Ethernet PON (EPON)
TDMA Interface in PHY Layer
and other considerations

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Scope of this presentation...

- TDMA manager in PHY
- EPON initialization (Plug and Play)
- Required OAM support
- PMD considerations
EPON downstream traffic

- Downstream channel uses true broadcast.
- Packets extracted by the MAC addresses.
- Not different from any shared-medium Ethernet LAN.
TDMA Interface in PHY

Main concepts

- TDM-like upstream time slicing
- No collisions, no grants
- No packet fragmentation
- Fixed timeslot size, flexible assignment

OLT

ONU 1

USER 1

ONU 2

USER 2

ONU 3

USER 3

802.3 frame

header Payload FCS

time slot
TDMA System Synchronization

Super Slot Timer Synchronization and Time Slot slicing

- ONU recovers clock from downstream data traffic (time reference)

- Intermittent framing signal (SLOT_SYNC code word) from OLT calibrates zero position of frame timer in ONUs

- Each ONU advances its clock by the RTT value

NOTE: Only 4 time slots shown

OLT Tx timer

ONT Rx timer

OLT Rx timer

ONU Tx timer

Propagation delay

Super Slot synchronization (SLOT_SYNC)

ONU advances its clock by RTT value

Upstream transmission

RTT

IEEE 802.3 EFM Study Group, Portland, OR, July 10-12, 2001
TDMA Timing and time slot structure

- **Guard Band**
- **Time Slot Payload # 1**
- **Time Slot Payload # 2**
- **Time Slot Payload # 3**
- **Time Slot Payload # 4**
- **Time Slot Payload #(n-1)**
- **Time Slot Payload # n**

- **Super Slot Reference (x) Point**
- **Time Slot Alignment Check (x) Position**
- **RTT # 1**
- **RTT # 2**
- **RTT # 3**
- **RTT # 4**
- **RTT # (n-1)**
- **TOF # n**

- **TX Enable (x)**
- **TX Disable (x-1)**
- **Idle Pattern (Time Slot Preamble)**
- **RX Capture**
- **CDR Lock**
- **Start of Time Slot**
- **ENB_ADV**

IEEE 802.3 EFM Study Group, Portland, OR, July 10-12, 2001
Start Of Time Slot field

- Time Slot Alignment is checked by the position of Alignment Pattern in Time Slot
- Empty Time Slot is detected if there is no Alignment Pattern found in the Time Slot
- Optional bit-oriented Embedded Operation Channel for time critical OAM reporting from ONU PHY
EPON normal operation
(downstream direction)

- OLT PHY inserts sync byte (SLOT_SYNC code word) in IPG (ONLY if beginning of super-slot coincides with IPG)
EPON normal operation
(upstream direction)

- Each ONU knows its time slot assignment and RTT compensation values.

OLT Rx channel
(time slots from 4 ONUs)
EPON Plug-and-Play

■ Goals
  ■ Fast detection of disconnected ONU
  ■ No manual configuration of cold ONU
  ■ No interruption to existing traffic flow during cold ONU start-up
  ■ Time Slot alignment (fine tuning)
ONU disconnection

- OLT PHY detects ONU’s disconnection (Empty Time Slot) by missing (not detecting) Start-of-Time-Slot (SOTS) flag

- OLT PHY inserts Empty Time Slot Indicator (ETS_IND) byte at the beginning of empty timeslot (in first IPG after the beginning of the empty time slot)
ONU initialization

- After ONU boots up, it sets RTT compensation value to zero and silently waits for ETS_IND.

- Upon receiving the ETS_IND, ONU immediately replies with an introduction (ECHO) packet.

**NOTE:** Time slot size must be larger than maximum RTT + Guard band + Time slot preamble + ECHO Packet + maximum ETS_IND delay (due to downstream packet).
ONU initialization (2)

- When OLT receives Intro (ECHO) packet it learns
  (a) – ONU’s MAC address
  (b) – ONU’s RTT

- OLT assigns ONU a time slot and RTT delay compensation value. (Use OAM communication channel to convey the information to ONU.)
ONU initialization (3)

- If several ONUs boot up simultaneously, their Intro packets may collide.

- **Solution:**
  If ONU does not receive timeslot assignment within **TIMEOUT** interval after it sent Intro packet, wait random number of ETS_IND code words and try again.
RTT compensation values fine-tuning

- OLT may fine-tune the RTT compensation values for each ONU by measuring drift in Start-of-Time-Slot (SOTS) flag arrival time.

- New values conveyed to ONUs through OAM control channels.
ONU’s state diagram

- Wait for ETS_IND
  - ETS_IND received
- Sending Intro packet
  - Intro packet sent
- Wait for timeslot assignment
  - Timeslot assignment received
  - TIMEOUT
- Done
  - Random backoff (skip n ETS_INDs)
Basic TDMA requirements

- No interruption to existing traffic flow during new ONU sign-in (Plug and Play)
  Time slot size > max. RTT + Guard Band +
  Time slot preamble + ECHO Packet + max. ETS_IND delay

- Each ONU assigned at least one time slot
  Number of time slots per frame $\geq$ number of ONUs

- Channel utilization greater than 85%
  Guard Band + Time slot preamble + Avg. unfilled time slot remainder < 15% of time slot size
Time Slot Size Considerations

- **Optical delay – Round-Trip time (RTT)**
  - 10 km round trip delay ≈ 100 µs
  - Fiber cable length may change 3% over season ≈ 3 µs

- **Guard Band < 8.0µs**
  - Max. laser disable/enable time: 1.0~3.0 µs
  - Max. receiver capture time: 1.5 µs
  - Max. clock recovery lock time: 0.8~2.5 µs
  - System margin: ± 1.0 µs (± 200 m)

- **Average unfilled time slot remainder**
  - ½ max. packet size ≈ 6 µs
  - No jumbo frames

- **Time slot preamble**: 4 bytes (32 ns)

Laser disable/enable time + system margin (3.6 µs)
## System Performance Examples

### System Parameters

<table>
<thead>
<tr>
<th>Configuration</th>
<th>10km, 1x16</th>
<th>10km, 1x32</th>
<th>20km, 1x16</th>
<th>20km, 1x32</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Time Slot Size</td>
<td>125</td>
<td>125</td>
<td>250</td>
<td>250</td>
<td>µs</td>
</tr>
<tr>
<td>Min. Number of Nodes</td>
<td>16</td>
<td>32</td>
<td>16</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Min. Super Slot</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>ms</td>
</tr>
<tr>
<td>Guard Band</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>µs</td>
</tr>
<tr>
<td>Average Unfilled Gap</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>µs</td>
</tr>
<tr>
<td>Time Slot Utilization</td>
<td><strong>88.4</strong></td>
<td>88.4</td>
<td>94.1</td>
<td>94.1</td>
<td>%</td>
</tr>
</tbody>
</table>

### Bandwidth Utilization (one empty Time Slot per Super Slot)

<table>
<thead>
<tr>
<th>Super Slot Size</th>
<th>4</th>
<th>4</th>
<th>8</th>
<th>8</th>
<th>ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Slot Size</td>
<td>125</td>
<td>250</td>
<td>125</td>
<td>250</td>
<td>µs</td>
</tr>
<tr>
<td>Number of Time Slots</td>
<td>32</td>
<td>16</td>
<td>64</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Super Slot Utilization</td>
<td>96.8</td>
<td>93.7</td>
<td><strong>98.4</strong></td>
<td>96.8</td>
<td>%</td>
</tr>
<tr>
<td>Overall static utilization</td>
<td><strong>85.5</strong></td>
<td>88.7</td>
<td><strong>86.9</strong></td>
<td>91.0</td>
<td>%</td>
</tr>
</tbody>
</table>
Rate adaptation in ONU upstream

From 802.3ae (clause 4.2.3.2.2): A larger value of interframe spacing is used for dynamically adapting the nominal data rate of the MAC sub-layer to SONET/SDH data rates (with packet granularity) for WAN-compatible applications of this standard.

Use similar approach for EPON:

- MAC extends IPG to match the bandwidth available to PHY
- PHY removes extra idles and buffers frames between time slots
- When high-water mark received from buffer, generate PAUSE frame to user (optional)
Loop-Back Test in EPON

- PHY Layer loop-back is supported in EPON only with Multiple P-P-P Emulation Layer attached.
- TDMA Control Layer is able to support Data Link Test (MAC layer loop-back) without Multiple P-P Emulation layer involved.
Required OAM Support for TDMA

- **System**
  - OLT able to download RTT compensation value to ONU
  - OLT able to assign time slot(s) to ONU
  - OLT able to revoke time slot(s) from ONU
  - MAC layer Data Link Test (ECHO packet)

- **Status monitoring in OLT PHY**
  - Empty Time Slot detection
  - Time slot drift alarm (drift over 0.25 µS)
  - Time slot alignment (offset) value

- **Status monitoring in ONU PHY**
  - SLOT_SYNC timeout
  - PLL: Loss of Lock
  - Initialization flag
EPON PMD Related Considerations

■ Security
  ■ ONU PMD must not emit light during ONU’s power on/off
  ■ ONU PHY shall have security feature to ensure transmitter is always off until time slot(s) assigned by OLT

■ ONU Transmitter
  ■ Burst-mode operation – average power will be fraction of continues mode (laser is cooler => longer life or may pump higher optical power). Minimum on/off duty ratio shall be specified if burst operation spec is taken in design
  ■ Laser enable/disable delay must be specified

■ OLT Receiver
  ■ Capture time and AGC time constant must be specified
Summary

- TDMA Interface Layer meets PHY requirements in 802.3 Model and allows native Ethernet to be multiplexed in PON

- Flow Control and Link Aggregation defined only for Point-to-Point links, and are not applicable to EPON. The compliance issues can be solved by attaching the Multiple P-P Emulating Layer in PHY