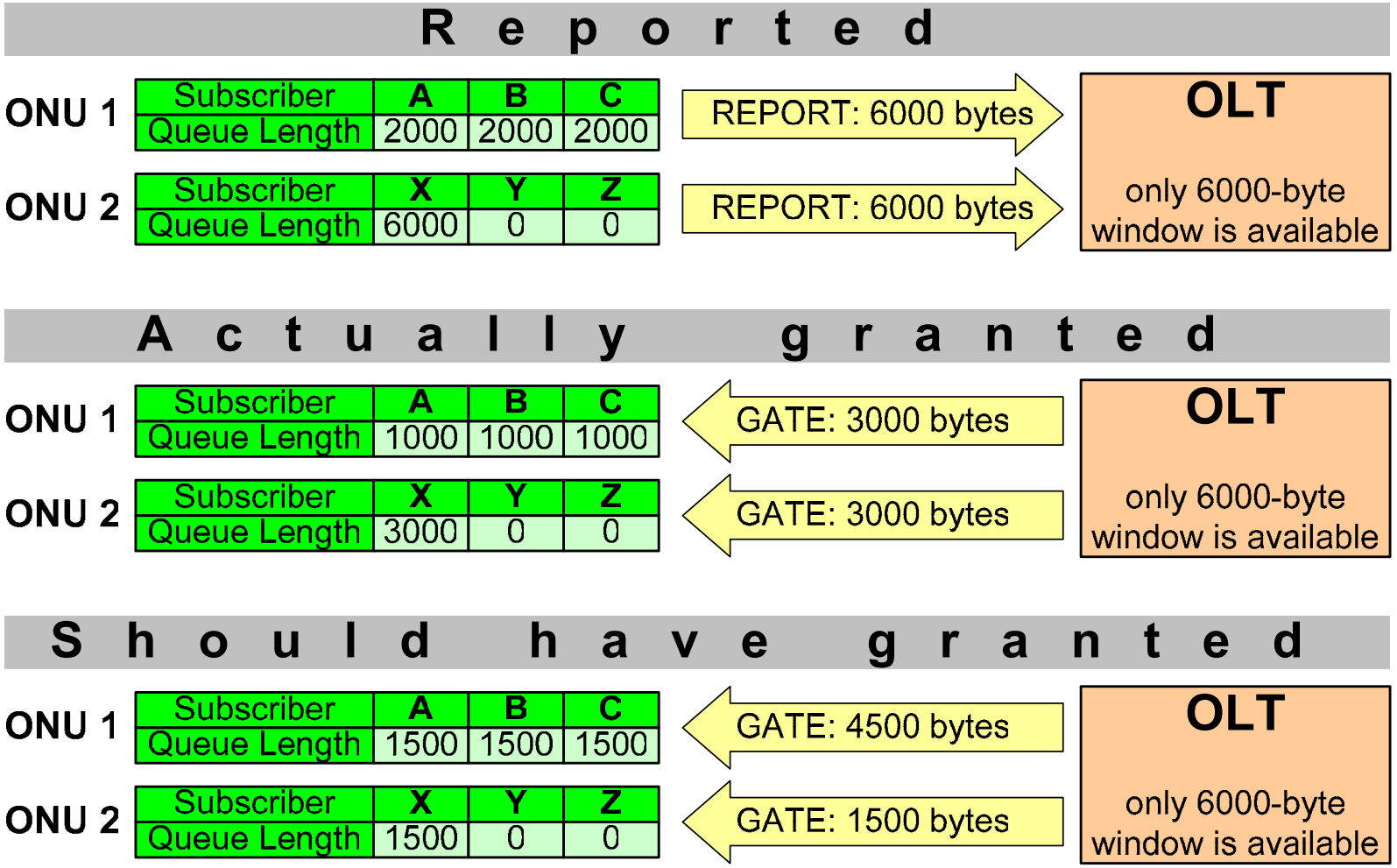
- Central scheduler schedules each queue independently
- No internal scheduler in ONU

Single LLID/ONU

- According to IEEE 802.3ah error counters are per LLID.
  - How usage statistics can be monitored per user or per service?
- Granting is per LLID
  - How can operator disable one user in ONU?
  - How can operator limit one traffic class or flow in ONU?
  - What scheduling algorithm ONU uses to fill granted slot with data from many users/services? How to control this algorithm?

Fairness Issue

With single LLID/ONU, fairness among multiple subscribers cannot be enforced



Multiple LLIDs per ONU

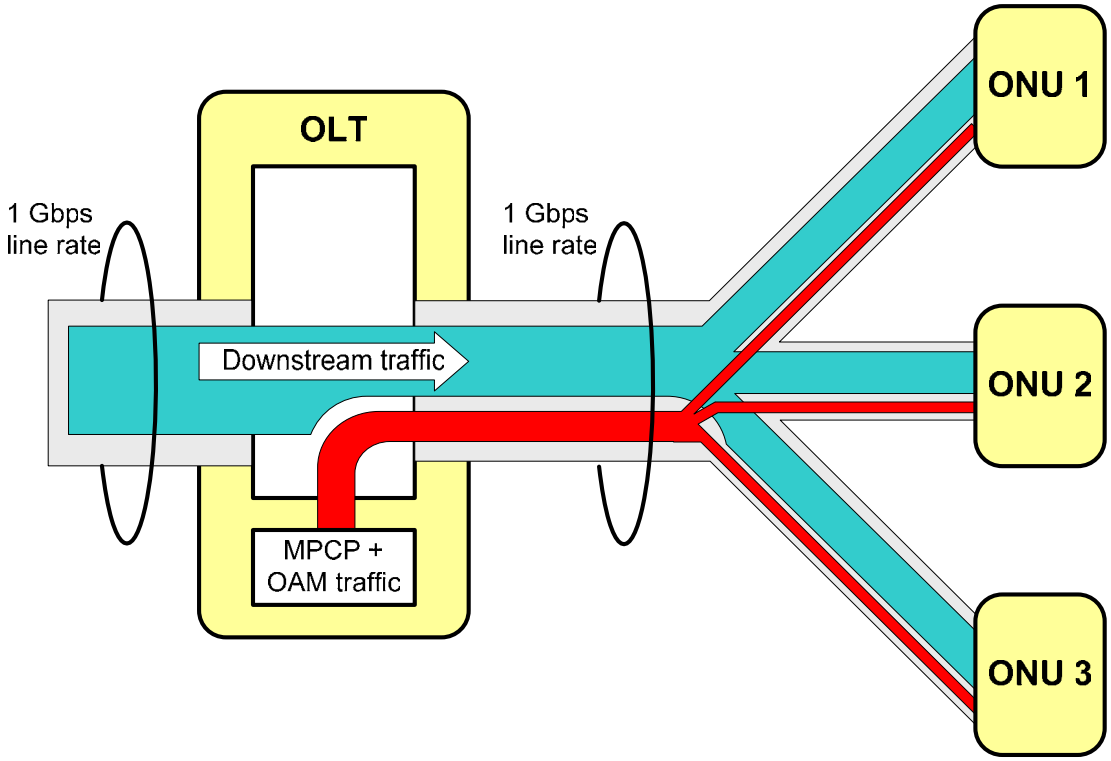
- User isolation
  - Independent SLA per user
  - Statistics monitoring per user
  - Protection from abusive users
- Service isolation
  - Independent QoS for different services (different polling intervals for different CoS)
  - Independent monitoring and billing of different services
- Separate networks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

Open Issues in EPON

- One or multiple logical links per ONU?
- **Downstream DBA**
- Open Access
- Variable capacity and CO-wide fairness
- Upgradeability

Why Downstream DBA?

- Downstream traffic may experience congestion at the OLT because additional MPCP and OAM flows are multiplexed in.
- Downstream DBA should ensure that voice and video do not experience excessive delay or loss.
  - Data loss should be fair for all subscribers.



Open Issues in EPON

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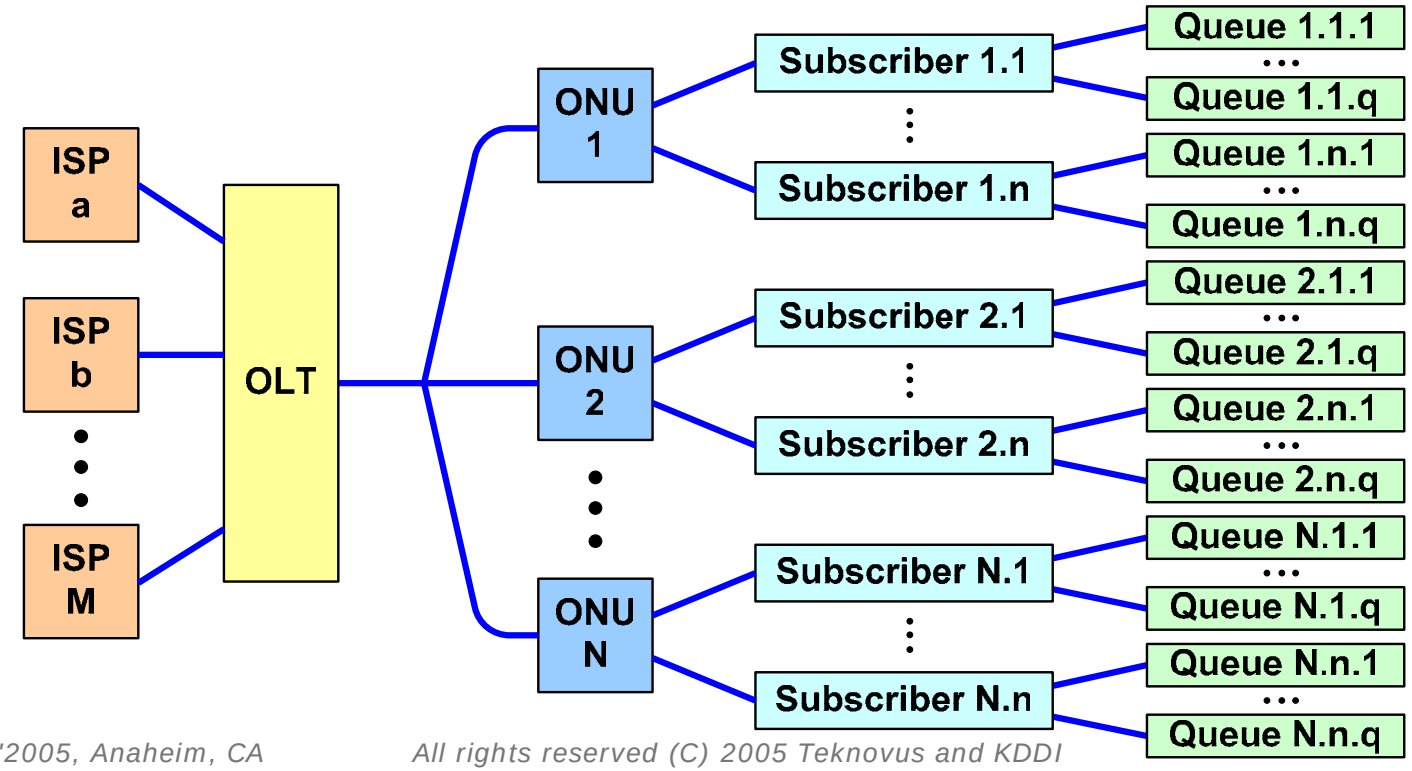
What is Open Access?

- EPON connects multiple ISPs to multiple subscribers
- Each subscriber can choose one or many service providers for various services or various sessions
- EPON can facilitate open access
  - Emulation sublayer isolates users and/or ISPs
  - A logical link is established between an ISP and a queue



Open Access Problem

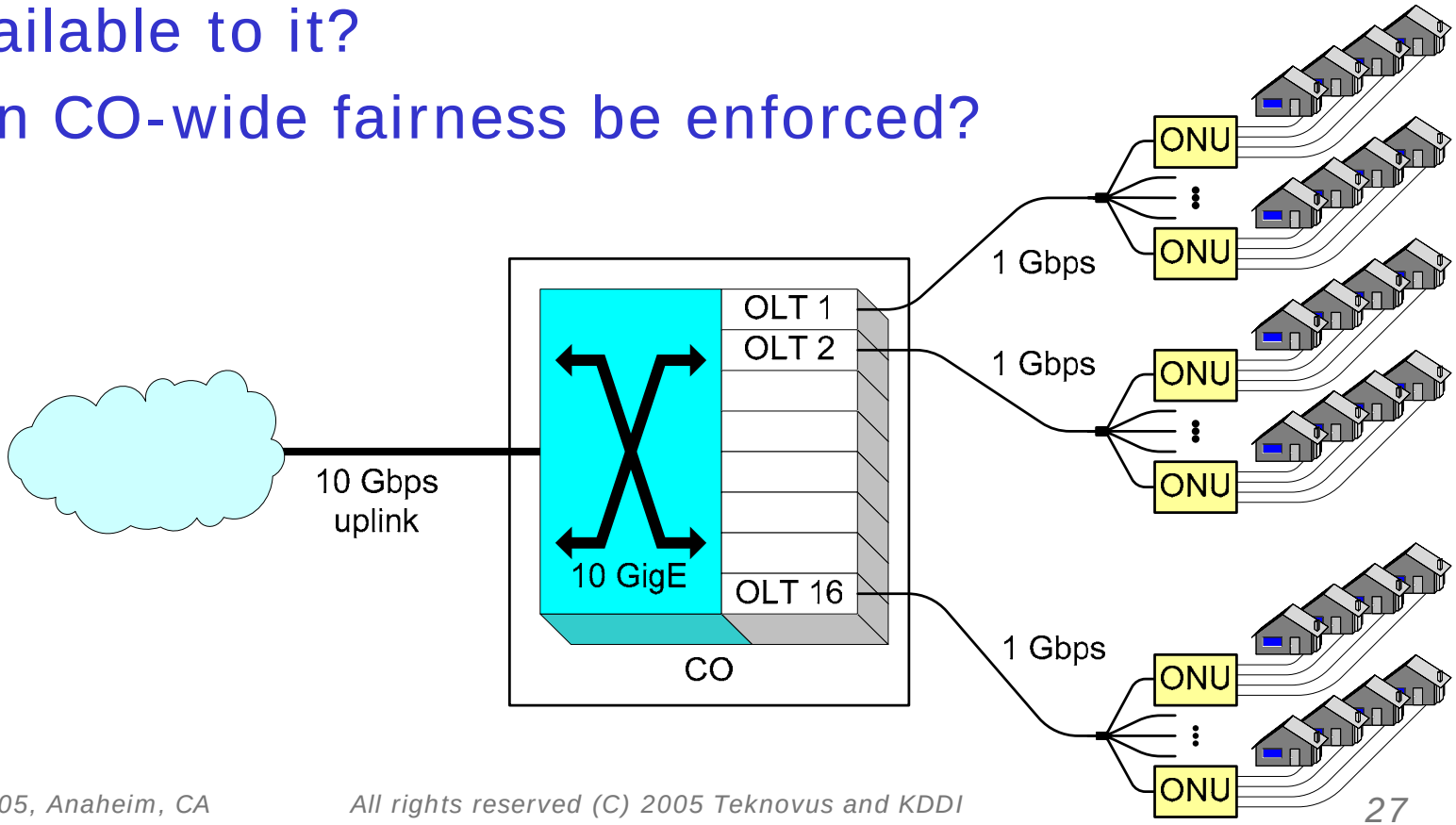
- Current trend is to provide unified billing to subscribers (one bill for all services)
  - Subscribers pay to ISPs
  - ISPs pay the network operator for access
- Who has SLA with network operator: subscriber or ISP?
  - If SLA is with ISP, how to guarantee service to subscribers?
  - How network operator can specify and maintain SLA with ISPs if users constantly migrate from one ISP to another?
  - If SLA is with subscribers, how ISP should pay to network operator (usage-based billing, flat fee)?
- Should network operator maintain dual SLAs: primary with subscribers, secondary with ISPs?
  - What scheduling algorithm could support this?

Open Issues in EPON

- One or multiple logical links per ONU?
- Downstream DBA
- Open Access
- **Variable capacity and CO-wide fairness**
- Upgradeability

CO-wide fairness

- Many existing DBA algorithms assume constant bandwidth (EPON capacity)
- In reality, uplinks are oversubscribed
- Can DBA handle variable bandwidth available to it?
- Can CO-wide fairness be enforced?



Open Issues in EPON

- One or multiple logical links per ONU?
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- Open Access
- Variable capacity and CO-wide fairness
- **Upgradeability**

EPON – an evolutionary step

- EPON is a giant step forward compared to technologies deployed today (DSL, CM)
- But, unavoidably, traffic demand will catch up (give us the bandwidth – we will find how to use it)
- EPONs should provide seamless and robust upgrade path. What will it be?

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)
  - Dispersion penalties affect maximum distance
- 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

To get more information about EPON …

Visit **IEEE EPON Forum**

- Journal article postprints
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- Online discussions

http://www.ieeecommunities.org/epon