Benefits of Optical Link Training “OLT”

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IEEE 802.3dj Task Force

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Overview

- **End user's feedback**
- **Response to some of the questions from Jan-24 interim**
- **Why optical link up is challenging**
- **Improving optical link up with DME and RTS**
- **Benefit of optical link training (OLT)**
- **Proposed OLT**
- **OLT control and status pages**
- **OLT flow**
- **Summary.**

End Users Feedback on OAN/OLT

- **Traditional DC/Enterprise**
  - With 11 IMDD PMDs with 5 based on FECo and 6 based on FECi OAN can facilitate deployment and configuration
  - Dual mode module can be configured based on remote module capability
  - OAN enables zero-touch in fronthaul networks parkholm_3dj_02_2311
- **Hyperscale feedback**
  - Would not use OAN as deployment is based on build-replicate
  - Reliable link up in timely manner
    - Based on past experience reliable optical link may take much longer than 802.3ck AN+LT link up timers (Make it clear)
    - Expecting reliable optical link up at 200G will be more challenging
  - OMA control with LT is most interesting
    - Mitigate overload
    - Mitigate compression
    - Energy efficiency
- **OIF EEI (Energy Efficient Interfaces) project has interest in collaborating and potentially leveraging OLT**
  - See liaison received from OIF OIF_liaison_IEEE_EEI_Project_21Jan24_Redacted .

Respond to Questions from Jan-2024

- **What problem OLT is solving**
  - Avoid link flaps, avoid unnecessary link/module resets, improve module link up, see next 2 pages
- **What is the key benefit of OLT**
  - Graceful predictive link start up and improve SI/error burst, see next 2 pages
- **Link training should be end-end**
  - OLT build on the ran_3dj_elec_01_240229 multi-segments training for AUI, CR, KR links
  - A key element of Ran proposal for reliable-predictable link up is sending RTS (Ready to Send) across multi electrical segment
  - OLT will be compatible with Ran proposal and will pass the RTS across the optical link for more robust-predictable end-end link bring up and training
- **Compatibility of OLT with TDECQ**
  - The current OLT proposal defines only pre-coder control and passing the RTS, so doesn't affect TDECQ test methodology
  - DJ or future IEEE task force may enable additional OLT features that may requrie some adjustment to TDECQ test methodology.

Why Optical Link Up Challenging

- **Today's optical SerDes must calibrate and adapt to blind data without even knowing if there is good data**
- **Link training facilitates reliable receiver link up in a more timely manner than just relying on waiting and blind link up**
- **Before any link up and timing recovery**
  - 1st the SAR(Successive Approximation Register) ADCs must be calibrated
    - Offset calibration between all 16/32/64 sub-SAR ADCs
    - Gain calibration between all 16/32/64 sub-SAR ADCs
    - Timing skew calibration between all 16/32/64 sub-SAR ADCs
    - AGC adjust input signal to fully utilize ADC resolution
  - CDR loop, Mueller-Muller or other type of clock recovery
  - DSP equalizer and adaptation
- **Today's optical DSP SerDes operating with blind start up may require several reset by the module uC while waiting and in hope of getting better SNR**
  - OLT will improve ADC calibration, improve timing recovery, and adaptation!

Optical Link Up Process Outdated

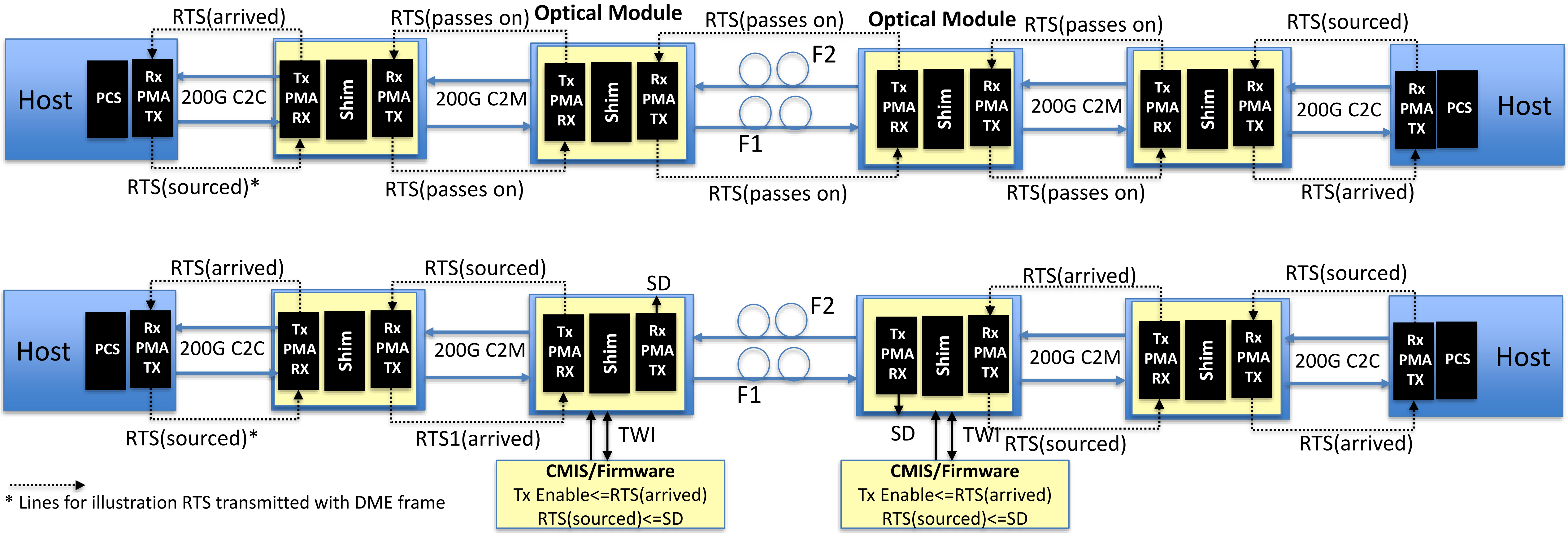
- **Current IMDD link up goes back to early days of FC**
  - Early optics were unretimed without any equalization on AUIs/PPI or optics with PCS relying on SD (Signal Detect)
- **What is making the current optical link up cumbersome and complex**
  - CMIS initializes module and data paths
  - CMIS adjust AUI SI parameters, then module enables it's optical TX
  - SD and CDR locks are used as indicator of good optical signal
  - As the module CDR/DSP is calibrating its ADC, recovering, equalizing, and propagating data to host there is no guarantee good data is being transmitted to the optical receiver
  - If receive PCS data is not good the host may reset the module Egress DSP and hoping for the best!

Improving Optical Link Up Process

- **OLT start up DME facility with known NRZ PRBS then switching to PAM4 improve optical receiver/DSP calibration and adaptation**
- **OLT passing RTS, ran_3dj_elec_01_240229, will improve reliable link up on both AUIs segments and optical link**
  - Optical SD/CDR lock are not always a reliable indicator of signal goodness and may falsely send RTS onto local AUI
  - The real benefit of RTS is not realized for optical links unless RTS propagates end-end from PCS-PMA to PMA-PCS
- **Reliable and predictive optical link up is required for 200G optics considering 100G optics pain points**
  - OLT with RTS will improve 200G optics to have more reliable and consistent link up in a timely manner!

RTS Propagation

- **RTS propagated across optical link with OLT offers reliable-consistent link up in timely manner**
  - RTS terminated in the optical module doesn't address optical link up challenges
  - Generating RTS based on not always reliable SD can exasperate optical link up!



* Lines for illustration RTS transmitted with DME frame

Benefits of Link Training for Optical Links

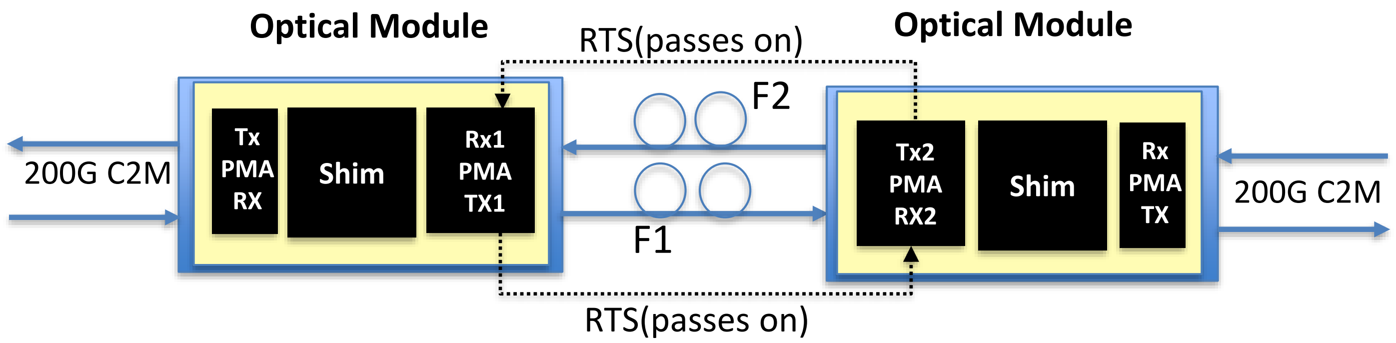
- **Support the basic OLT (Optical Link Training) facility – topic of this proposal**
  - Pre-coder control for burst error mitigation
  - Support RTS for reliable and predictable optical and AUI link up
  - OLT DME facility starting with known NRZ PRBS then switching to PAM4 offers reliable optical SerDes receiver start up in a timely manner – A major benefit of just having OLT DME facility
- **Other beneficial OLT parameters that may get defined in DJ or later projects, and/or OIF EEI project – area of further study**
  - Preset
  - Adjusting transmit FFE (pre-emphasis)
  - OMA control
  - MZM compression
  - EA modulators asymmetrical compression
  - CD penalty on links > 2km on outer wavelengths L0 and L3.

Why pre-coder on/off necessary for DJ optical PMDs

- **Largely due to severe BW limitation from TIA-VGA-ADC cascaded bandwidths requiring the DFE/MLSE to work very hard**
  - TDECQ is measured with BW=Baudrate (53.125 GHz FECo/56.72 GHz FECi) and pre-emphasis adjusted on that basis
  - Initial 200G optics front end TIA-VGA-ADC BW expect to have an aggregate BW ~34 GHz but over time aggregate BW expected to increase ~50 GHz
    - On top these BW there will be ~±15% BW variation due to components variations (early on some low BW TIA-DSP may fail sensitivity due to low aggregate BW)
- **Some receiver may have unacceptable burst errors without a pre-coder enabled**
  - Pre-coder may be required on any link from DR to LR4
  - Enabling pre-coder on every optical link requires optical PMDs to have better pre-FEC BER
  - Controlling pre-coder on/off with the method of CL136/162 LT is the best proven method.

Proposed Optical OLT

- **Leverage CL136/162 to enable pre-coder on/off based on receiver requests**
  - After completion of AN the DME frame (request/status) and PRBS13Q are transmitted on F1 and F2
    - Rx1 or Rx2 receiver may need pre-coder to be enabled on the transmitter
    - RX1 or Rx2 may respectively request precoder to be enabled on Tx2 and Tx1
- **Propagate the RTS from the 200G AUI link across the 200G optical links**
  - In case of 200G optical PMDs operating with 100G AUI RTS not utilized
  - In case of 200G optical PMDs with 100G AUI on one end and 200G AUI on the other end, RTS is sourced and terminated in the 200G module PMA attached to 100G AUI
- **Illustration F1/F2 is for one duplex link, OLT can be supported across any 1 to N lanes PMDs as long as Tx/Rx pairing are preserved.**

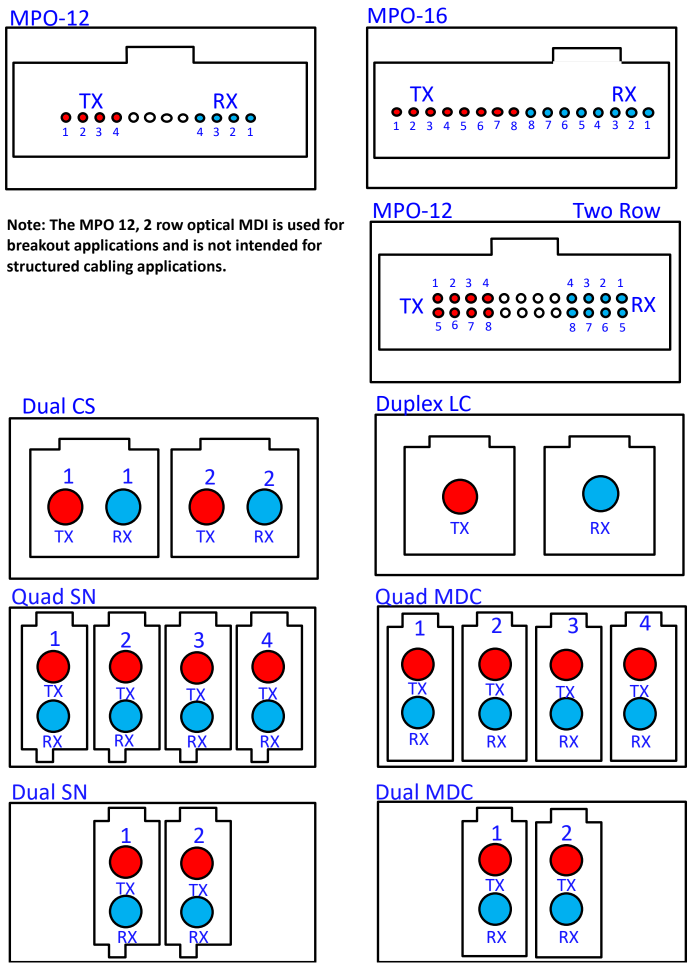


Both CMIS and Optical Module Enforce Tx/Rx Pairs

- **CMIS data-path pairs electrical Tx/Rx lanes to optical Tx/Rx lanes**
  - Table and figure below from QSFP-DD MSA Rev. 7.0 illustrates the concept.

Electrical data input/output	Optical port mapping (see Figure 15)				
	Duplex LC, CS, SN, or MDC	MPO-12, Dual (CS, SN, MDC, Duplex LC, or MPO-12)	MPO-12, Quad (SN or MDC)	MPO-12 (two row), MPO-16, or Dual MPO-12	MPO-12, SN, MDC (BiDi)
	1 TX fiber 1 RX fiber [1]	2 TX fibers 2 RX fibers [1]	4 TX fibers 4 RX fibers [1]	8 TX fibers 8 RX fibers [1,3]	8 Tx (Rx) fibers [2,3]
Tx1			TX-1	TX-1	TR1
Tx2				TX-2	RT1
Tx3		TX-1	TX-2	TX-3	TR2
Tx4	TX-1			TX-4	RT2
Tx5			TX-3	TX-5	TR3
Tx6				TX-6	RT3
Tx7		TX-2	TX-4	TX-7	TR4
Tx8				TX-8	RT4
Rx1			RX-1	RX-1	RT1
Rx2				RX-2	TR1
Rx3		RX-1	RX-2	RX-3	RT2
Rx4	RX-1			RX-4	TR2
Rx5			RX-3	RX-5	RT3
Rx6				RX-6	TR3
Rx7		RX-2	RX-4	RX-7	RT4
Rx8				RX-8	TR4

Notes:
1. TX-n or RX-n where n is the optical port number as defined Figure 15.
2. TRn or RTn where n is the optical port number as defined Figure 15.
3. Some QSFP-DD/QSFP-DD800/QSFP-DD1600 modules may require fewer CS, SN, or MDC connectors. In such cases, Port #1 is always the left-most port. Successive ports then follow sequentially from left-to-right as shown in Figure 15.



Leverage CL 136/162 Control/Status Field Structure for OLT

- **Use Table 162-9 and 162-10 with number of fields changed to reserved and added RTS**
  - Number of DME pages proposed to be 4 instead of 2 (with all fields in page 3 and 4 reserved).

Table 162-9 Control field structure with modification highlighted

Bit(s)	Name	Description
15:14	Reserved	Transmit as 0, ignore on receipt
13:11	Reserved	Transmit as 0, ignore on receipt
10	RTS	1 = Ready to send 0 = Not ready to send
9:7	Modulation and precoding request	9 8 7 1 1 1 = PAM4 free-running PRBS31 with precoding 1 0 1 = Reserved 1 1 0 = PAM4 free-running PRBS13 with precoding 1 0 0 = PAM4 PRBS13 0 1 1 = PAM4 free-running PRBS31 0 1 0 = PAM4 free-running PRBS13 0 0 1 = PAM2 free-running PRBS31 0 0 0 = PAM2 PRBS13
6:5	Reserved	Transmit as 0, ignore on receipt
4:2	Reserved	Transmit as 0, ignore on receipt
1:0	Reserved	Transmit as 0, ignore on receipt

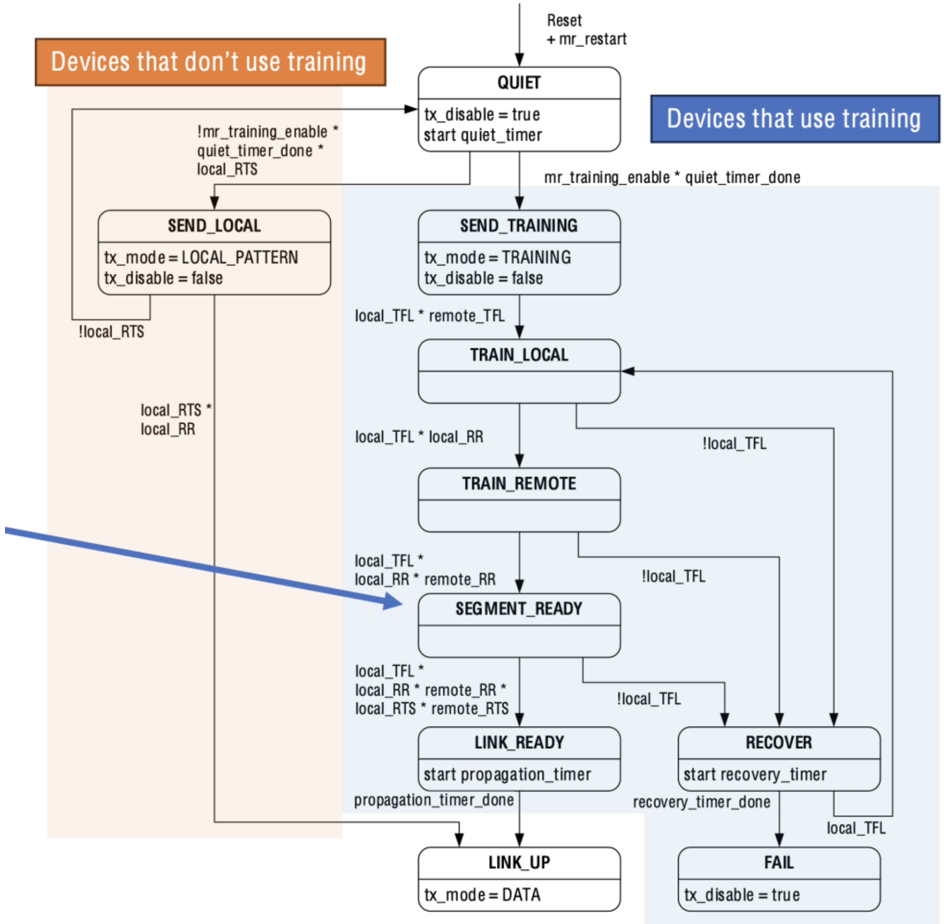
Table 162-10 Status field structure with modification highlighted

Bit(s)	Name	Description
15	Receiver ready	1 = Training is complete and the receiver is ready for data 0 = Request for training to continue
14:13	Reserved	Transmit as 0, ignore on receipt
12:10	Modulation and precoding status	9 8 7 1 1 1 = PAM4 free-running PRBS31 with precoding 1 0 1 = Reserved 1 1 0 = PAM4 free-running PRBS13 with precoding 1 0 0 = PAM4 PRBS13 0 1 1 = PAM4 free-running PRBS31 0 1 0 = PAM4 free-running PRBS13 0 0 1 = PAM2 free-running PRBS31 0 0 0 = PAM2 PRBS13
9	Receiver frame lock	1 = Frame boundaries identified 0 = Frame boundaries not identified
8	Reserved	1 = Updated 0 = Not updated
7	Parity	Even parity bit
6	RTS Extended Training echo	1 = No data is available, continue training 0 = Switch to data when training is completed
5:3	Reserved	Transmit as 0, ignore on receipt
2:0	Reserved	Transmit as 0, ignore on receipt

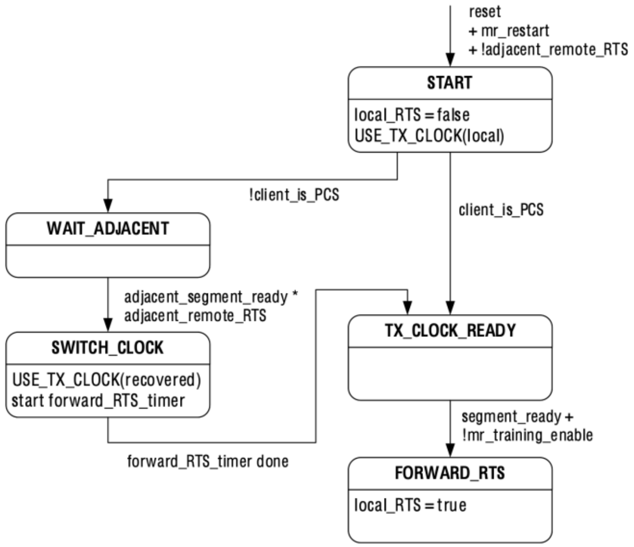
Highlighted text per ran_3dj_elec_01_240208 proposal to support free running PRBSs.

Leverage CL 136/162 State Diagram

- Leverage DJ proposed electrical link training lusted_3dj_02_2401 as well as RTS from ran_3dj_elec_01_240229 with goal to stay align with the AUI segment by segment training.



PMD control flow Fig 136-7 replaced with Ran control diagram with RTS



RTS State Diagram Per Ran Proposal

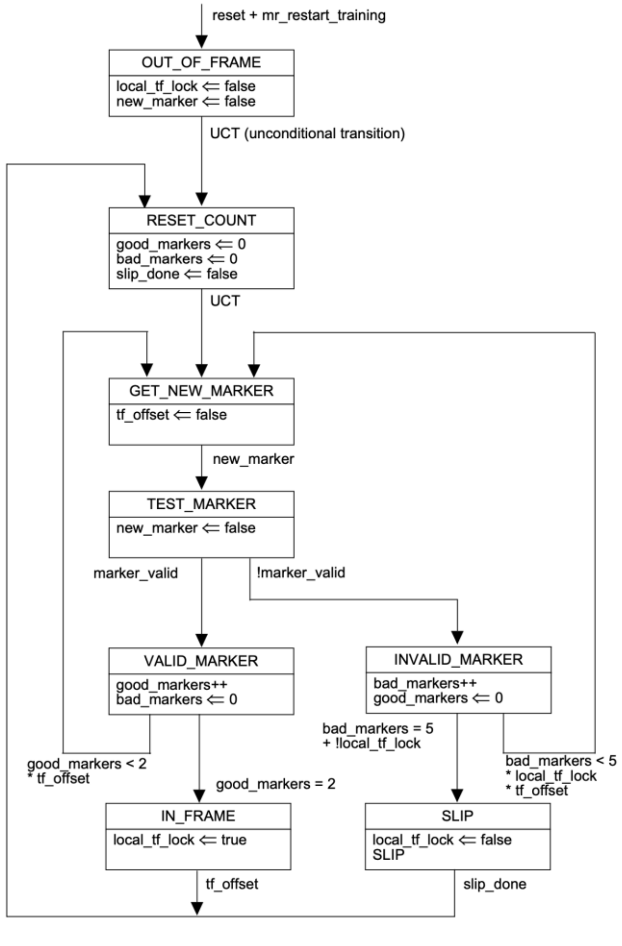


Figure 136–8—Training frame lock state diagram

Summary

- **Considering all the FECo and FECi PMDs defined in the DJ task force Optical PHY Type Auto-Negotiation (OAN) will facilitate interoperability**
  - Facilitate zero-touch deployment and address the challenge with breakout applications
  - The logic to support OAN and OLT in the PMA are common, and will be leveraged from 200G-AUI
  - OLT will leverage as much as possible from proven Clause 136/162 training and flow, and 200G AUI training updates including RTS
- **What does proposed OLT provide**
  - Pre-coder control will mitigate problematic burst on optical links from DR to LR4
  - The OLT training facility starting with NRZ then transition to PM4 provide robust receiver/ADC/DSP start up
  - RTS transmitted across optical links provides graceful mechanisam to transition from training to PCS data in predictable and timely manner
  - Proposed OLT also will address many of the 100G optical link/DSP start up pain-point issues
- **What doesn't the current proposal provide**
  - Number of larger end-uses want OMA control
  - OIF Energy Efficient Interfaces (EEI) interested in OMA control for energy efficiency
  - Several optics suppliers interested to have few presets
  - Future 200G MMF task force likely may require explicit tap control which can be enabled for some PMDs
- **802.3dj is the right project to add OAN and OLT to 200G optical Phys, while the PMA's for 200G are being developed**
  - This is true even if some of the features are not used for the PMD's developed in this project, trying to add the facility later in a future project will be much more difficult.