Time of day Distribution over E-PON

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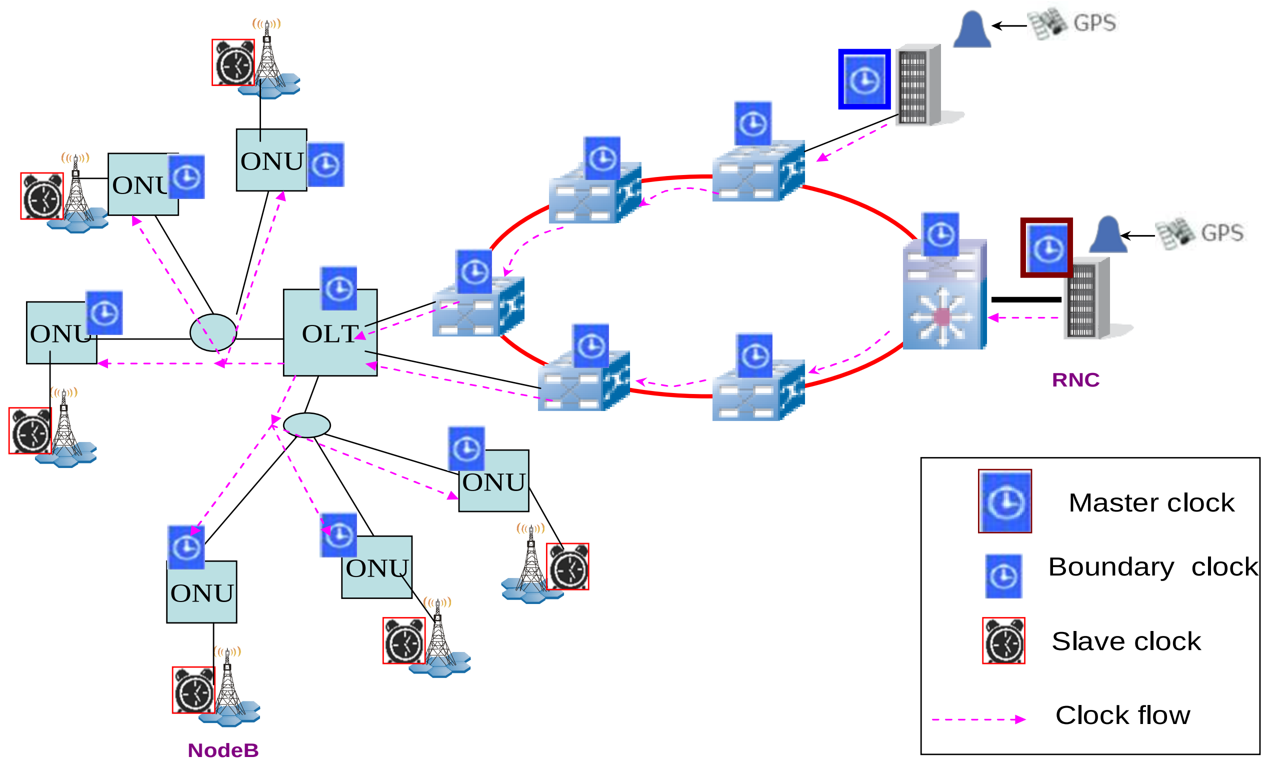
EPON as wireless backhaul

- EPON is an efficient and cost-effective way of carrying cellular data to remote base-stations
- Good for domestic/enterprise applications (Pico-cells, Femto-cells)
- <u>Challenge: providing time-of-day info in EPON</u>
  - Precise time-of-day info is required by each wireless technology

Wireless tech	Frequency accuracy	Time-of-day accuracy
GSM	50 ppb	Supported by in-band channel
WCDMA	50 ppb	Supported by in-band channel
CDMA2000	50 ppb	3us (GPS)
TD-SCDMA	50 ppb	3us (GPS)
WiMAXTDD	50 ppb	1us (GPS)
WiMAX FDD	50 ppb	N/A
LTE	50 ppb	Needs time-of-day sync

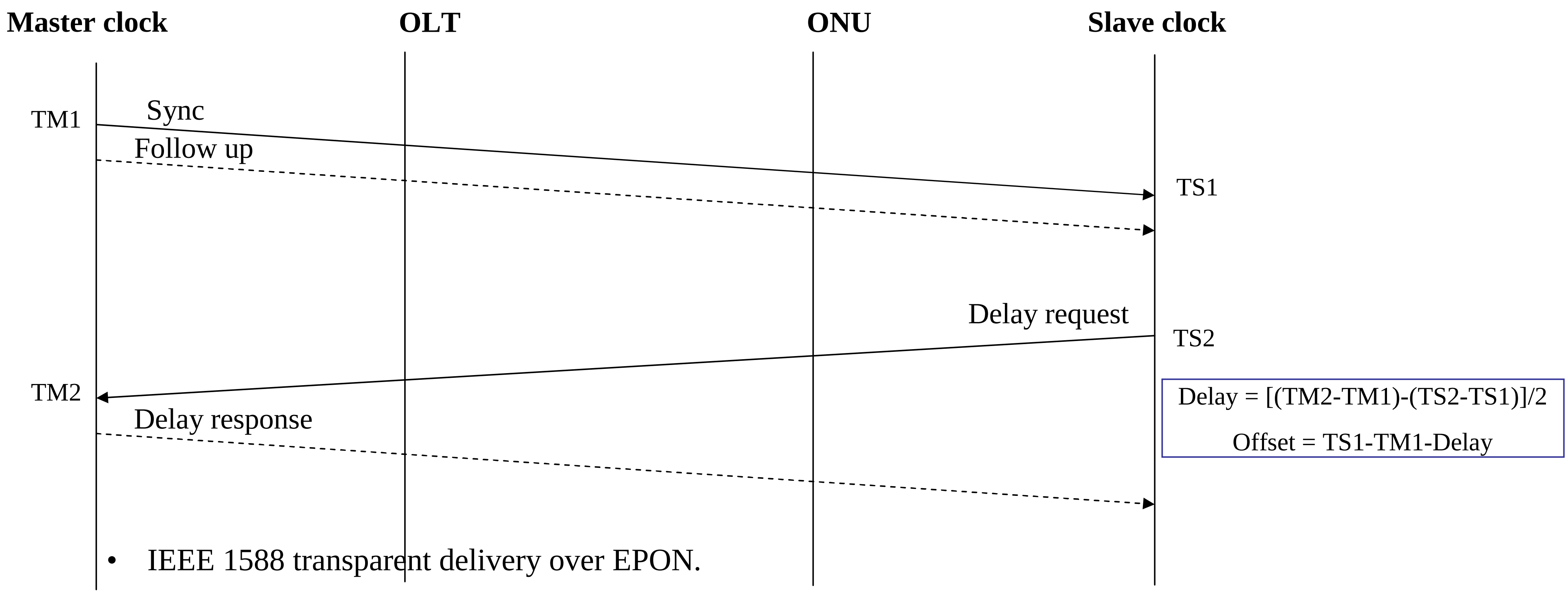
Time-of-day sync in EPON

- Not specified by EPON standard
  - **OLT obtains time-of-day (ToD) info from master/boundary clock**
  - **OLT distributes ToD to ONUs in EPON**
  - **ONU sets slave clock accordingly**



Why not choose IEEE 1588?

IEEE 1588 performs perfectly in some systems. However, in the case of EPON:



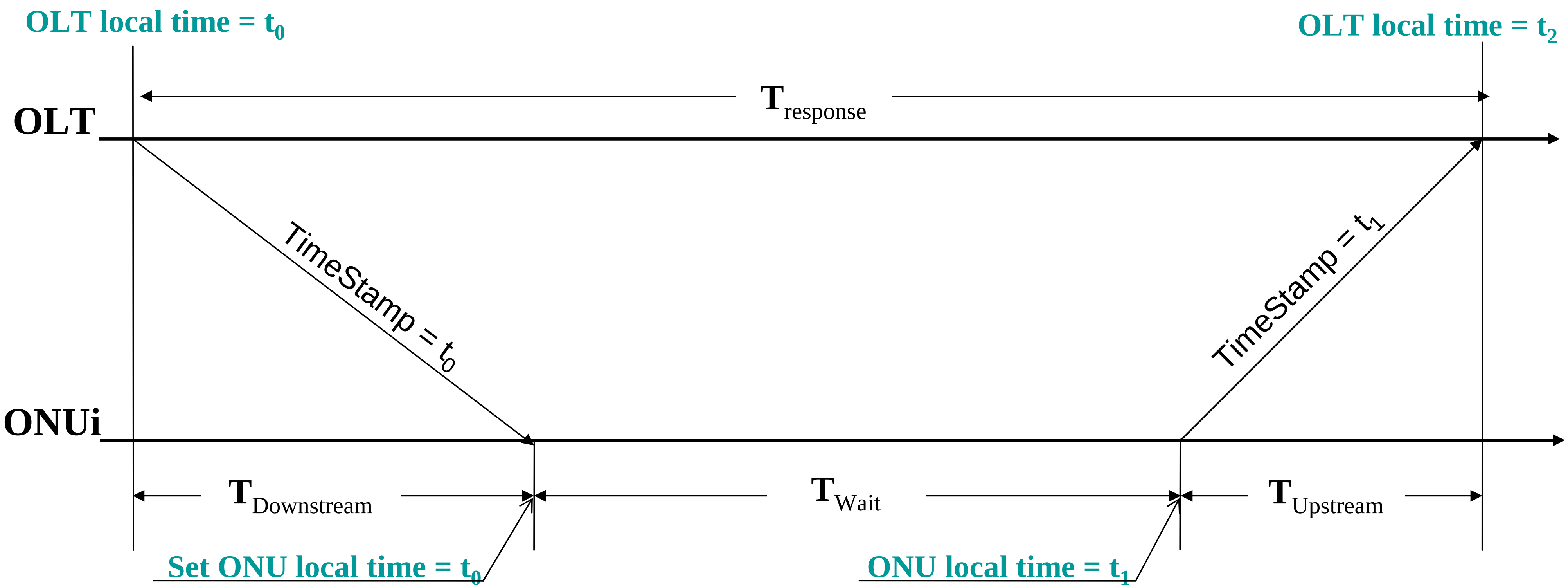
- IEEE 1588 transparent delivery over EPON.

- EPON downstream delay (from OLT to ONT) is different from upstream delay (from ONT to OLT) due to frame queuing (on the order of 100 microseconds)
- Link asymmetry impairs timing accuracy
- Transparent delivery cannot distribute precise time/frequency

EPON has its own time management facility: MPCP

- **Both the OLT and ONT have a local MPCP clock**
  – Each ‘tick’ of this clock is 16ns, as measured by the OLT’s line clock
  – This clock is the reference for the timestamps and grants
- **MPCP distributes a timestamp**
  – 32 bit timestamp value
  – Roll-over occurs every ~68.72 seconds
- **OLT generates grants of upstream time such that ONU collisions are avoided**

Review: TDMA in EPON



$T_{downstream}$ = downstream propagation delay

$T_{upstream}$ = upstream propagation delay

T_{wait} = wait time at ONU = $t_1 - t_0$ [Note: ONU is instructed to transmit at time t_1]

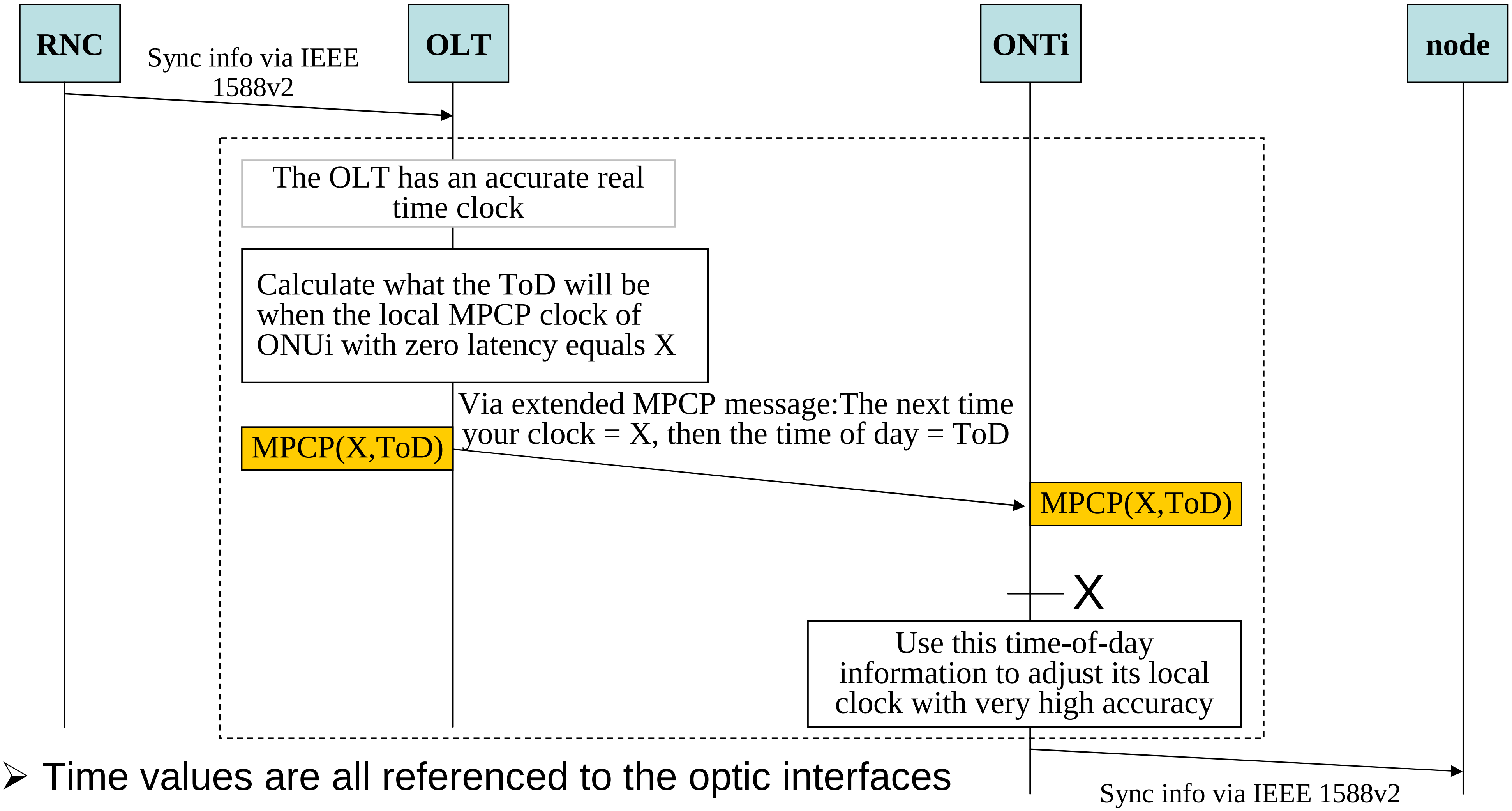
$T_{response}$ = response time at OLT = $t_2 - t_0$

$RTT = T_{downstream} + T_{upstream} = T_{response} - T_{wait} = (t_2 - t_0) - (t_1 - t_0) = t_2 - t_1$

Basic problem: How to relate the timestamp with the real Time of Day?

- **The ONUs do not know how far away they are from the OLT**
- **In normal operation, the OLT modifies the ONU's grant times to make up for the measured RTT**
  - Tgranted = Tdesired – RTT
- **The OLT can calculate the offset between its MPCP clock and the ONU's MPCP clock**
  - The OLT is responsible for factoring in its own internal delays
  - The OLT assumes that the ONU has an idealized zero internal delay
  - The ONU is then responsible for factoring it its actual delay

Proposed Solution – Principle

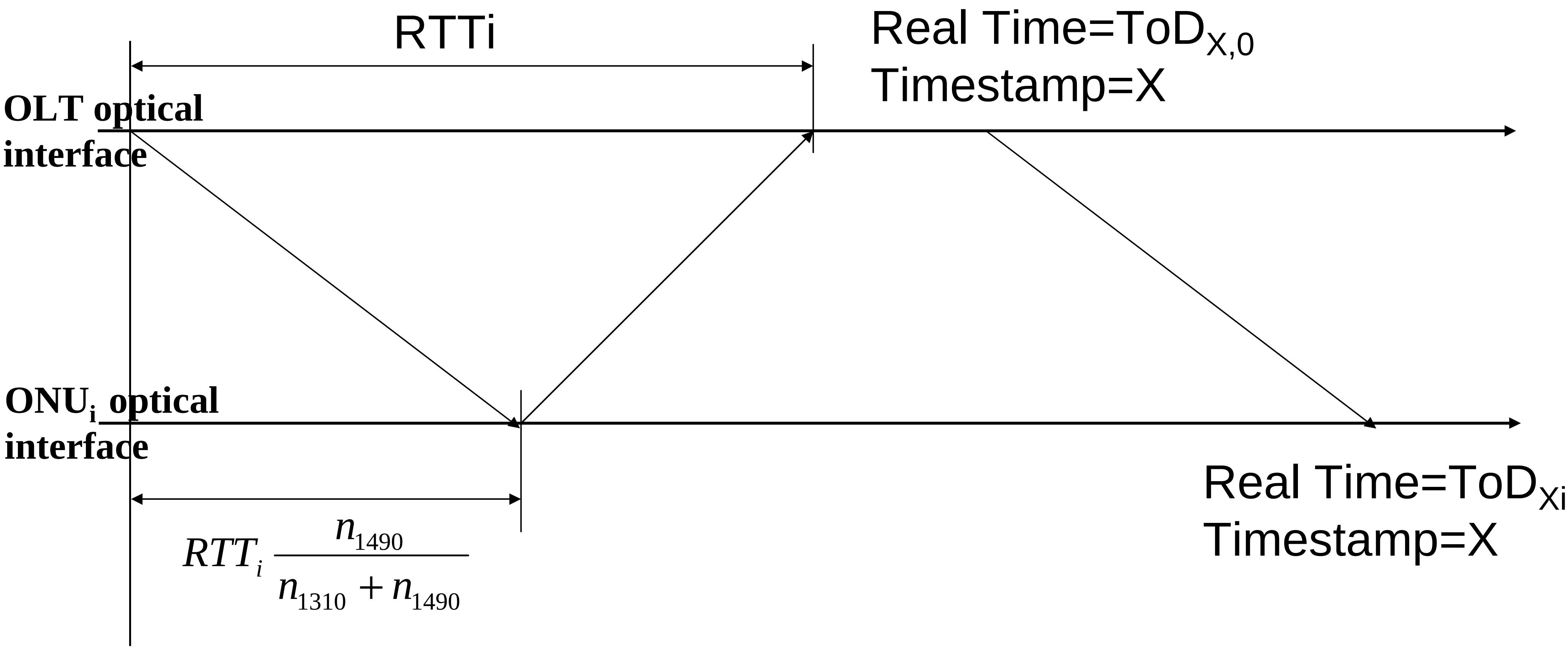


- Time values are all referenced to the optic interfaces
- OLT and ONU need to compensate for their own internal delays
- Downstream propagation delay is calculated by OLT
- The frame queuing delay can be eliminated

Proposed Solution (1) - Notations

- **ToD**$_{X,i}$ **-** The time-of-day when the first bit of a downstream MPCP frame that would carry a timestamp of X would have arrived at an ONU that has zero latency
  - **The arrival of the signal at the ONU is defined to be when the optical signal crosses the optical connector or splice that is the boundary between the ODN and the ONU**
- **ToD**$_{X,0}$ – The exact time-of-day at which the first bit of a downstream MPCP frame that would carry the timestamp *X* would have departed from the OLT
  - **The departure of the signal is defined to be when the optical signal crosses the optical connector or splice that is the boundary between the OLT and the ODN**
- **RTT**$_i$ – The round trip time measured by the OLT for ONUi
  - **This round trip time should not include any internal OLT delays: it is measured relative to the optical departure and arrival times**
- **n**$_{1310}$ – the index of refraction for 1310nm wavelength light in the ODN.
- **n**$_{1490}$ – the index of refraction for 1490nm wavelength light in the ODN.

The zero latency ONU



$\boldsymbol{RTT_i} = \boldsymbol{T}_{\text{downstream}} + \boldsymbol{T}_{\text{upstream}}$

To zero'th order: $\boldsymbol{T}_{\text{downstream}} \approx \boldsymbol{T}_{\text{upstream}} \rightarrow \boldsymbol{T}_{\text{downstream}} = \boldsymbol{RTT_i}/2;$

To first order: $\boldsymbol{T}_{\text{downstream}} = RTT_i \dfrac{n_{1490}}{n_{1310}+n_{1490}}$

$$ToD_{X,i} = ToD_{X,0} + RTT_i \frac{n_{1490}}{n_{1310}+n_{1490}}$$

Timing Process

- **The OLT calculates the RTTi for ONU_i continuously**
- **When the RTT_i has changed significantly, the OLT will adjust the ONU's ToD**
- **The OLT selects an arbitrary MPCP timestamp value, X, that will be used as a reference**
  - This timestamp must occur far enough in the future so that the messages are processed in time
- **The OLT calculates the time-of-Day for ONU_i according to the following equation:**

$$ToD_{X,i} = ToD_{X,0} + RTT_i \frac{n_{1490}}{n_{1310} + n_{1490}}$$

- **OLT sends this value (X, $ToD_{X,i}$) to the ONUi via the MPCP.**
- **When ONU_i's MPCP local clock equals X, it can set its real-time-clock to the value $ToD_{X,i}$ plus any internal delays**

Carrying the information

- **Message carries (X, $ToD_{X,i}$) from OLT to ONU_i**
  - X is 4 byte field
  - $ToD_{X,i}$ is 10 byte field – same format as IEEE1588
- **Most likely candidate would be MAC Control**
  - Perhaps the first application of the ITU extension?
  - Or, something that could be done in 802.3

Performance analysis: Clock accuracies

- **MPCP clock inaccuracy**
  - **Since the timer unit is 16ns, this offset is up to ±8ns;**
- **TimeStamp drift error**
  - **The TDMA scheme has a certain amount of tolerance, the guardThresholdOLT, which is ±12 Time quanta (192ns), as defined in 802.3av 64.2.2.1**
  - **A properly operating PON should have a RTT variation within this range**
  - **The variation of ToD is then ±96ns (and typically much better)**

Performance analysis: Fiber propagation

- **Downstream is 1480~1500nm, Upstream is 1260~1360nm**
- Zero order analysis: Index factor is 0.5
- First order analysis: For typical SMF-28 fibers, n_{1310}=1.4677, n_{1490}=1.4682, so the index correction factor is 0.500085
  - **The approximation of 0.5 results in a systematic error of 170ppm**
  - **~17ns in a 20km long (100μs one-way delay) PON system**
- Second order analysis: The laser wavelengths and the fiber dispersion can vary over certain ranges, so the index factor can vary from 0.500041 to 0.500090
  - **This is a slowly varying error of ±50ppm (±5ns)**

Conclusion

- **Distribution of time-of-day is needed in EPON**
  - Simple application of IEEE1588 schemes will be inaccurate
- **The basic TDMA scheme in EPON can be used**
  - A message tying the MPCP timestamp to the time-of-day is needed
  - MAC Control extension message is needed
- **The accuracy of this method is quite good**
  - OLT timing accuracy ±8 ns
  - TimeStamp drift error ±96 ns
  - Propagation error ±5 ns
  - Total allocated error for EPON system could be set at ±125ns (?)

Thank you