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

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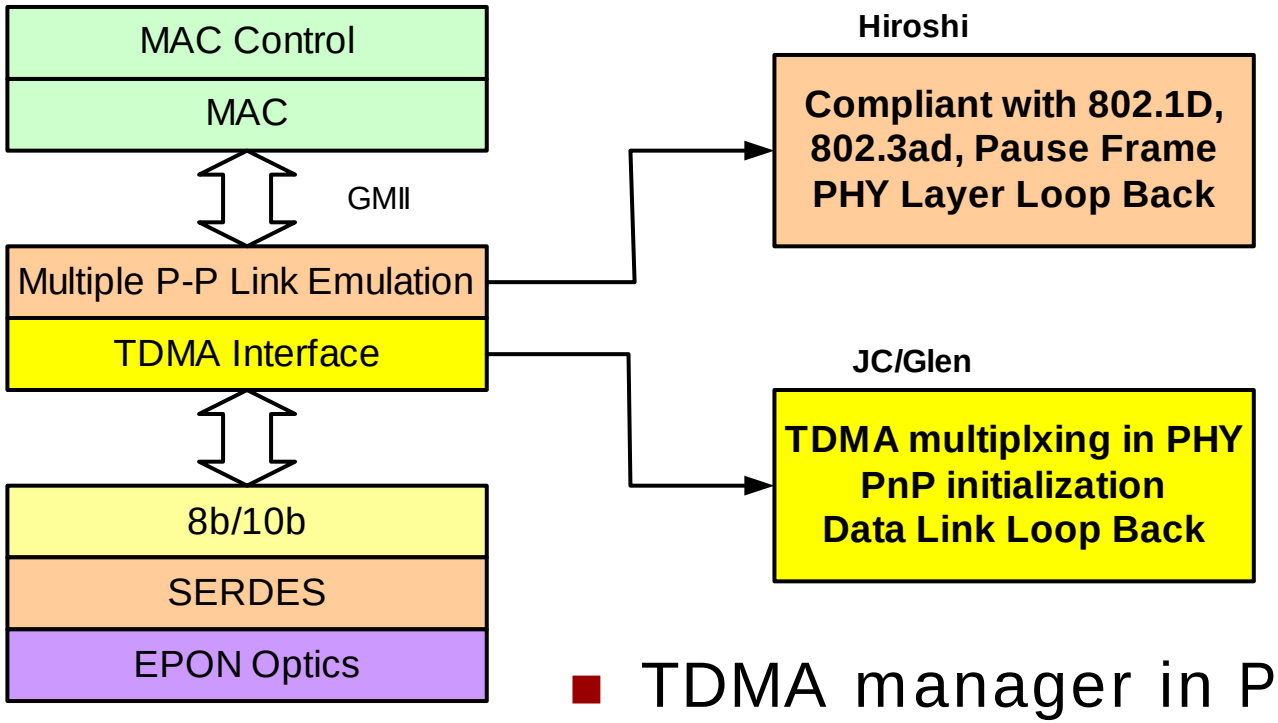
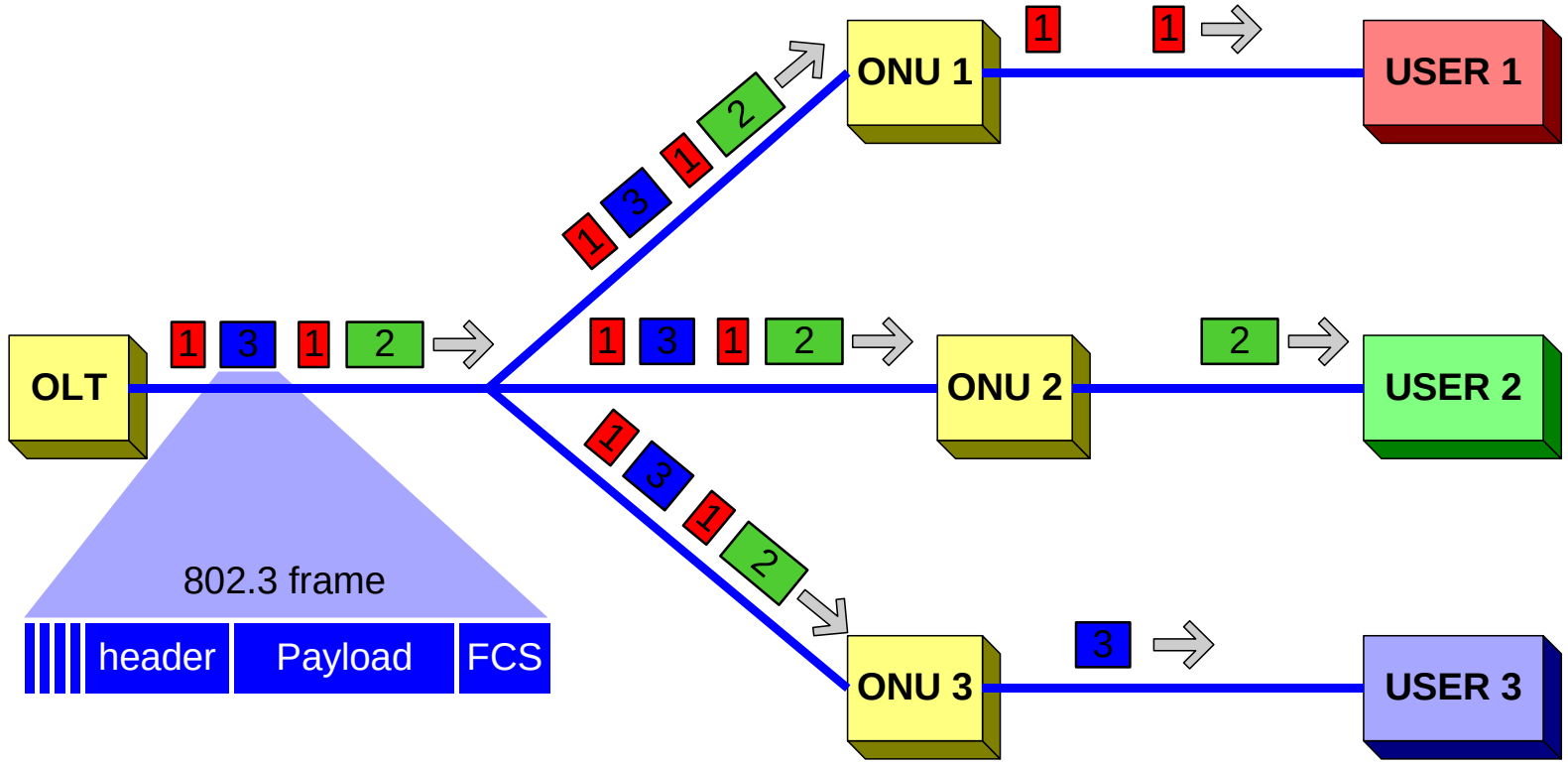
Scope of this presentation…



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

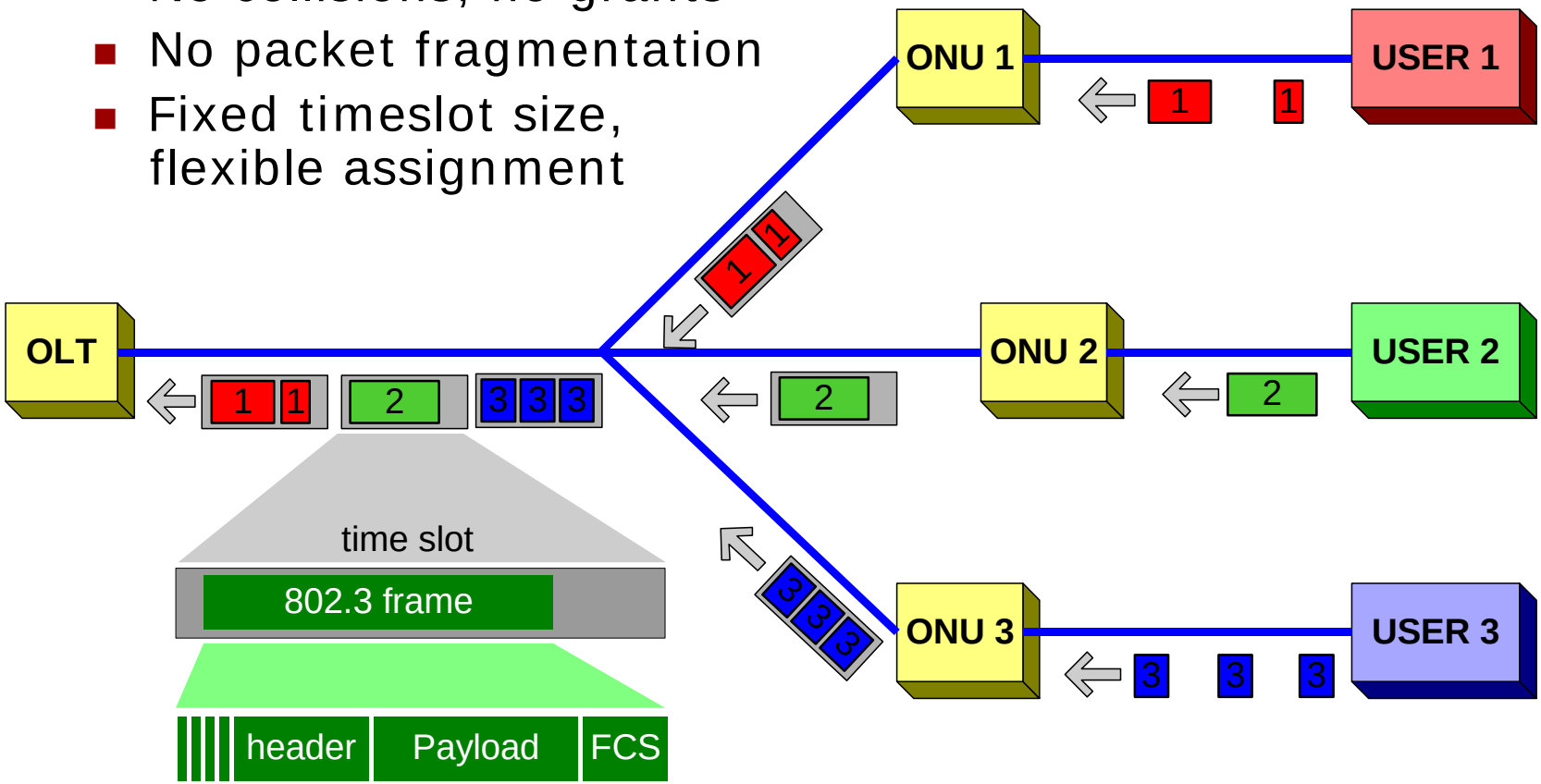
EPON downstream traffic



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

TDMA Interface in PHY

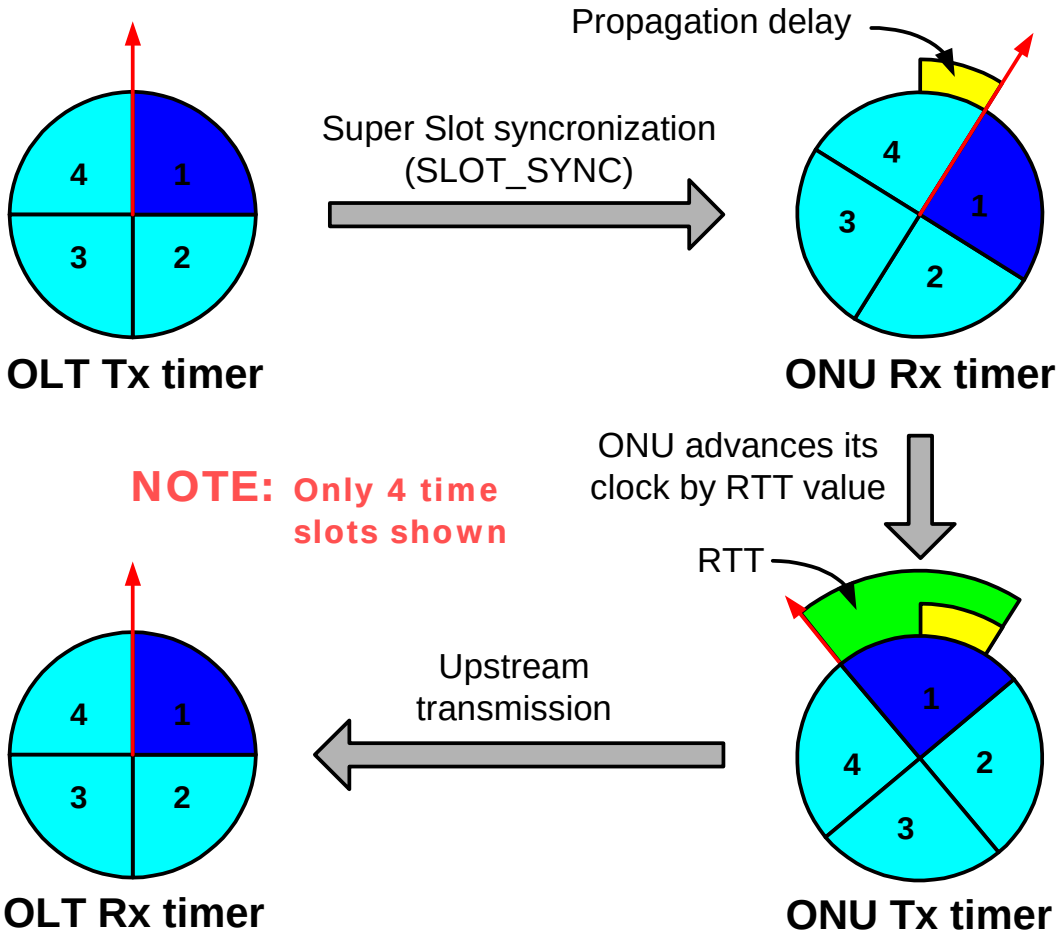
- Main concepts
  - TDM-like upstream time slicing
  - No collisions, no grants
  - No packet fragmentation
  - Fixed timeslot size, flexible assignment



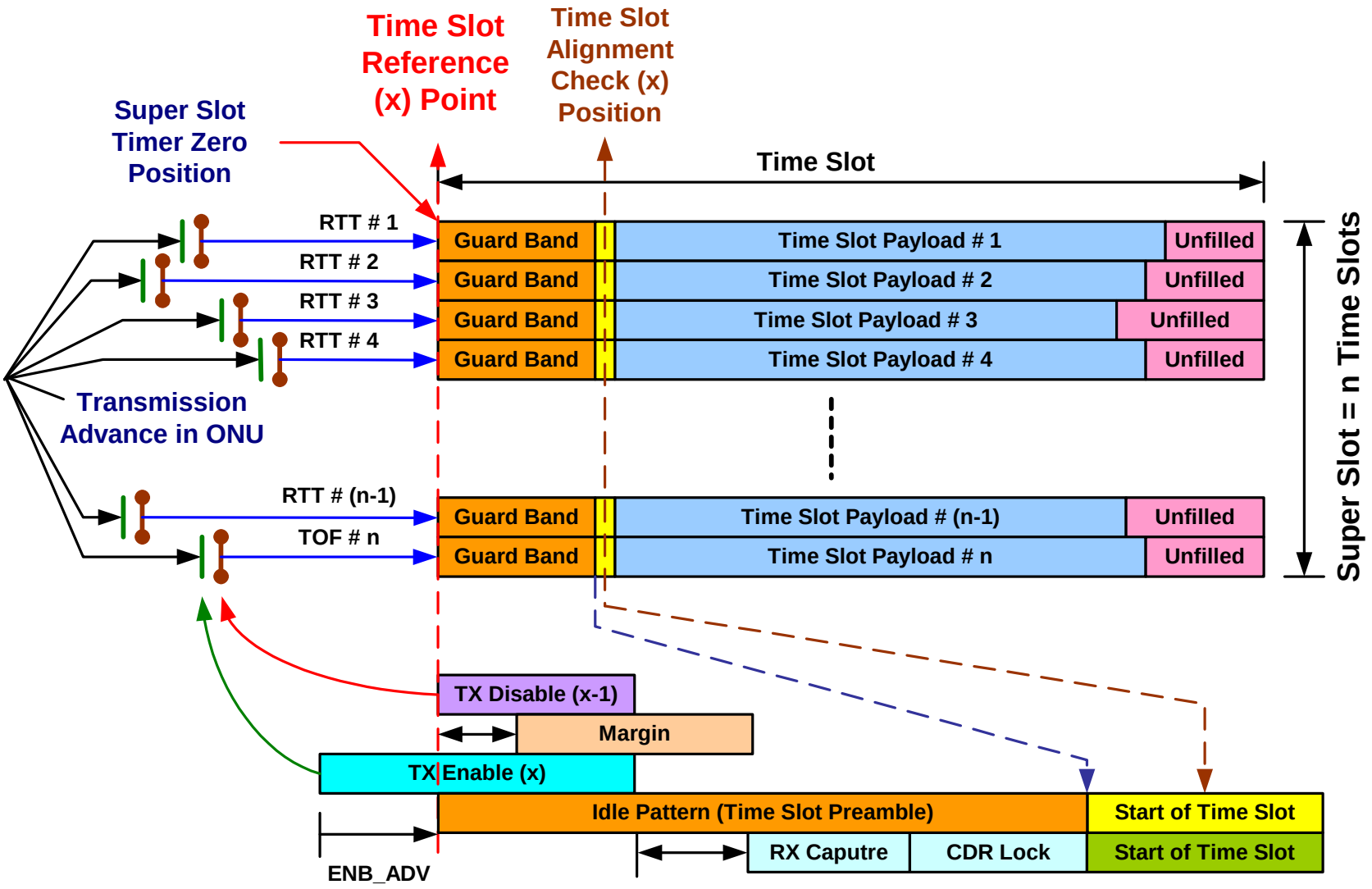
TDMA System Synchronization

Super Slot Timer Synchronization and Time Slot slicing

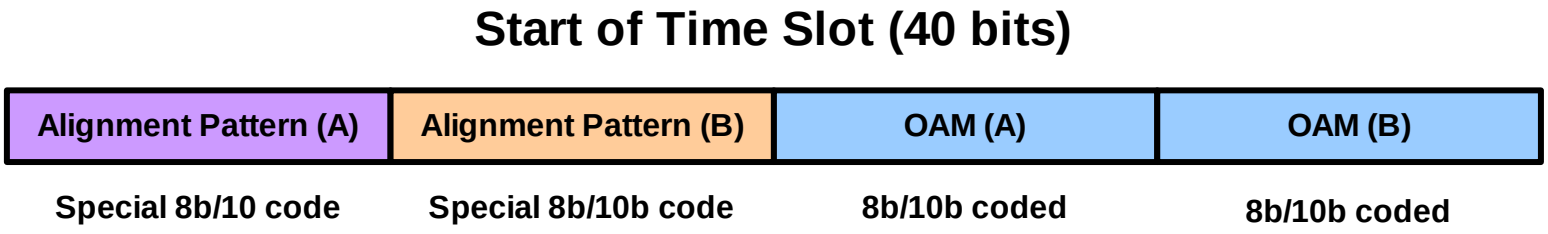
- ONU recovers clock from downstream data traffic (time reference)
- Intermittent framing signal (**SLOT_SYNC** code word) from OLT calibrates zero position of frame timer in ONUs
- Each ONU advances its clock by the RTT value



TDMA Timing and time slot structure



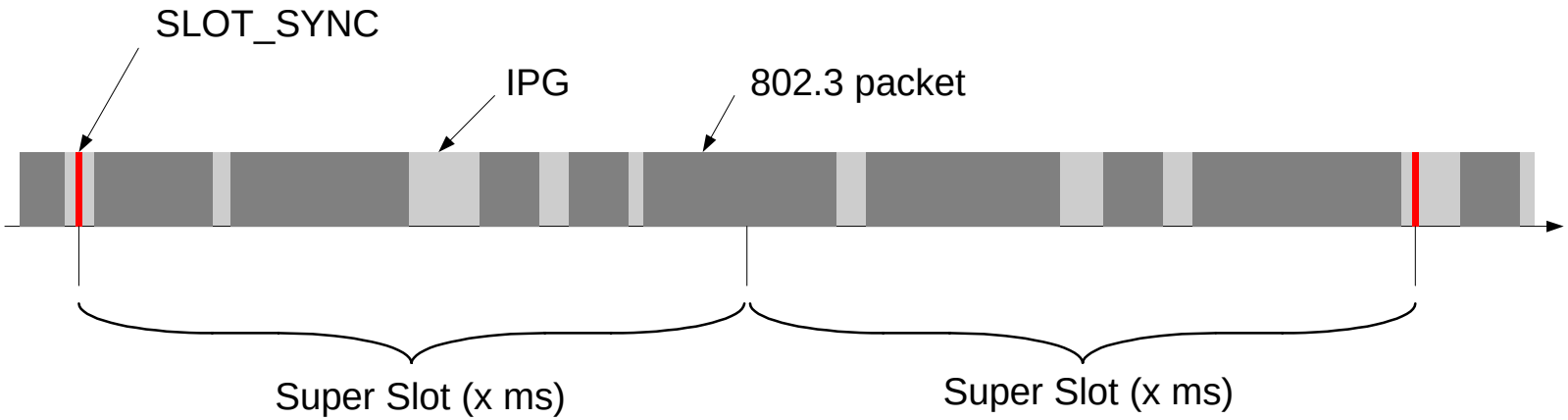
Start Of Time Slot field



- 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

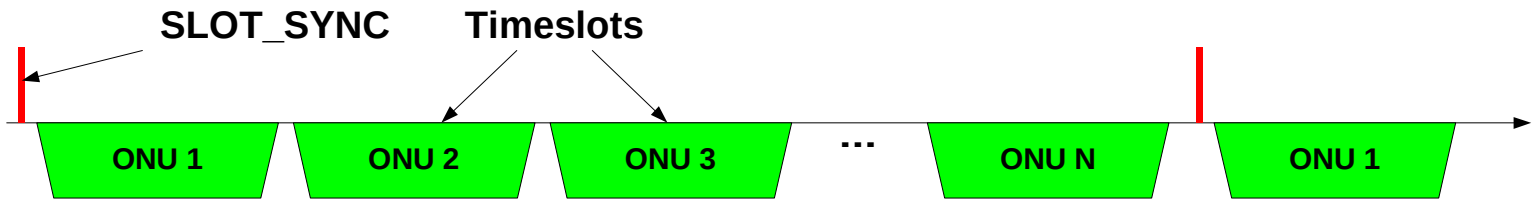
(downstream direction)



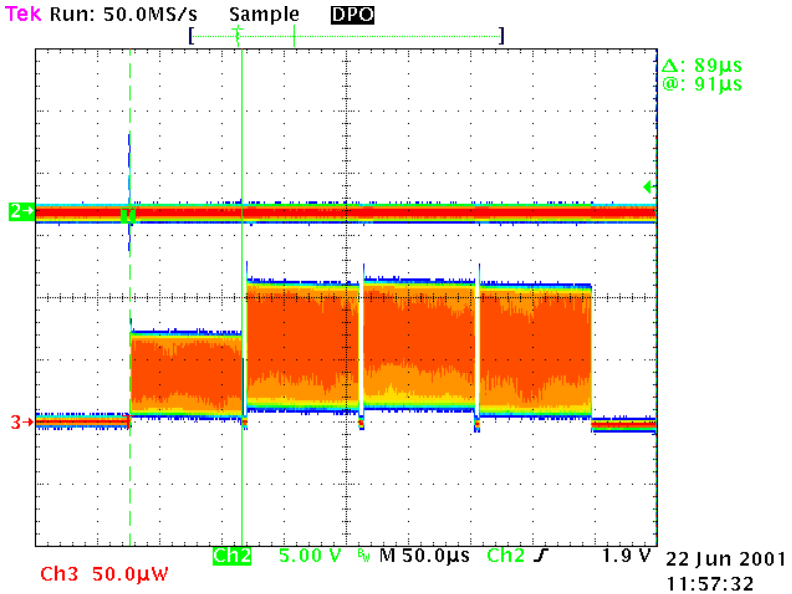
- OLT PHY inserts sync byte (SLOT_SYNC code word) in IPG (ONLY if beginning of super-slot coincides with IPG)

EPON normal operation

(upstream direction)



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



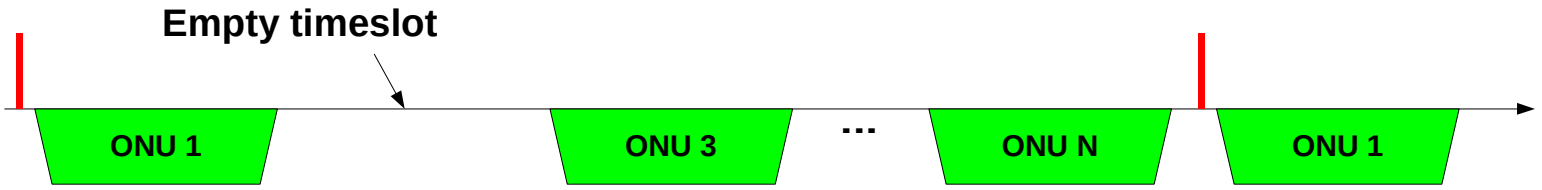
OLT Rx channel (time slots from 4 ONUs)

EPON Plug-and-Play

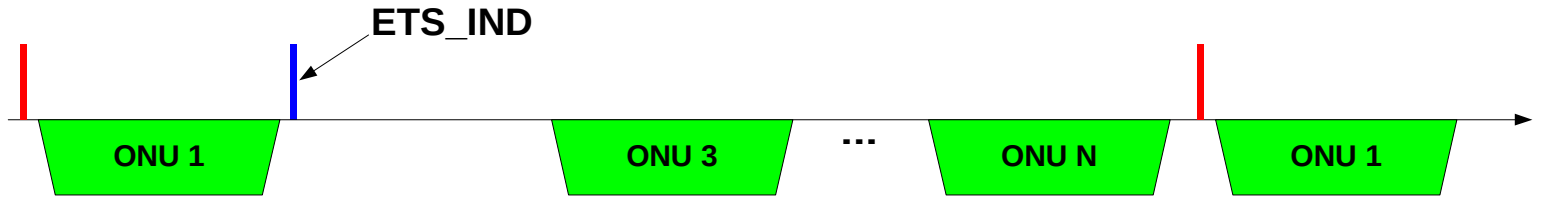
- Goals
  - Fast detection of disconnected ONU
  - No manual configuration of cold ONU
  - No interruption to existing traffic flow during cold ONU start-up
  - Time Slot alignment (fine tuning)

ONU disconnection

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

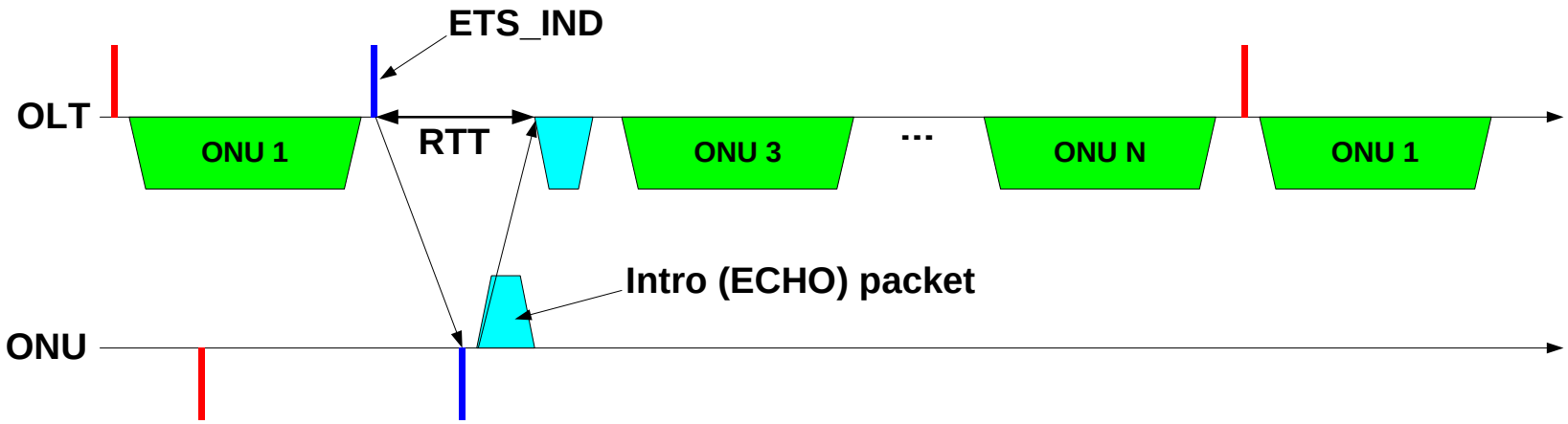


- OLT PHY inserts Empty Time Slot Indicator (ETS_IND) byte at the beginning of empty timeslot (in first IPG after the beginning of the empty time slot)



ONU initialization (1)

- 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)

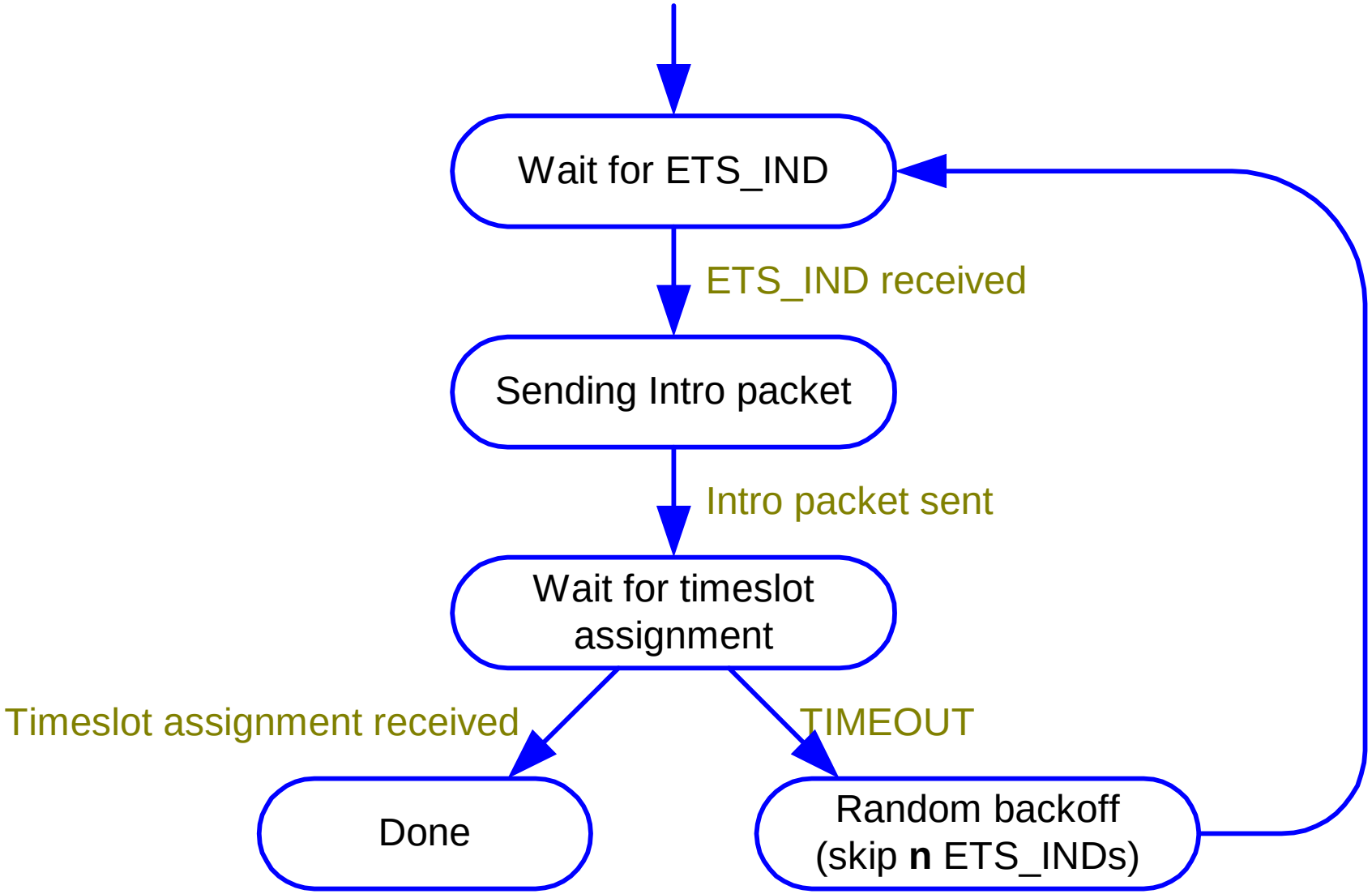
- If several ONUs boot up simultaneously, their Intro packets may collide.

- 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

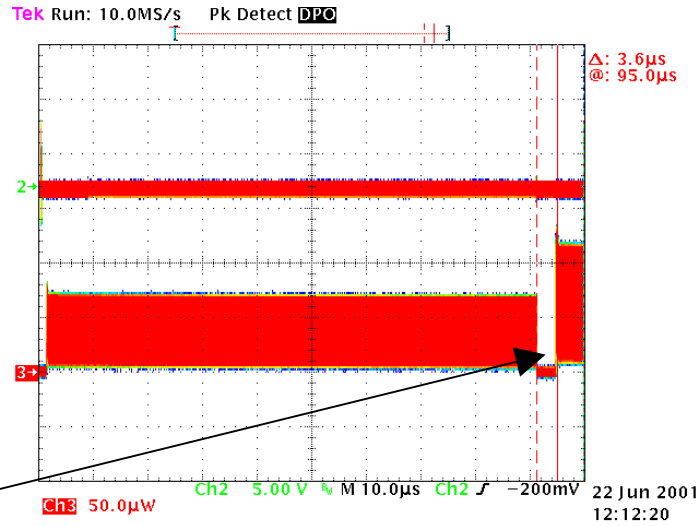


Basic TDMA requirements

- 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 ≥ 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

Configuration	**10km, 1x16**	10km, 1x32	20km, 1x16	20km, 1x32	Unit
Time Slot Size	**125**	125	250	250	µs
Min. Number of Nodes	**16**	32	16	32	
Min. Super Slot	**2**	4	4	8	ms
Guard Band	**8**	8	8	8	µs
Average Unfilled Gap	**6**	6	6	6	µs
Time Slot Utilization	**88.4**	88.4	94.1	94.1	%

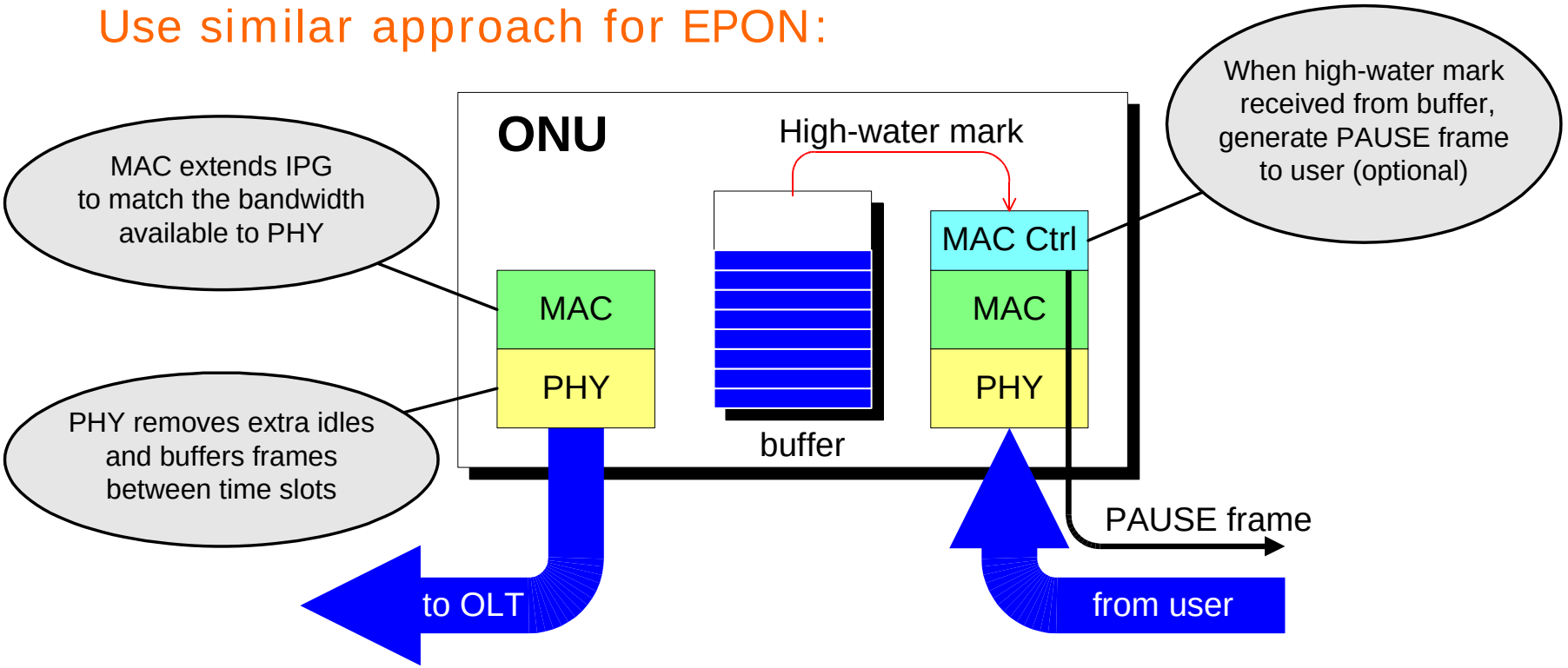
Bandwidth Utilization (one empty Time Slot per Super Slot)

Super Slot Size	4	4	**8**	8	ms
Time Slot Size	125	250	**125**	250	µs
Number of Time Slots	32	16	**64**	32	
Super Slot Utilization	96.8	93.7	**98.4**	96.8	%
Overall static utilization	85.5	88.7	**86.9**	91.0	%

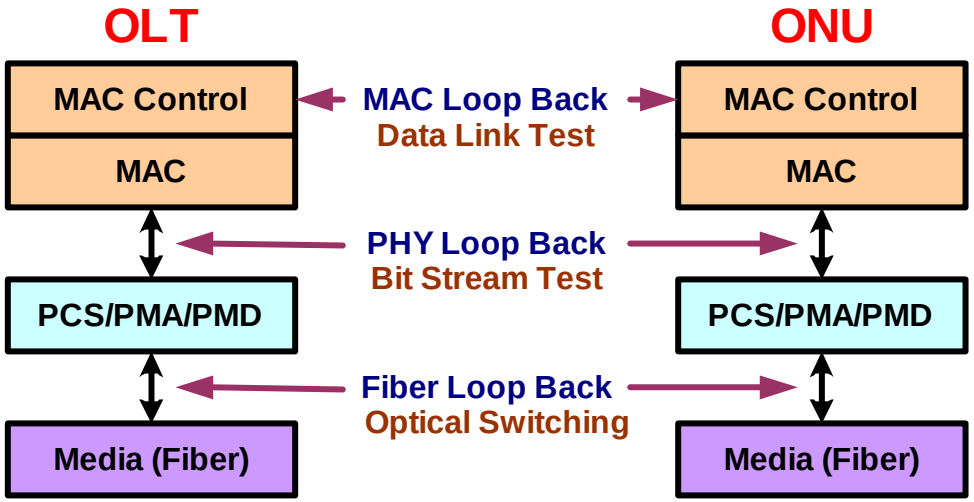
Rate adaptation in ONU upstream

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:



Loop-Back Test in EPON



- PHY Layer loop-back is supported in EPON only with Multiple 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