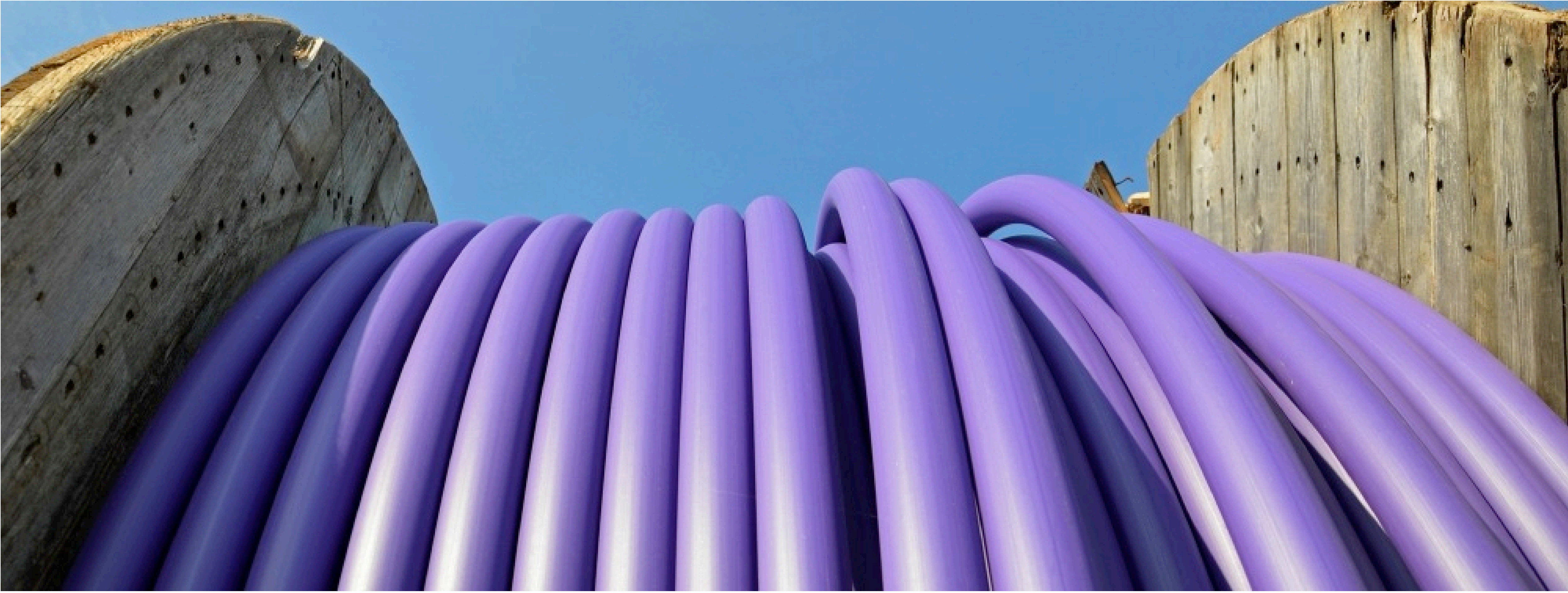

EPoC Time Transport

IEEE 802.3bn Task Force / Waikoloa meeting

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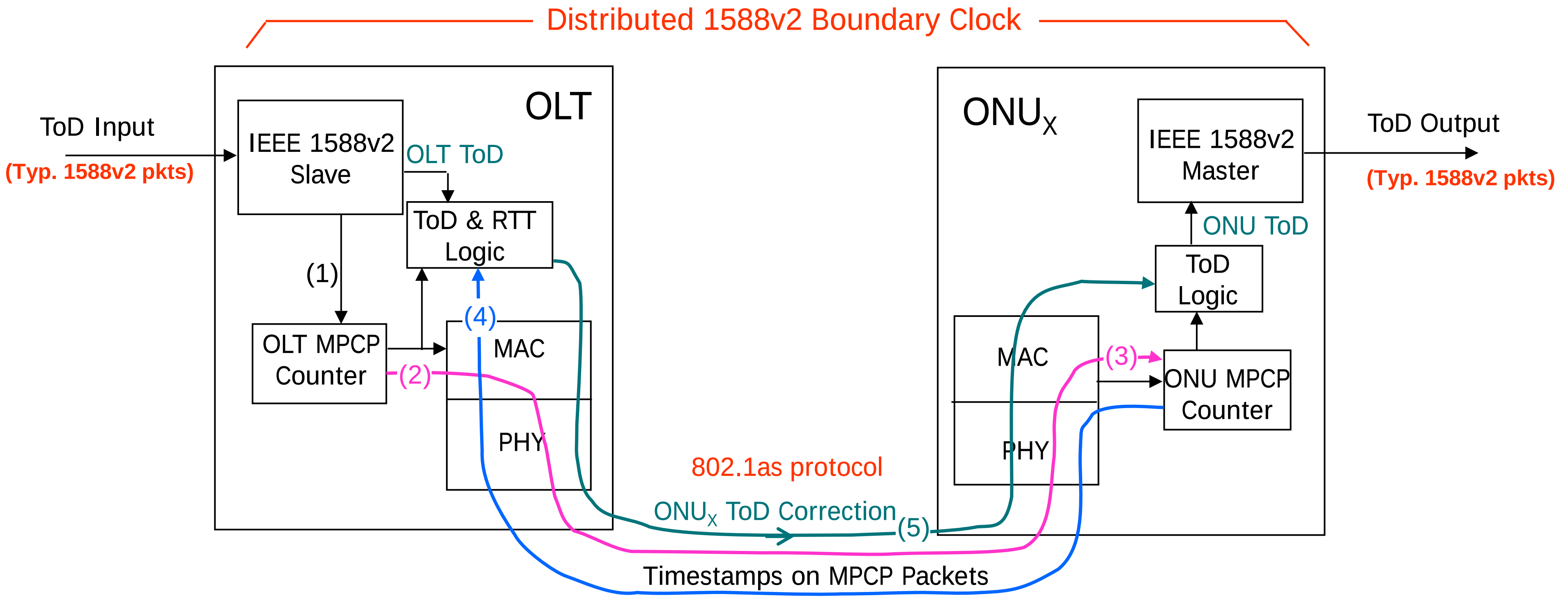
July 13-14, 2015

Agenda

- EPON time transport method
- Cascaded EPON & EPoC links
- EPoC OFDM ranging mechanism
- Improved EPoC time transport method
- Clause 90 (aka 802.3bf) Timesync Min/Max PHY time delay parameters
- PHY TX/RX path asymmetry
- EPoC PHY delay correction parameter to 802.1as EPON time transport method
- Recommended changes to 802.3bn Clause 105.1

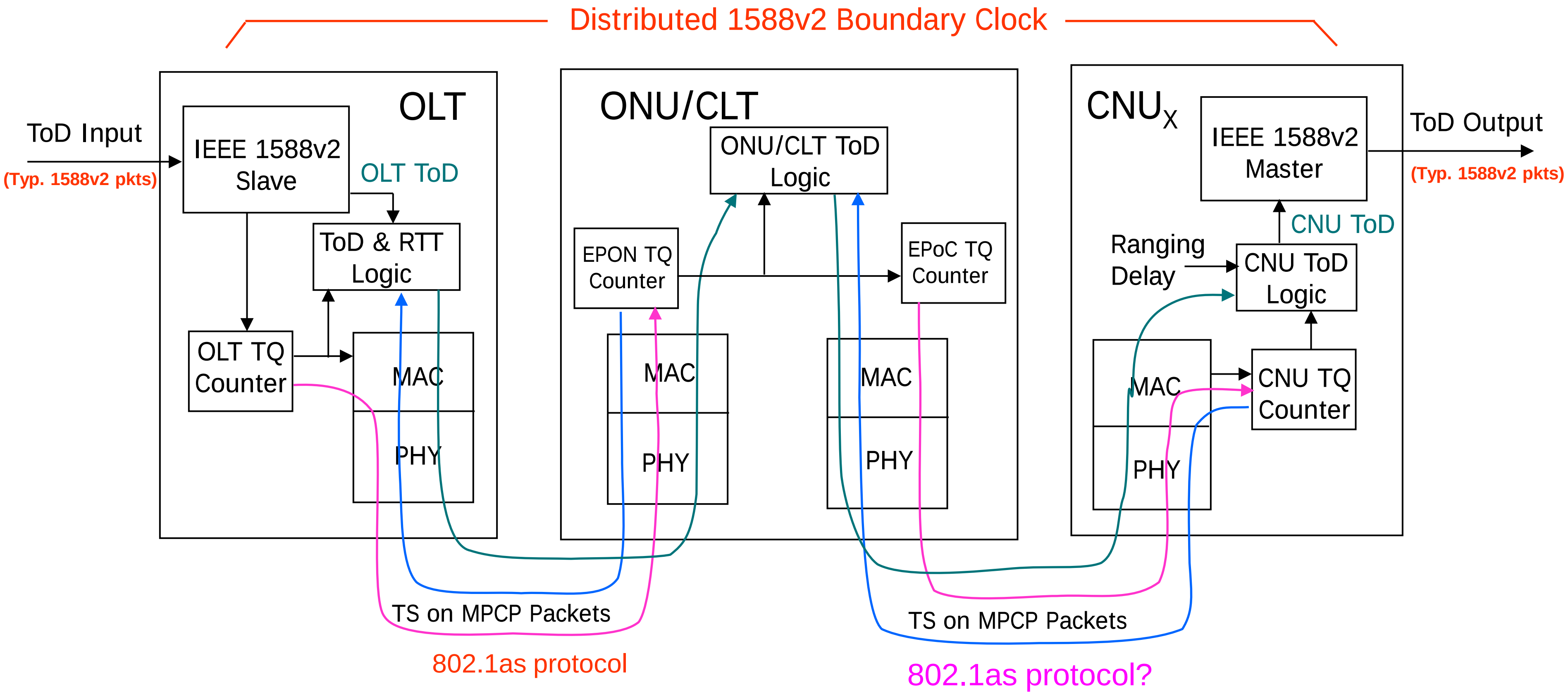
1G/10G EPON time transport mechanism



- EPON time transport method defined in IEEE 802.1as, clause 13
- The local 32b MPCP (TQ) counter in the OLT (1 TQ = 16ns) is timed from an external time source (1)
- MPCP messages sent to ONUs have OLT MPCP counter value loaded into timestamp field at the OLT EPON MAC (2)
- At the ONU, the timestamp is recovered from received MPCP messages and used to reset the local ONU MPCP counter (3)
- OLT calculates RTT for a particular ONU from local MPCP counter vs. return timestamps from the ONU (4)
- ToD at ONU$_X$ calculated from local MPCP counter, ranging delay, & slow ToD correction (5)
- Range of time transport error: OLT-to-ONU ~120 ns [1] [local ctr - 8ns, ½ RTT drift - 96ns, DS/US fiber -17ns]

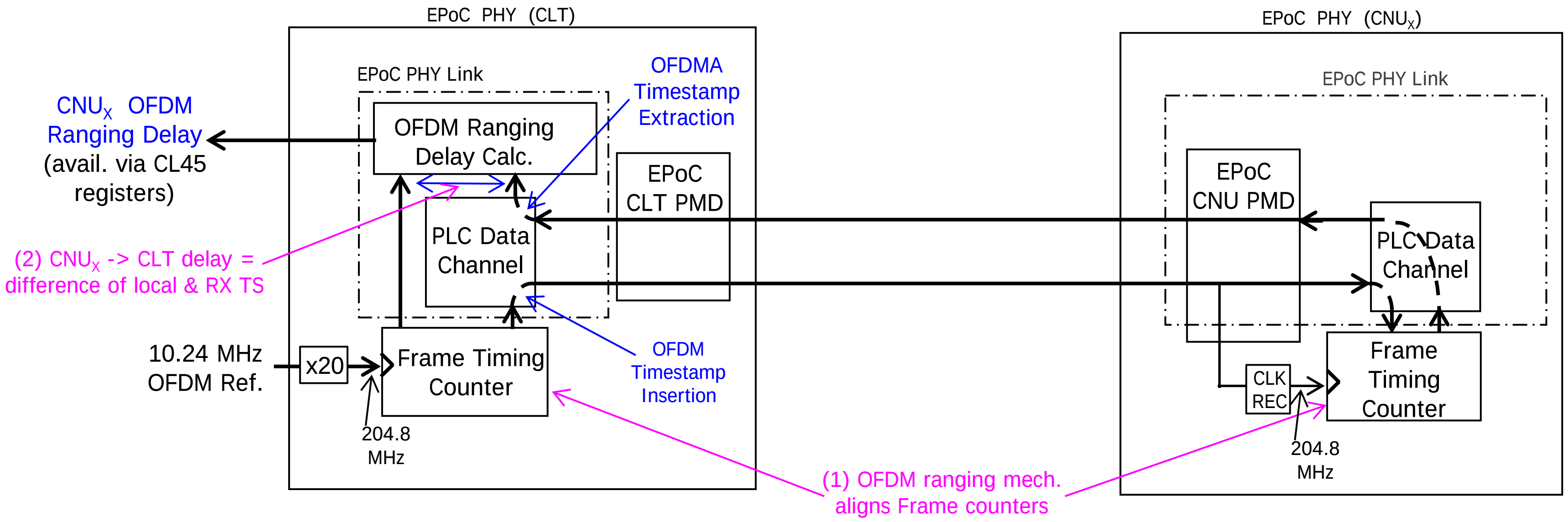
[1] Time Synchronization over Ethernet Passive Optical Networks, Yuanqiu Luo, Frank Effenberger- Huawei, Nirwan Ansari-NJIT, IEEE Communications Magazine, Oct, 2012.

Time transport errors to a CNU typically include both EPON and EPoC links



- Simply re-using the 802.1as protocol from the EPoC MPCP layer will likely more than double the OLT->CNU time transport errors of EPON (may get additional delay error through the EPoC OFDM/OFDMA PHYs)
- Since time transport errors through the EPoC CLT->CNU link are in addition to EPON time transport errors from the OLT->ONU/CLT, it is recommended to minimize EPoC time transport errors far below the inaccuracy of EPoC MPCP ranging

EPoC OFDM Ranging delay calculation



EPoC PHY (CLT)

EPoC PHY Link

OFDM Ranging Delay Calc.

OFDMA Timestamp Extraction

EPoC CLT PMD

PLC Data Channel

Frame Timing Counter

x20

10.24 MHz OFDM Ref.

204.8 MHz

OFDM Timestamp Insertion

CNU$_X$ OFDM Ranging Delay (avail. via CL45 registers)

(2) CNU$_X$ -> CLT delay = difference of local & RX TS

EPoC PHY (CNU$_X$)

EPoC PHY Link

EPoC CNU PMD

PLC Data Channel

CLK REC

Frame Timing Counter

204.8 MHz

(1) OFDM ranging mech. aligns Frame counters

- EPoC OFDM ranging delay for each CNU$_X$ is computed in units of the PHY 204.8 MHz OFDM clock
- Although the OFDM ranging delay only needs to be computed to a fraction of the smallest OFDMA CP (Cyclic Prefix), or a few hundred ns, it should be possible to compute the OFDM ranging delay to ~25 ns or less using OFDM fine ranging
- Since time transport errors through the EPoC CLT->CNU link are in addition to EPON time transport errors from the OLT->ONU/CLT, it is recommended to minimize EPoC time transport errors far below the inaccuracy of MPCP ranging
- **QUESTION** – Can we use the more accurate PLC OFDM ranging delay to improve time transport through EPoC?

Improved EPoC time transport method

EPON ranging & Time Transport

- 802.1as Clause 13 species a methodology to calculate ToD_EPON_X for each ONU_X at a future MPCP frame & sends this value to each ONU_X. This method assumes the DS/US PHY delays are symmetric.

EPoC ranging & Time Transport

- The PLC OFDM ranging delay, although much more accurate than the MPCP ranging delay, is referenced to the PLC OFDM counters buried in the PHY. Time delays of this counter referenced to the MPCP counters in the MAC are uncertain, as well as DS/US PHY delay symm.
- EPOC PHY time delay asymmetry may be much larger than EPON PHY delay asymmetry
  => Potential worse time transport performance than EPON
- Instead of sending a future ToD value (ToD_MPCP) to each CNU_X calculated using the MPCP ranging delay (T_MPCP_X),
  an improved version of the 802.1as Clause 13 protocol could send:

$ToD\_EPOC = ToD\_MPCP_X + T\_CORR_X$

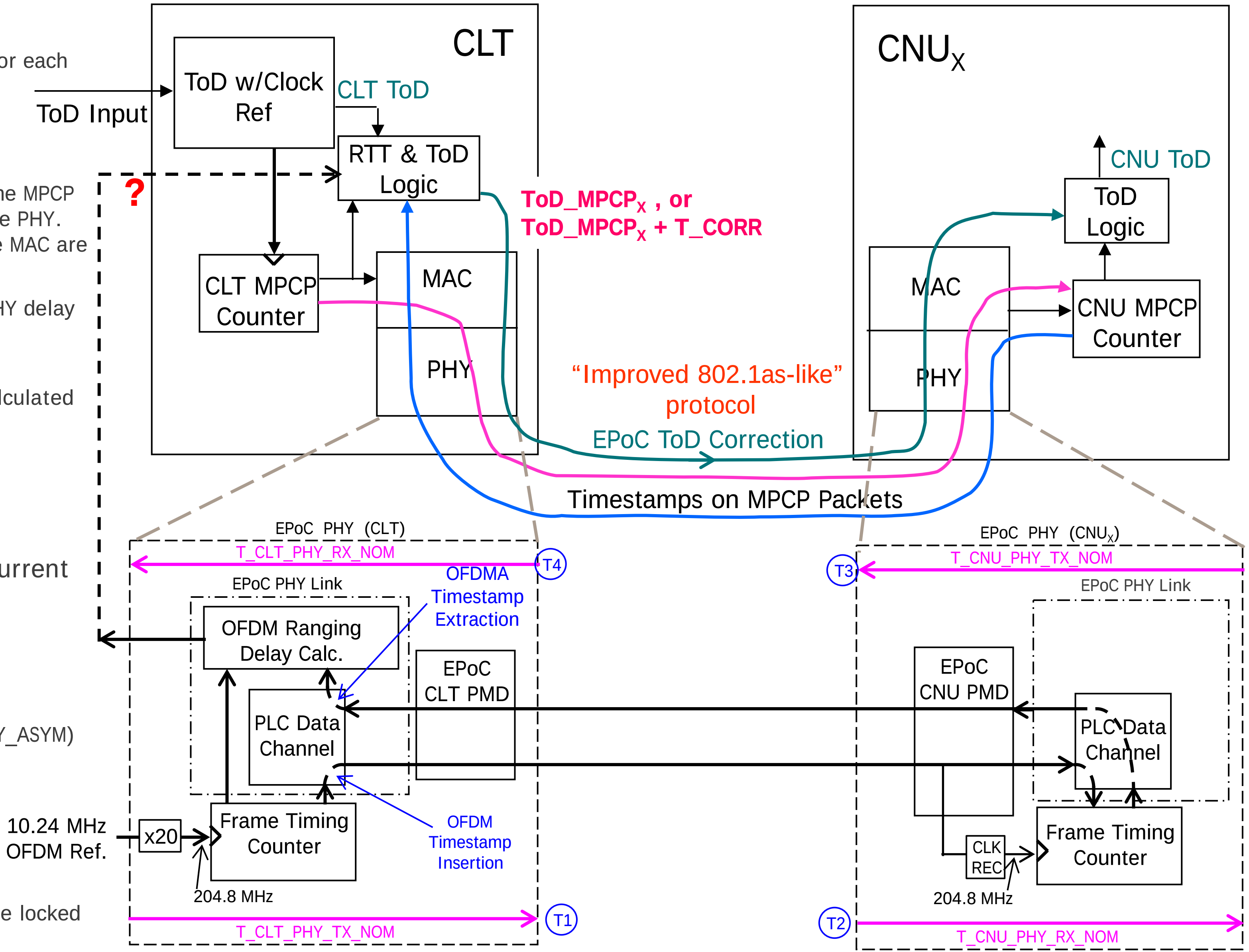
to each CNU_X at a future MPCP frame N (similar to the current 802.1as CL13 protocol), where:

$$
\begin{aligned}
T\_CORR_X &= PHY\,[T_{DS} - 1/2(T_{DS}+T_{US})] = (T1+T2) - 1/2\,(T1+T2+T3+T4)\\
&= 1/2\,(T1+T2) - 1/2\,(T3+T4)\\
&= 1/2\,[(T1+T2)-(T3+T4)]\\
&= 1/2\,[(T1-T4) - (T3-T2)] = 1/2\,(CLT\_PHY\_ASYM - CNU\_PHY\_ASYM)
\end{aligned}
$$

T_MPCP_X = EPoC MPCP ranging delay for CNU_X (~1/2 RTT)

$T\_CORR_X = 1/2\,(CLT\_PHY\_ASYM - CNU_X\_PHY\_ASYM)$

- The future ToD_X value to each CNU_X should be sent periodically to compensate for slow often thermally-induced changes in CNU ranging delay
- The CLT MPCP counter and EPOC CLT PHY Frame Counters should be locked to a common clock (phase locked)



802.3bf (802.3 Clause 90) Ethernet PHY Timesync parameters

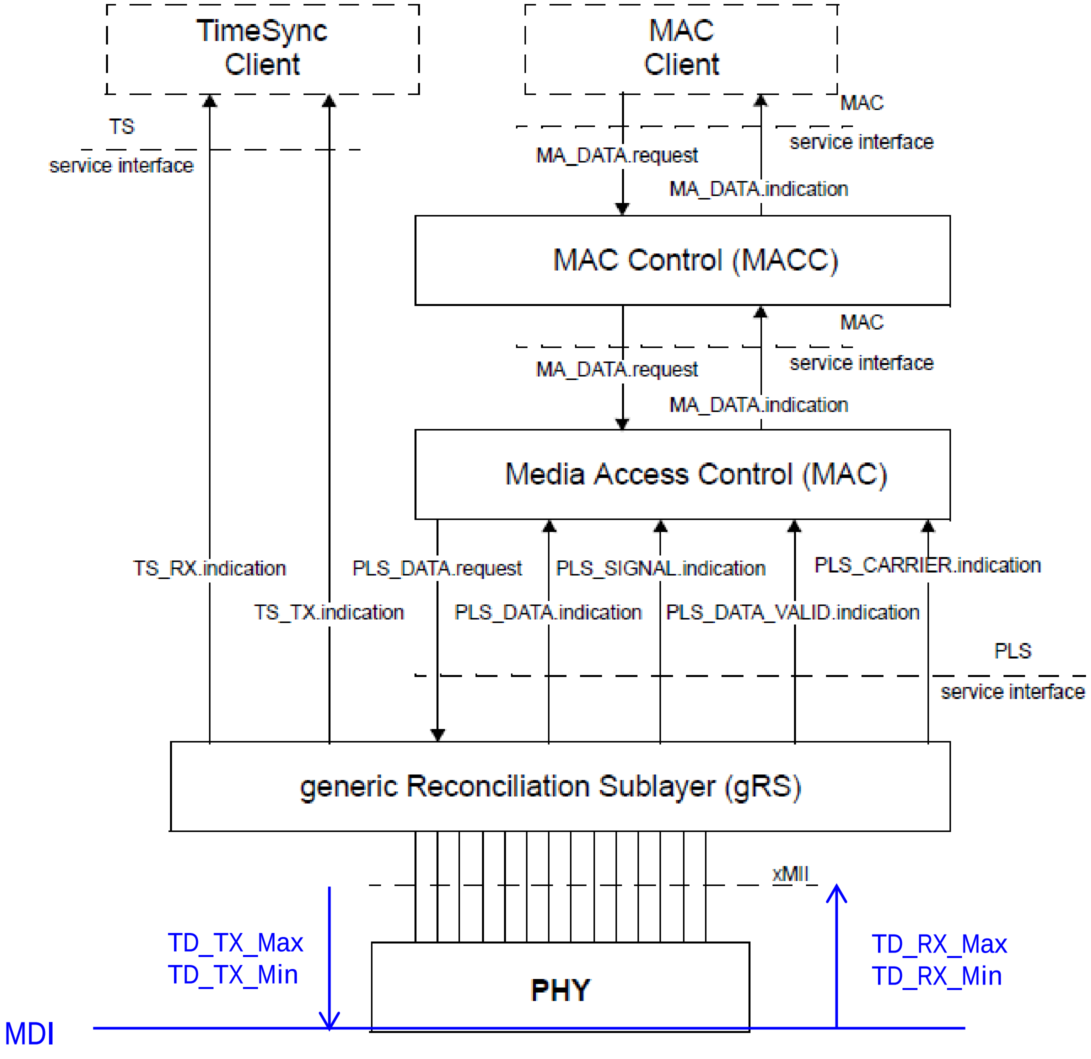


Figure 90–1—Relationship of the TimeSync Client, TSSI and gRS sublayer relative to MAC and MAC Client and associated interfaces

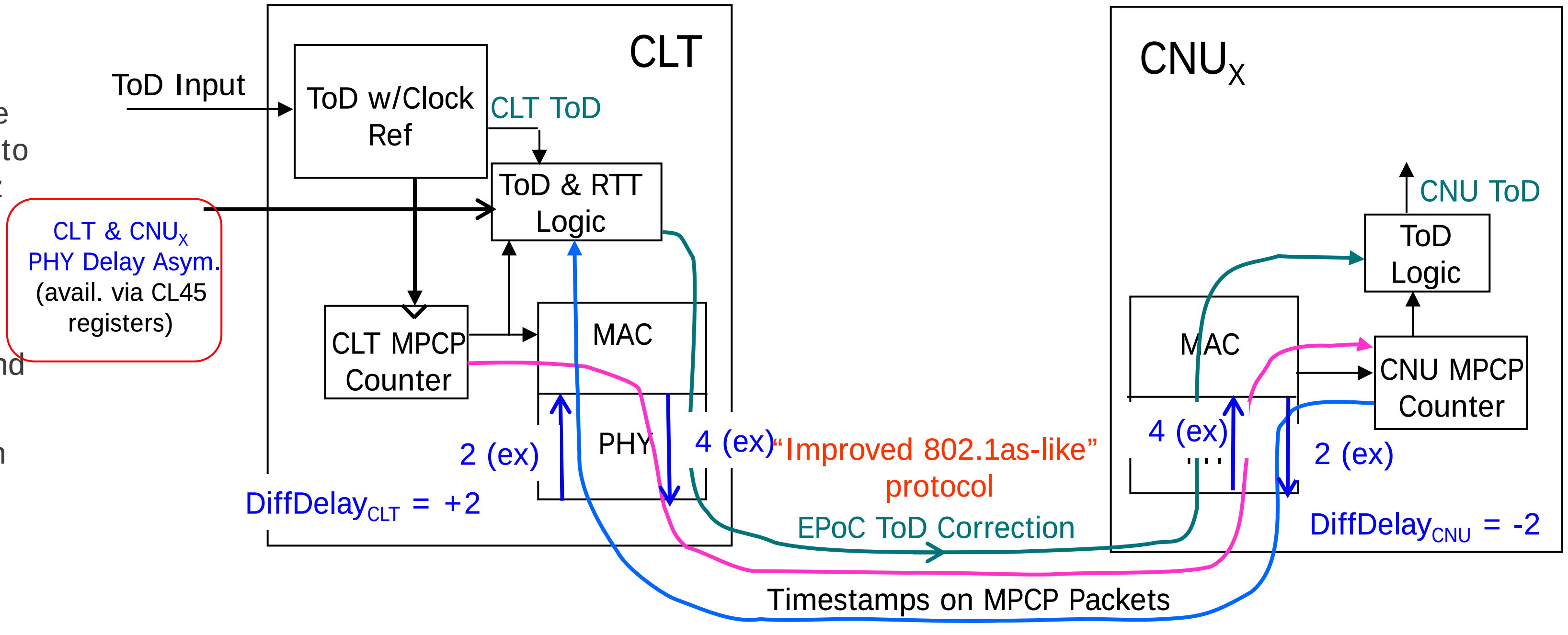
- Goal for minimizing time transport errors:
  TD_TX = TD_RX
- Clause 90 parameters
  - PHY TX delay – max
  - PHY TX delay – min
  - PHY RX delay – max
  - PHY RX delay – min
- Issue - No required bound on min/max or TX/RX PHY delay symmetry
- Ideal PHY behavior for time transport:
  TD_TX – TD_RX = 0 (symmetric delay)
- We really only care about the magnitude of the asymmetry, not min, max or even nominal delays

PHY transmit/receive path asymmetry

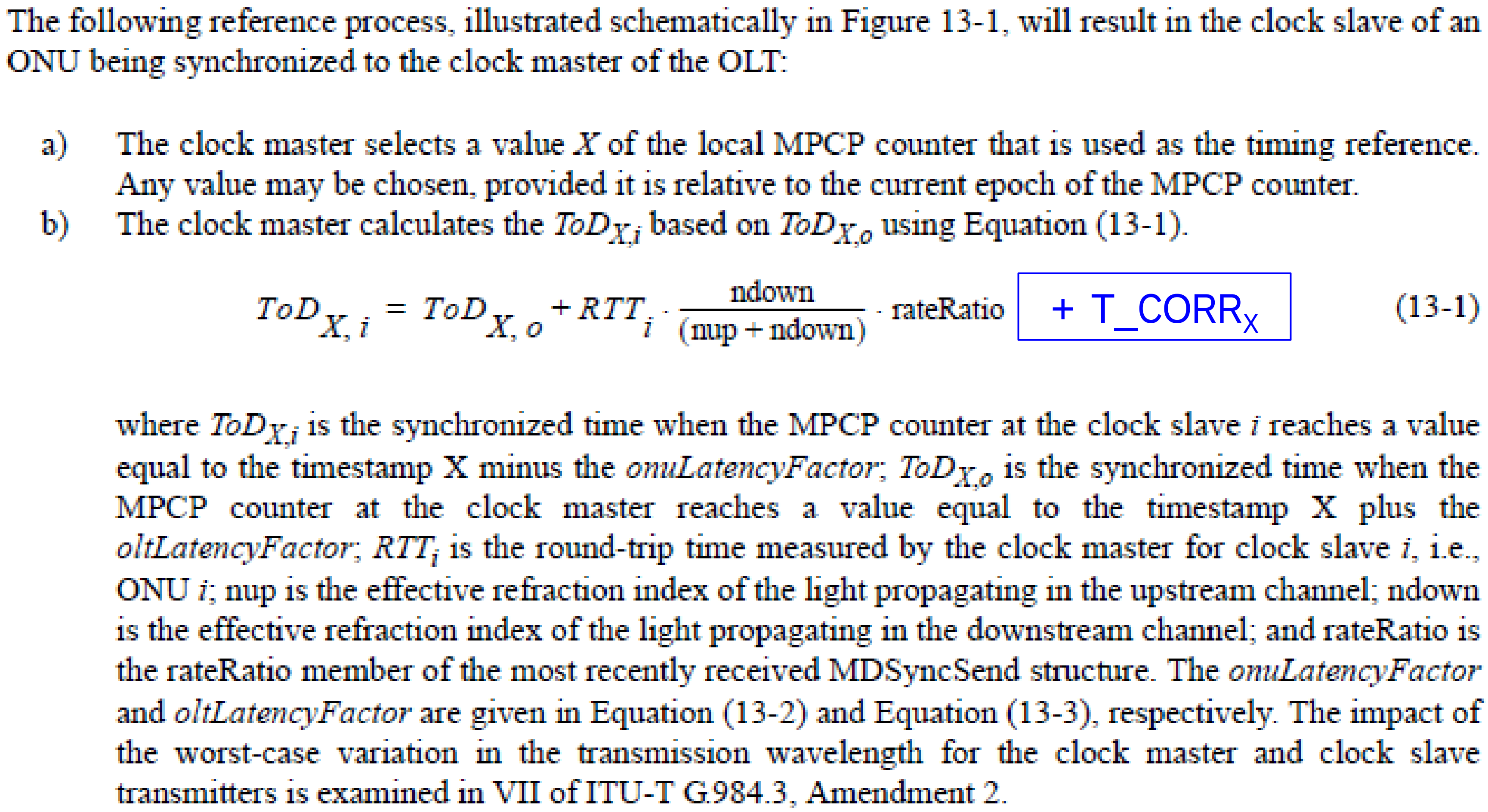
New Clause 45 PHY delay parameters

- DiffDelay
  difference in delay between the XGMII interface to the MDI interface path and the MDI interface to the XGMII interface path in units of 1/204.8 MHz
- DiffDelayTol
  the tolerance (max error) of the DiffDelay variable in units of 1/204.8 MHz
- Above variables defined for both the CLT PHY and the CNU PHY
- 1/2($DiffDelay_{CLT}$ – $DiffDelay_{CNU}$)= DS/US PHY path asymmetry
- Example shown:
  T_{CORR}=1/2($DiffDelay_{CLT}$ – $DiffDelay_{CNU}$)
  = 1/2[+2 – (-2)] - +2
  Check:
  DS PHY Delays (CLT_{TX} + CNU_{RX}) = 4 + 4 = 8
  US PHY Delays (CNU_{TX} + CLT_{RX}) = 2 + 2 = 4
  TOD_{EPOC} = 1/2(T_{MPCP}) +T_{CORR}
  TOD_{EPOC} = 1/2(T_{DS}+T_{US}) +T_{CORR} = 6 + 2 + 8

  Possible different manufacturers for CLT & CNU silicon so we cannot expect DS PHY delays to equal US PHY delays
- This method does not require DS/US delay symmetry, but can compensate for asymmetry if Diff params specified for each end and even for differences in delays between silicon manufacturers



802.3bn Timesync Clause 105.1 & 802.1as Clause 13



The following reference process, illustrated schematically in Figure 13-1, will result in the clock slave of an ONU being synchronized to the clock master of the OLT:

a) The clock master selects a value *X* of the local MPCP counter that is used as the timing reference. Any value may be chosen, provided it is relative to the current epoch of the MPCP counter.

b) The clock master calculates the $ToD_{X,i}$ based on $ToD_{X,o}$ using Equation (13-1).

$$ToD_{X,i} = ToD_{X,o} + RTT_i \cdot \frac{\mathrm{ndown}}{(\mathrm{nup} + \mathrm{ndown})} \cdot \mathrm{rateRatio} \quad \boxed{+\ T\_CORR_X} \qquad (13\text{-}1)$$

where $ToD_{X,i}$ is the synchronized time when the MPCP counter at the clock slave *i* reaches a value equal to the timestamp X minus the *onuLatencyFactor*; $ToD_{X,o}$ is the synchronized time when the MPCP counter at the clock master reaches a value equal to the timestamp X plus the *oltLatencyFactor*; RTT_i is the round-trip time measured by the clock master for clock slave *i*, i.e., ONU *i*; nup is the effective refraction index of the light propagating in the upstream channel; ndown is the effective refraction index of the light propagating in the downstream channel; and rateRatio is the rateRatio member of the most recently received MDSyncSend structure. The *onuLatencyFactor* and *oltLatencyFactor* are given in Equation (13-2) and Equation (13-3), respectively. The impact of the worst-case variation in the transmission wavelength for the clock master and clock slave transmitters is examined in VII of ITU-T G.984.3, Amendment 2.

- Propose to add wording to 802.3bn Clause 101.5 to “enhance” the above 802.1as Clause 13 equation for EPoC to add T_CORR_X as defined below:

  $T\_CORR_X = 1/2\ (CLT\_PHY\_ASYM - CNU_X\_PHY\_ASYM)$

Summary

- MPCP ranging algorithm only estimates 1-way time delay (1/2 RTT) to ~100ns accuracy
- The EPoC PLC OFDM ranging calculation should provide ~10-25 ns OFDM ranging accuracy, but it is “buried” in the middle of the PHY PLC area (delays relative to MPCP counter unknown)
- CLT & CNU PHY delay asymmetries can be used to minimize additional time transport errors for EPoC due to large PHY time delay times & asymmetries
- Clause 90 (aka 802.3bf) PHY time delay parameters specify registers for min/max values with no guarantee of TX/RX symmetry
- Use of newly proposed EPoC DiffDelay and DiffDelayTol parameters to specify PHY delay asymmetry & max error can additionally enhance a future 802.1as Clause 13 time transport algorithm improvement