Optical Communications and Networking

Nov. 4, 2019
Asymmetric Optical Access Networks

Point-to-point

Active Optical Network

Passive Optical Network (PON)

Lecture 8: Optical Access Networks
Asymmetric Optical Access Networks

1-to-1 Delivery  
Broadcast-and-Select  
Low Cost and Promising!

Key:  
A - Data or voice for a single customer.  
V - Video for multiple customers.
PON Terminologies

- OLT: Optical line terminal located at the service provider’s central office
- ONU: Optical network units located at/near end users
- Upstream: Communication from ONU to OLT
- Downstream: Communication from OLT to ONU
History of PON Standards

- Broadband PON (BPON)
  - International Telecommunications Union (ITU)
  - 622 Mb/s downstream, 155 Mb/s upstream

- Gigabit PON (GPON)
  - International Telecommunications Union (ITU)

- Ethernet PON (EPON)
  - IEEE Initiative

BPON, GPON and EPON are all TDM-PON, i.e., the bandwidth resources are allocated based on fixed time-slots.
TDM-PON Network Infrastructure

- PON multiplexes upstream and downstream on a single fiber using WDM.
- Upstream: 1310 nm (Why? Lowest loss in SMF)
- Downstream: 1490 nm (Why? High-power transmitter is available and cheap.)
- BPON, GPON and EPON have the same basic wavelength plan.
- Two most important things to worry about in PON: Cost and Power Budget.
Communications in TDM-PON

- **Downstream (broadcast-and-select):**
  - OLT broadcasts data packets
  - ONU selects data packets according to the destination address

- **Upstream (request-and-grant):**
  - OLT ranges the ONUs
  - ONU sends requests and asks for transmission opportunities
  - OLT grants the requests by specifying a defined interval of time for ONU’s upstream transmission.
  - ONU uses the time interval to transmit data packets.
Upstream Bandwidth Allocation

- ONU can lie at different distance from the OLT
- OLT measures delay for synchronization.
- OLT transmits grants to ONUs with MAP messages.
- The grant MAP is dynamically re-calculated every few msec.
Upstream Bandwidth Allocation

- Video/Audio traffic: fixed bandwidth allocation
- Data traffic: dynamic bandwidth allocation (DBA)
- GPON: status-reporting DBA, non-status-reporting DBA
- EPON: status-reporting DBA
Advantages: fixed time slots, good fairness, easy control.

Disadvantages: low channel utilization, cannot adaptive to user’s bandwidth.
Asynchronous TDM

Advantages: high channel utilization, adaptive to users’ bandwidth.

Disadvantages: more complicated.
Multi-Point Control Protocol (MPCP): a signaling protocol between the OLT and the ONUs to facilitate a dynamic timeslot allocation scheme.

MPCP consists of three functions:

- **Discovery Processing**: the OLT discovers and registers new ONUs.
- **Report Handling**: the OLT handles the REPORT messages that include bandwidth requirements generated by ONUs to make bandwidth assignments accordingly.
- **Gate Handling**: the OLT sends gate messages to ONUs to grant time slots for them to transmit data.
MPCP: Discovery Processing

OLT

- GATE discovery:
  - Type = Broadcast
  - Content = Discovery window start, end times

- REGISTER_REQ:
  - Content = ONU Mac address

- REGISTER:
  - Content = Assigned LLID

- GATE:
  - Content = Grant

ONU

- Random Delay

- REGISTER_ACK

Discovery Window

ONU registered and logical connection established

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MPCP: Report Handling

OLT

MAC Control Client

MA_Control.indicator (REPORT)

MAC Control

Clock Register

RTT Register

TB

TBO

TBO

ONU

MAC Control Client

Generate REPORT message

MA_Control.request (REPORT)

MAC Control

Clock Register

Timestamp REPORT message

TB

TBO

TBO

MAC

PHY
MPCP: GATE Handling

OLT
MAC Control Client
- Start
- Stop

MAC Control
- Clock Register
- Time Stamp
- GATE message

ONU
MAC Control Client

MAC Control
- TS
- Start
- Stop

Write Registers
- TS
- Start
- Stop

Laser ON/OFF
- Clock Register
- Slot Start Register
- Slot Stop Register

MA_Control.request (GATE)

MA_Control.indicator (GATE)

MA_DATA.request (?

Upstream Data Path

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The physical distances between OLT and ONUs are different.

Packets cannot arrive OLT in their pre-allocated time slots, resulting in conflicted packets.

OLT cannot recognize the conflicted packets, resulting in high bit error rate and sync loss.
**Timestamp Ranging**

\[ \text{RTT} = T_{\text{Downstream}} + T_{\text{upstream}} = (T_4 - T_1) - (T_3 - T_2) = T_4 - T_3 \]

Balance Delay: \[ T_d = T_{equ} - \text{RTT} \]
Dynamic Bandwidth Allocation (DBA)

Status-Reporting DBA
- ONU sends status of their input packet queue to OLT with the REPORT message.
- OLT grants ONU transmission opportunities according to the service level agreement with the GATE message.

Non-Status-Reporting DBA
- OLT continuously allocates a small amount of extra bandwidth to each ONU.
- ONU transmits idle frames when there is nothing to send
- If OLT observes a large number of idle frames, it will reduce the bandwidth allocation.
- OLT increases bandwidth allocation when there is no idle frames from a ONU.
DBA Example

OLT

ONU1

ONU2

ONU3

ONU4

84

1800

3000

2700

84

1800

3000

2700

84

1800

3000

2700

84

1800

3000

2700

GATE message with grant length = 84 bytes (excluding optical overhead)

REPORT message reporting queue length of 1800 bytes

1800 bytes of user data, including Ethernet frames and idles

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WDM-PON

- Each ONU gets a wavelength channel, and achieves dedicated bandwidth and guaranteed QoS.
- Logical P2P network infrastructure to ensure protocol, data-rate transparency, and better security.
Challenges for WDN-PON Systems

- Colorless ONU is mandatory
- To realize high-performance colorless ONU with low cost is difficult
  - Tunable laser
  - Injection-locked Fabry-Perot laser
  - Reflective semiconductor optical amplifier
Colorless Light Sources

- **Spectrum Sliced Broadband Lightsouce**
  - LED/SLED/SOA as colorless lightsource
  - Spectrum sliced by AWG for appropriate channels

- **Injection locked FP laser**
  - Specially designed FP laser as colorless lightsource
  - FP laser operates on the wavelength of external injected lightwave

- **Reflective Semiconductor Optical Amplifier**
  - Semiconductor optical amplifier as lightsource
  - External injected lightwave is amplified, modulated and reflected to CO
  - Using the saturation property of SOA, the downstream wavelength can be used as an injection to SOA and hence reused for upstream transmission

- **Tunable Laser**
  - Widely tunable semiconductor laser as colorless lightsource
  - Need protocol to set the operating wavelength
Spectrum Slicing

- **Advantages**
  Low cost; no seed light is needed.

- **Disadvantages**
  Low bit rate (<155Mb/s), short transmission distance.

Because of the low bit rate, spectrum slicing is not a good option for WDM PON.
Tunable Lasers

- **Advantages**
  No Seed light is needed
  High bit rate (>2.5Gb/s), long transmission distance (~80km)

- **Disadvantages**
  Very expensive; dynamic wavelength assignment algorithm is needed
Injection Locked FP Laser

**Advantages**
- Low cost

**Disadvantages**
- Seed light is needed
- Limited bit rate and transmission distance
Reflective Semiconductor Optical Amplifiers

- **Advantages**
  - Relatively higher bit rate

- **Disadvantages**
  - Seed light is needed
  - Limited transmission distance
TWDM-PON Basic Architecture

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Main Advantages: improve downstream bandwidth capacity, compatible with traditional TDM-PON and leverage network expansion and upgrade.
WDM-based TWDM-PON

Main Advantages: simplify network control protocol, no need to coordinate ONUs’ data transfer and perform load balancing.
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TDM-over-WDM TWDM-PON

Diagram showing the structure of TDM-over-WDM TWDM-PON.
WDM-over-TDM TWDM-PON

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Hybrid Fiber-Coaxial (HFC) Networks

- New Services Opportunities
  - HVAC control
  - Fire sense & control
  - Security
  - Air quality monitoring
  - Child monitoring
  - Energy management, etc.

- Network Components
  - Operator Core Backbone
  - Operator Aggregation network
  - Aggregation Network
  - Access Network

- Services
  - MPEG Services
  - IP Services
  - Remote file sharing
  - Shared calendar
  - Unified messaging
  - Managed services

- Components
  - Backend
  - Headend
  - CPE
Hybrid Fiber Coax (HFC) Network

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Global Subscriber Growth

![Graph showing the growth of worldwide users over years, with categories HFC/Cable and FTTH/PON.](image)
Cisco CMTS: uBR10k
Infrastructure of DOCSIS 3.0 HFC Network

Cable Modem Termination System

Transmitter Channel Set (TCS)

Receiver Channel Set (RCS)

Internet

CMTS

HFC Network

US0
US1
US2
US3
US4
US5
US6
DS0
DS1
DS2
DS3
D3.0 CM

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What’s Channel-Bonding?

Upstream Channels

Downstream Channels

Pre DOCSIS 3.0 CM

DOCSIS 3.0 CM

Bonding Group as one virtual channel
Dynamic Bonding Change (DBC)

Upstream Channels

DBC_REPLACE

DBC_DELETE

DBC_ADD

Downstream Channels

Transmitter Channel Set (TCS)

DOCSIS 3.0 CM

Receiver Channel Set (RCS)
Channel-Bonding Technology

Boost access bandwidth and user experience

Increase power consumption
Operation of Access Networks
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Tradeoff

Performance

Power Consumption