400GE DMT Multi-Vendor Interoperability Requirements

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Summary

- For multivendor interoperability – agreement on the DMT link initialization protocol is required
- This presentation covers the detailed protocols for setting up the LCC (link communication channel) and the DMT (traffic) link
- LCC
  - Each wavelength uses its LCC to control the DMT settings to/from each end of the link
- DMT link
  - Requires each subcarrier to be provisioned with a constellation and relative power setting
- For interoperability, each supplier shall follow a common protocol for these features

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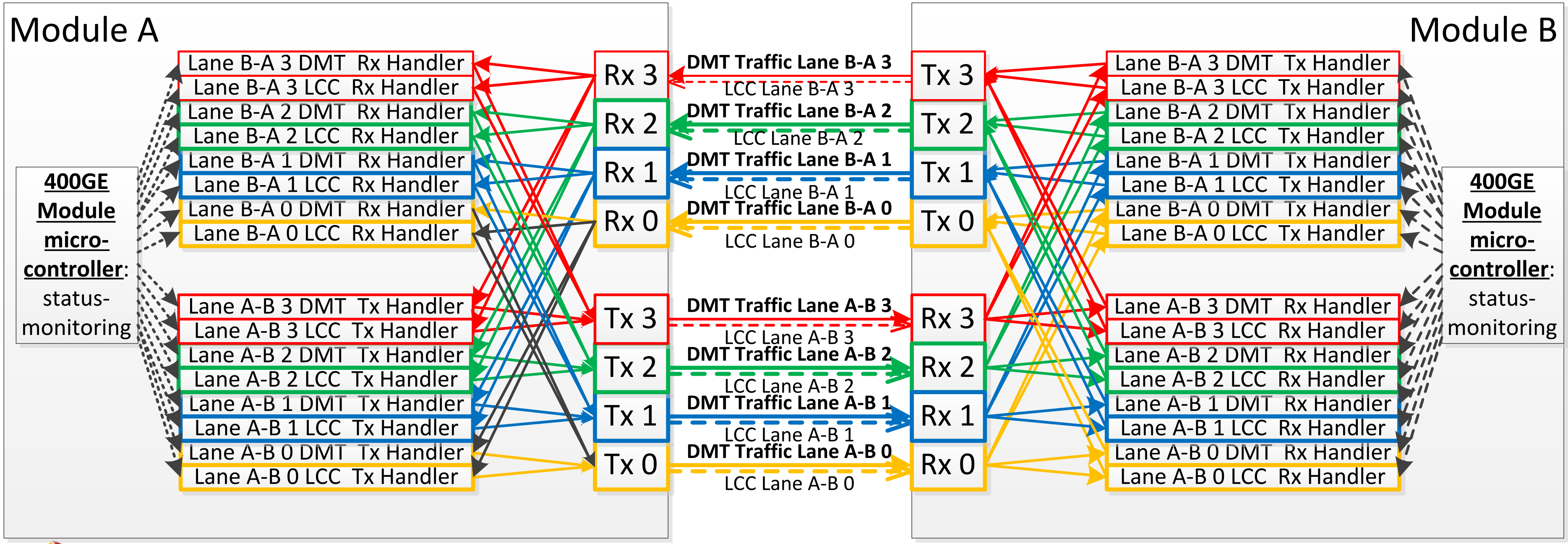
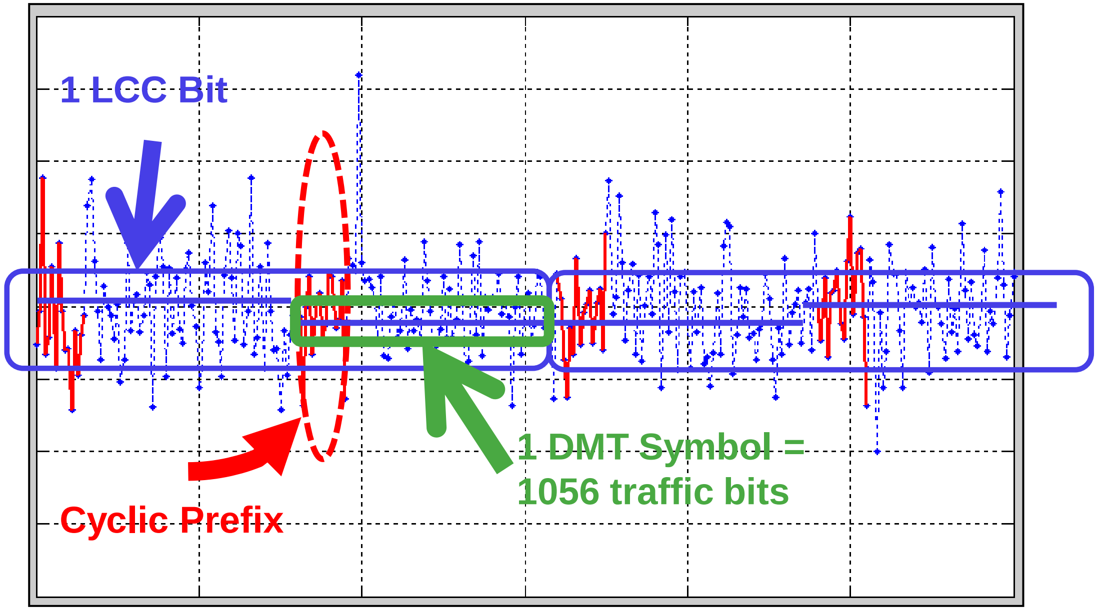
Interoperability: High Level Definition

- With Discrete-Multi-Tone, traffic is modulated on available subcarriers based on channel equalization and SNR parameters.
- DMT makes use of a bi-directional Link-Communication-Channel embedded in the DC subcarrier (details explained in *lewis_3bs_01_0514*)
- Each wavelength lane (carrying ~100Gbit/s of data) is comprised therefore of a traffic (DMT) link, and an LCC link.
- The DMT link and the LCC link each have their own handlers, running on the DMT chip micro.
- A high-level reference illustrated below describes the LCC and DMT handlers existing in a 400GE module.



LCC Recap

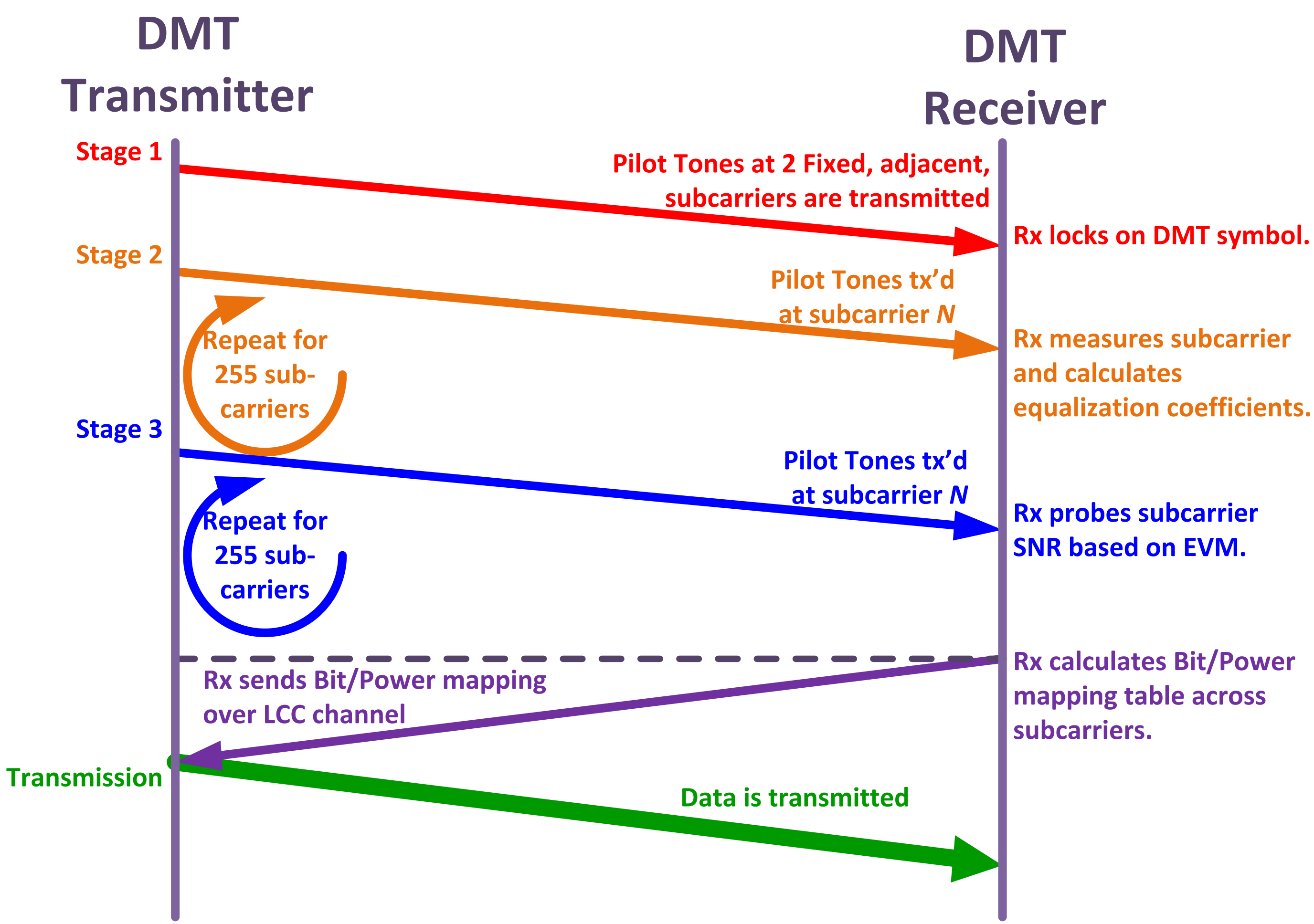
- The Link Communication Channel (LCC), uses transitions of the DC component of the FFT.
- To provide clocking information, Manchester encoding is being used (*lewis_3bs_01_0514*):
  - A logical “0” is represented by a transition from high to low.
  - A logical “1” is represented by a transition from low to high.



- One key feature we propose for the LCC is that it toggles between 2 rates:
  - This feature does cause more complexity in the state machines as it is critical that the 2 ends do not get out of sync.
  - However, this feature allows LCC to be operational and recoverable for multi-rate devices, because at the slow-rate, DMT frame synchronization is **not** required.
  - This allows 2 modules operating at different rates to still have a management channel, and even signal a rate mismatch.

Link Negotiation Recap

- In *lewis_3bs_01_0514*, we presented a high level view of the link negotiation between 2 far ends.
- This presentation proposes further details of the protocol to promote interoperability.

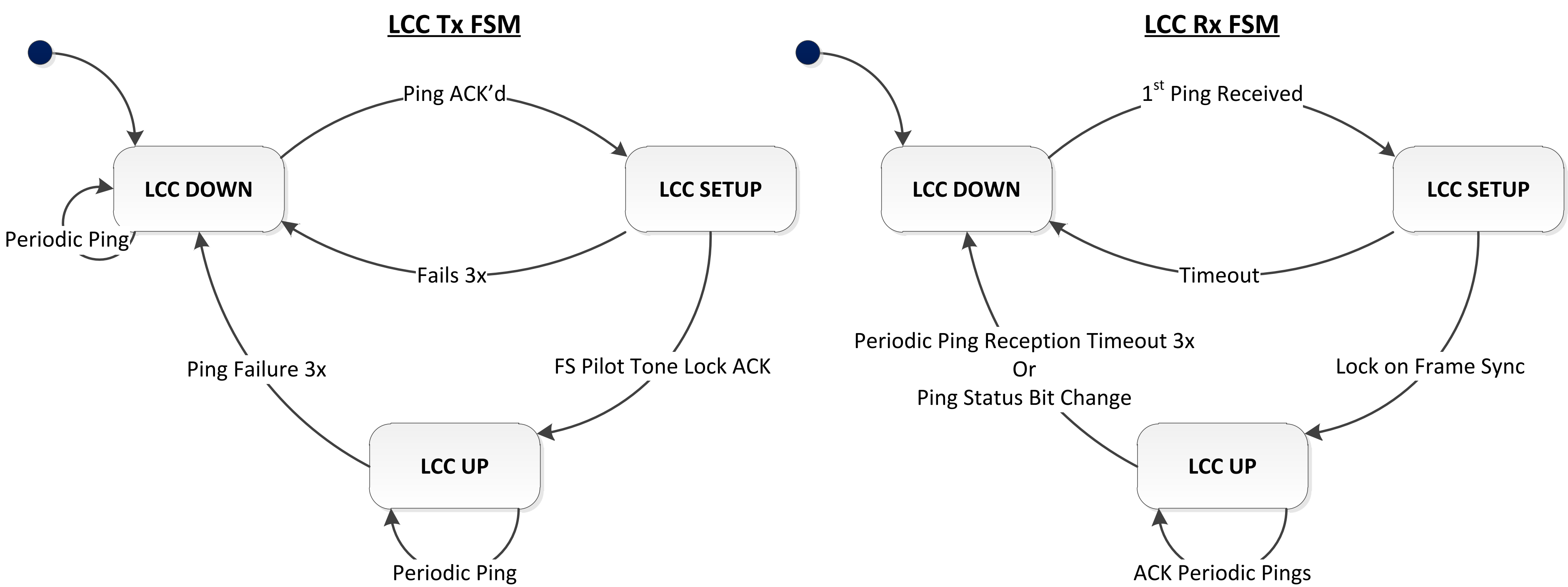


Interoperability: State Machines

- In any given module, four handlers exist per lane, with associated finite state machines:
  - Lane X LCC Tx Link Handler
  - Lane X LCC Rx Link Handler
  - Lane X DMT (traffic) Tx Link Handler
  - Lane X DMT (traffic) Rx Link Handler
- Some of the principles guiding the LCC Finite State Machines (FSMs) are:
  - DMT Traffic must not be shut down simply because the LCC is “down” or inactive.
  - LCC Rate (Slow or Fast) is closely tied with status of DMT lock. If DMT Rx can lock on Frame-Synchronization Pilot-Tones, then the LCC link rate in this direction should be Fast.

Interoperability: LCC State Machines

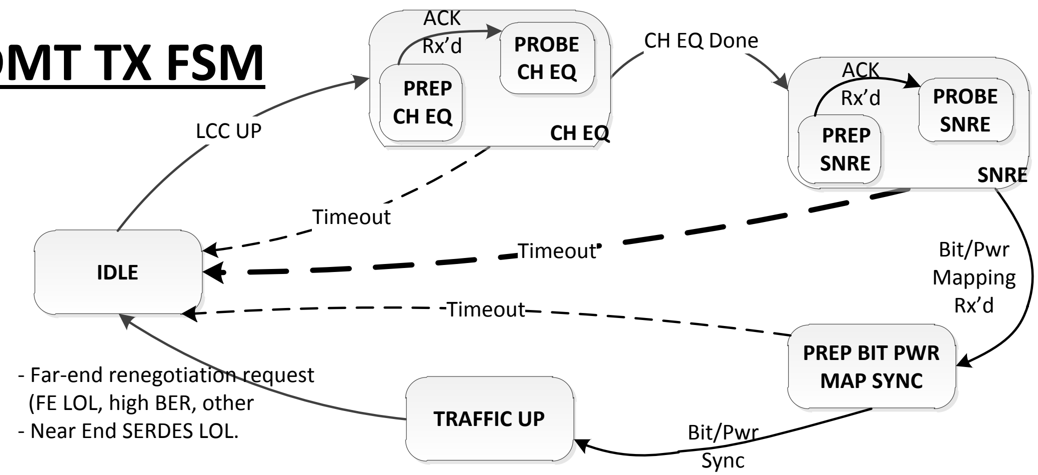
- Below are the proposed diagrams for the LCC Tx and Rx handlers.
- 3 states are sufficient to ensure a robust handling of the link.
  - “LCC DOWN” corresponds to the state where the LCC link is not operational.
  - “LCC SETUP” is a state where successful messaging has taken place and a path towards fully operational DMT management is taking place.
  - “LCC UP” is a state where the LCC is working at full rate, synchronized with DMT framing.
  - “LCC DOWN” and “LCC SETUP” use the slow LCC rate.
  - “LCC UP” uses the fast LCC rate



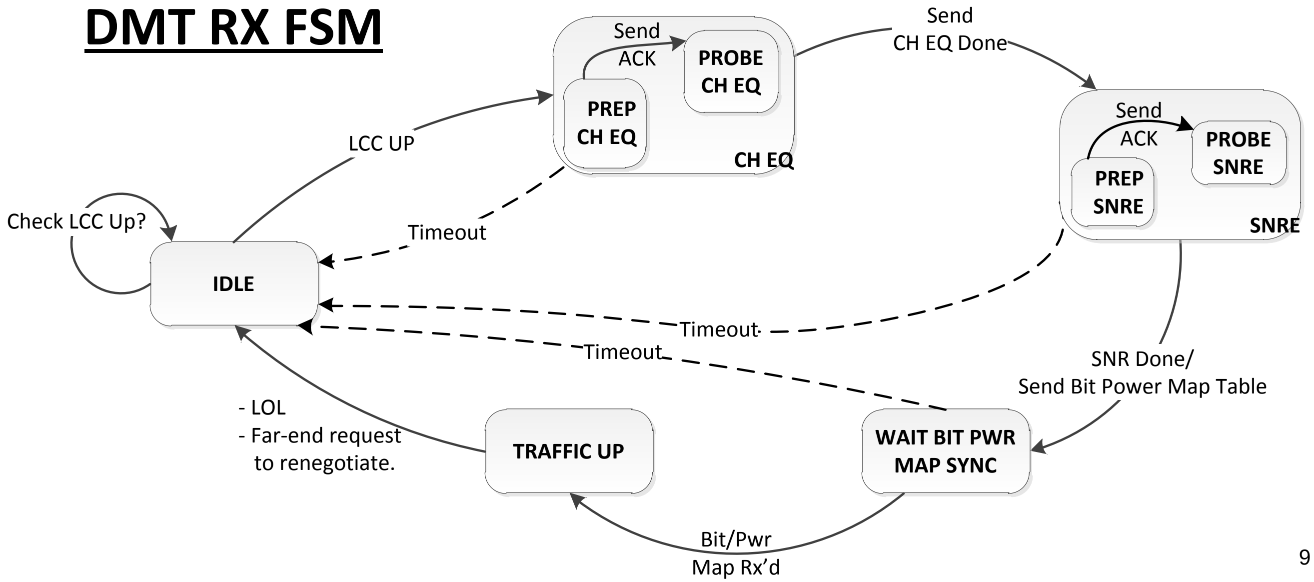
Interoperability: DMT (Traffic) State Machines

- Below are the State Machines (FSMs) for the DMT (Traffic) Tx and Rx Handlers
- The purpose of the various states become more clear by following the DMT link-negotiation flow-chart.

DMT TX FSM

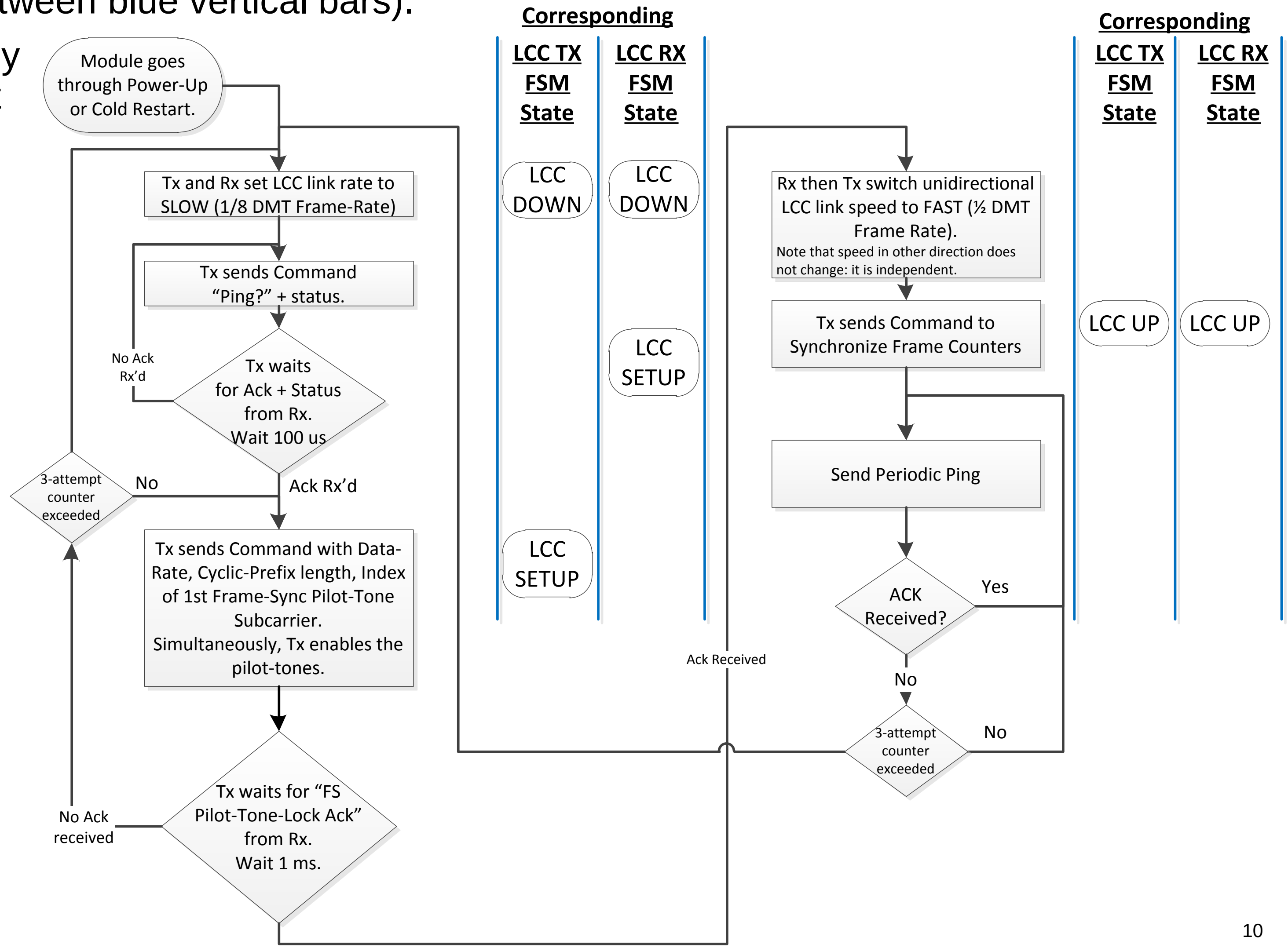


DMT RX FSM



Interoperability: LCC Turn-up Flow-Chart

- As an illustration of how the LCC handlers navigate through the State Machines, the link-initialization process flow is shown.
- Each of the flow-chart stages can be associated with an upstream or downstream FSM state (shown to right between blue vertical bars).
- This flow chart only shows a cold-start scenario.



LCC Turn-up Flow-Chart: Some explanations

- *Assumption that module has knowledge of the Data-Rate.*
  - *Either through user (host) configuration, or*
  - *Serdes rate discovery*
- *Default cyclic-prefix length is 16 unless otherwise specified.*
- *Index of 1st of 2 adjacent frame-synchronization pilot tones implies index of 2nd pilot tone.*
- *For “LCC SETUP”, only frame-synchronization pilot tones are enabled **during a power-up or cold-start**, with all other subcarriers muted. If traffic already running (LCC renegotiation due to warm-restart or LCC timeout), no need to change anything on DMT traffic side.*
- *Far-end Rx can check internal ASIC registers to determine if DMT Rx Lock (frame-synchronization) is acquired.*
- *Pilot-Tone Lock “Ack” implies ability to switch to high-speed LCC, and reset of DMT frame counters.*
  - *Rx changes listening speed as soon as Pilot-Tone Ack is sent upstream.*
  - *Tx changes listening speed as soon as Pilot-Tone Ack is received.*

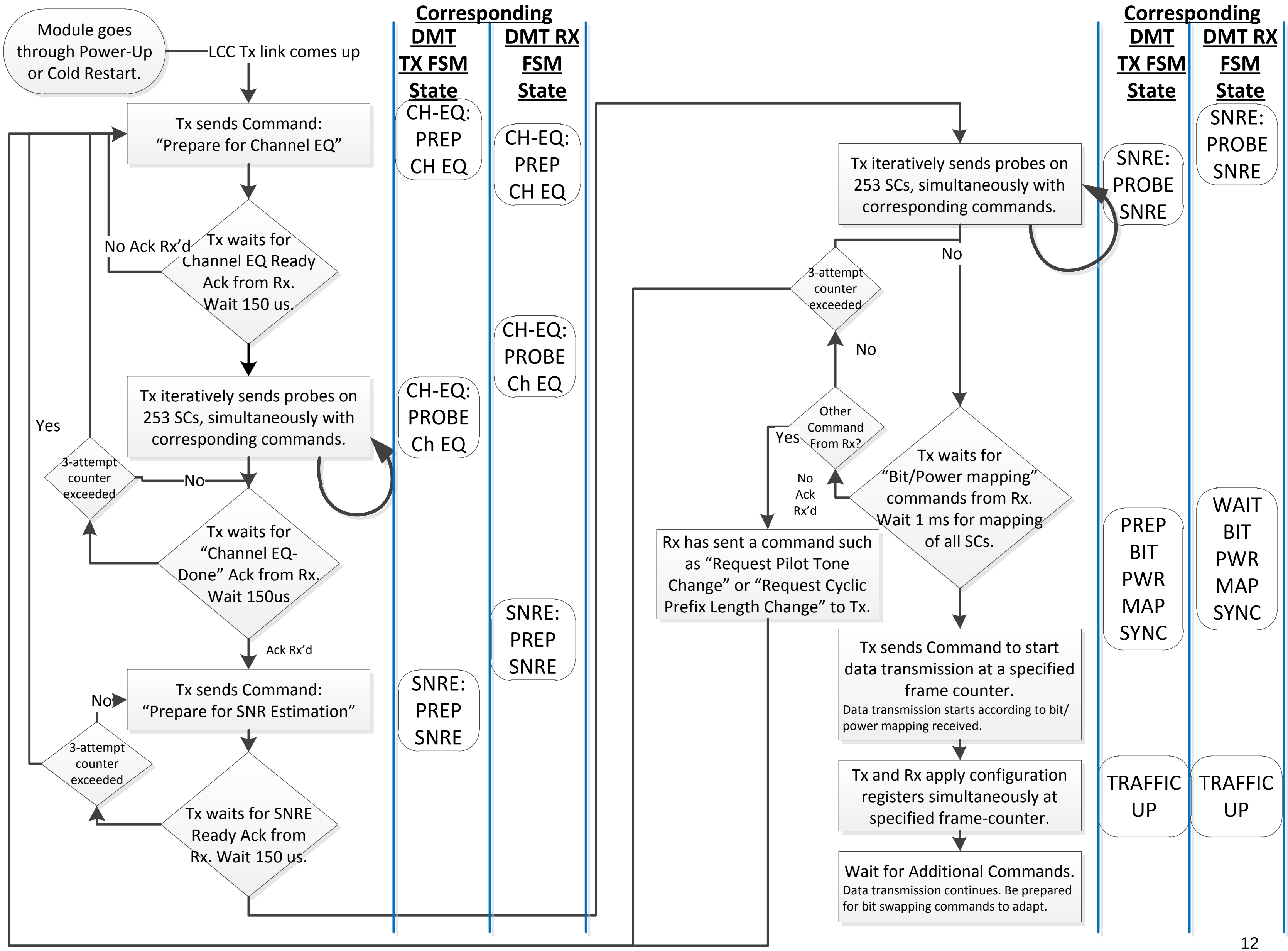
Interoperability: DMT (Traffic) Link Negotiation Flow Chart

This flow-chart only shows a cold-start scenario.

Note:

Link negotiation does not proceed further until data-rate is known.

This is Part of entry-criteria for PREP CH EQ

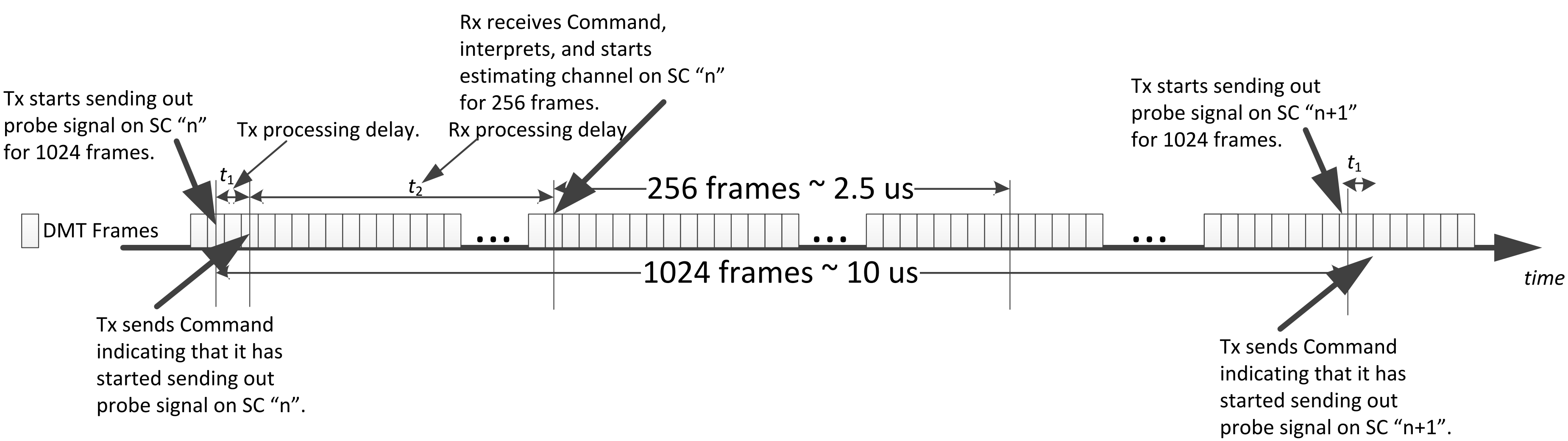


Channel Estimation

- During channel-estimation (channel equalization and SNR measurement), Tx repeats the following sequence, starting at 1st available subcarrier and ending at last available subcarrier ("availability" takes into account frame-sync pilot-tone subcarriers):
  - *set DMT engine to send probe-signal on subcarrier* n,
  - *set random tones on other subcarriers,*
  - *leave Frame Synchronization intact,*
  - *send notification command including*
    SC probe index, &
    frame-counter index
    to Rx (explained on next slide)
- Channel estimation requires iteration through all subcarriers twice
  - Once for equalization
  - Once for SNR estimation

Channel Estimation (continued)

- The target link negotiation duration is ~10ms.
- A link-length up to 10 km incurs a round-trip delay over fiber on the order of 100 us.
- Message-acknowledgement during both *channel estimation sequences* is being avoided so as not to incur round-trip delays (see flow-chart).
- For this purpose, we propose that the Tx hold any given subcarrier probe-signal for 10us, while the Rx only needs to measure the probe-signal for a 2.5us sub-set of the 10us hold time.
- It is anticipated that this intended redundancy will allow sufficient processing time per subcarrier:
    - *Design must ensure that [t1 + t2 + duration(256 frames)] < duration(1024 frames)*



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Preliminary Command List

Some Commands	Parameters	Speed	Comments	Initiator
PING + STATUS	3 status bits: Local LCC Rx up or down, Local DMT-Rx Lock status, Local DMT Tx Carrying Data	Slow or Fast	Ping including 3 Status bits	LCC Tx
PING ACK + STATUS	3 status bits: Local LCC Rx up or down, Local DMT-Rx Lock status, Local DMT Tx Carrying Data	Slow or Fast	Ping ack including 3 status bits	LCC Rx
DR & CPL & FSPT IDX	Data-Rate, Cyclic Prefix Length, Index of 1st Frame-Sync Pilot Tone.	Slow or Fast	Data-Rate, CP and FS Pilot-Tone Index	LCC Tx
FSPT LOCK ACK	none	Slow or Fast	Implies reception of DR, CPL, FSPT Idx, and indicates Lock.	LCC Rx
SYNC FC	Frame Counter Sync Word	Fast	Synchronize Frame Counters. Both ends of Tx-Rx unidirectional link synchronize their Frame Counters.	LCC Tx
FC SYNC ACK	none	Fast	Rx acknowledges that Frame counter has been sync'd.	LCC Rx
PREP CEQ	none	Fast	Tx tells Rx to prepare for Channel Equalization. 1st available SC is SC001, unless frame-sync pilot-tones are located at SC1.	DMT Tx
CEQ RDY	none	Fast	Rx acknowledges it is ready for Channel Equalization.	DMT Rx
CEQ NXT	SC Index, Frame Counter at start of probe signal	Fast	Tx indicates subcarrier to probe Channel Equalization circuits for, as well as 1st valid frame-counter for probe-signal. No Ack Expected	DMT Tx
CEQ ACK	Success status	Fast	Rx indicates whether it has succesfully measured Channel Equalization, and indicates it is ready to move to next step.	DMT Rx
SNRE PREP	none	Fast	Tx tells Rx to prepare for SNR Estimation (Rx to get probing circuits ready, scanning first available SC).	DMT Tx
SNRE RDY			Rx acknowledges it is ready for SNR Estimation.	DMT Rx
SNRE NXT	SC Index, Frame Counter at start of probe signal	Fast	Tx indicates subcarrier to probe Channel Equalization circuits for, as well as 1st valid frame-counter for probe-signal. No Ack Expected	DMT Tx
BIT PWR MAP	Sub-set of subcarriers (1 through 32)	Fast	Rx indicates the number of bits (constellation) and power assigned to a sub-set of 8 subcarriers.	DMT Rx
START DMT TX RX	frame counter to start at	Fast	Tx indicates at what moment (frame-counter) to start traffic using the bit/power allocation just received.	DMT Tx
BIT PWR SWAP	Sub-set of subcarriers (1 through 32)		Rx indicates the number of bits (constellation) and power assigned to a sub-set of 8 subcarriers.	DMT Rx

Other Details

- During “Ping” and corresponding acks, link status will be sent as part of the information:

Link Status Bits	Description
DMT Tx (Traffic)	Traffic carrying status (Yes or No)
DMT Rx (Traffic)	Frame-Synchronization Pilot-Tone Lock status
LCC Rx	Message received recently (Yes) or timeout (No)

- Physical Layer
  - Manchester encoding / decoding extracts clock and ensures bit alignment
  - LCC Redundancy is also required, but is not the exact method is not yet being proposed:
    - CRC can allow for single-error correction; or at minimum error detection leading to retransmission requests
    - Alternative is Majority-voting over odd number of transmissions
  - IDLE commands are sent on LCC during absence of messages: preferably handled by hardware
  - Their goal is maintain synchronization and word alignment at the LCC layer
  - Status of IDLE commands in LCC Rx Queue (present or absent) could be used at the FSM layer, but has not been assumed for the proposals above.
  - Time to transmit 32 raw bits of data:
    - Slow Rate: 4.7 us
    - Fast Rate: 582.5 ns

Conclusions

- Presented a basis for multivendor interoperability – particularly the DMT link initialization protocol
- Covered the detailed state diagrams for setting up the LCC (link communication channel) and the DMT (traffic) link
- LCC
  - Each wavelength uses its LCC to control the DMT settings to/from each end of the link
- DMT link
  - Each subcarrier is provisioned with a constellation and relative power setting
- For interoperability, each supplier follows the common protocol for these features