Inner FEC Synchronization Proposal

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Introduction

- Binary(128,120) code has been adopted as inner FEC code for 200G/lane optical PMDs, then a method to find the FEC codeword boundaries is necessary.
- Two synchronization methods, inner FEC self-sync and frame sequence(FS) sync, were proposed.
  - Self-sync uses the intrinsic feature of inner FEC code, as proposed in he_3dj_03b_2307.
  - FS sync uses the inserted fixed pattern, alignment marker, as proposed in farhood_3dj_01a_230206, barakatain_3dj_01a_2303.
- he_3dj_optx_01_230815 presentation listed out the benefits of self-sync proposal for Inner FEC synchronization.
- This presentation describes details of above scheme, and proposes to adopt self-sync method for inner FEC synchronization.

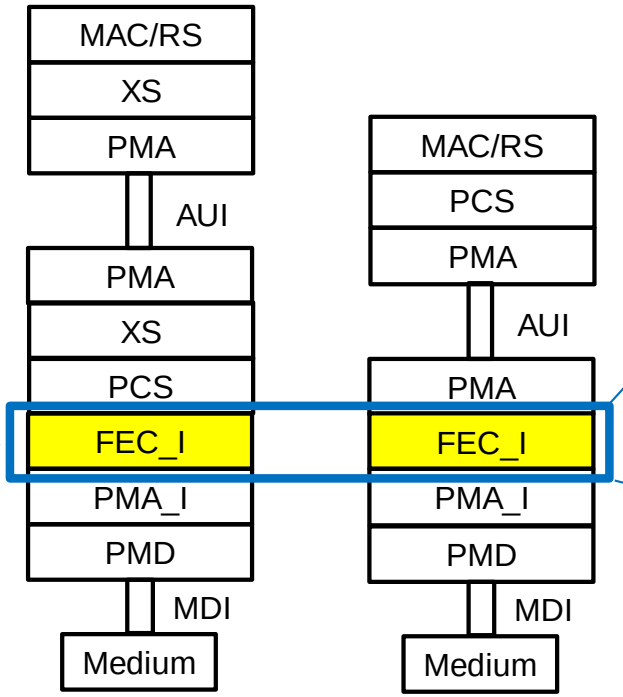
PHYs covered

Ethernet Rate	Assumed Signaling Rate	AUI	BP	Cu Cable	MMF 50m	MMF 100m	SMF 500m	SMF 2km	SMF 10km	SMF 40km
200 Gb/s	200 Gb/s	1 lane	1 pair	1 pair			1 pair	1 pair		
400 Gb/s	200 Gb/s	2 lanes	2 pairs	2 pairs			2 pairs	2 pairs		
800 Gb/s	200 Gb/s	4 lanes	4 pairs	4 pairs			4 pairs	1) 4 pairs 2) 4 λ's	Single SMF 4 λ's	
	800 Gb/s								Single SMF 1 λ	Single SMF 1 λ
1.6 Tb/s	100 Gb/s	16 lanes								
	200 Gb/s	8 lanes	8 pairs	8 pairs			8 pairs	8 pairs		

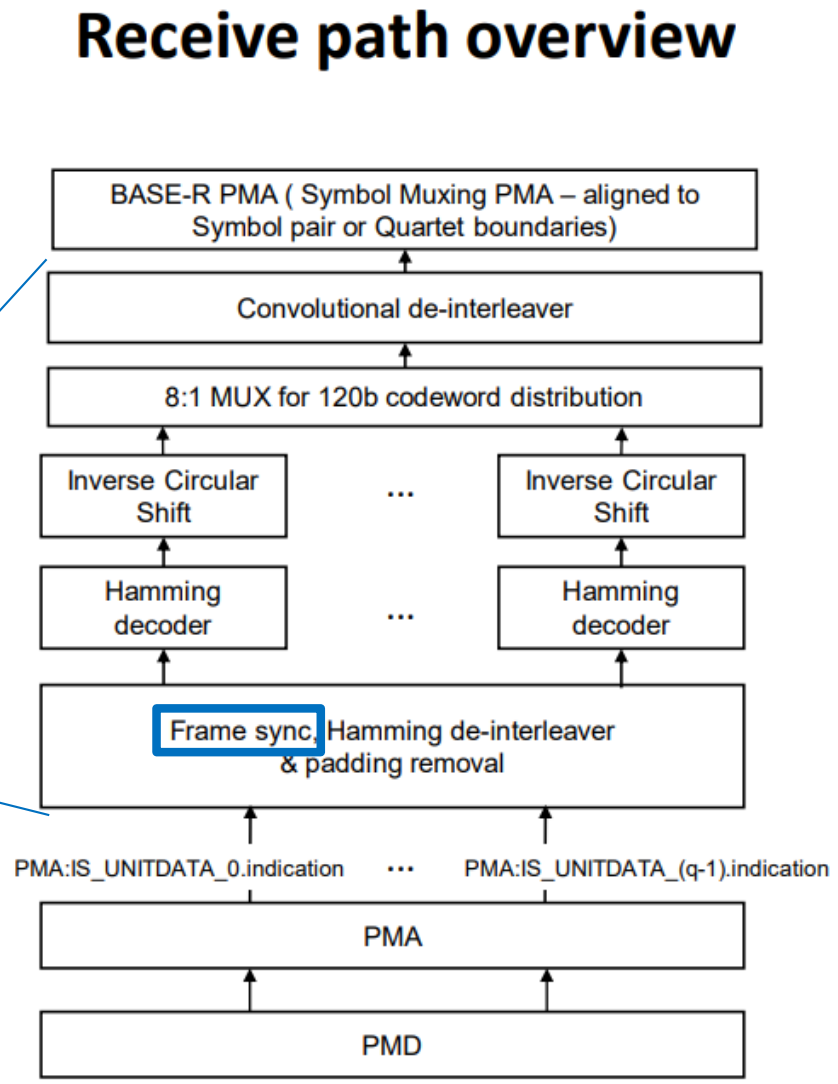
- All PHYs with 200G/lane IMDD optical PMDs can be covered by this presentation, where inner FEC exists.

Architecture Overview

- Targeted PHY/FEC scheme is Type 2.
- Inner FEC sync is performed on the receive side.



Interesting sublayer of this presentation



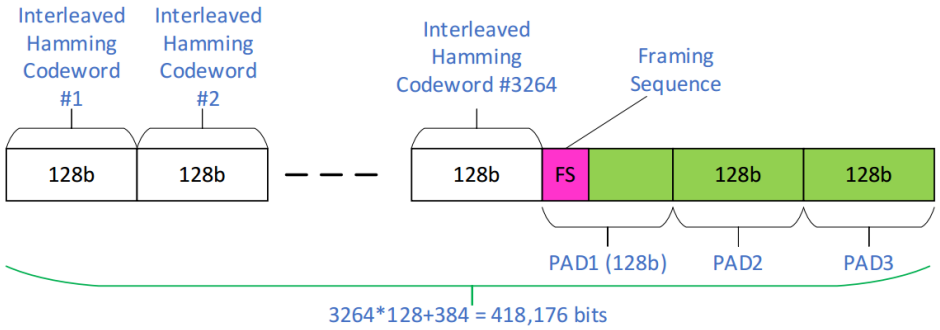
From [he_3dj_01_2307]

- Up to two AUI segments in each PHY or Extender.

Padding insertion methods

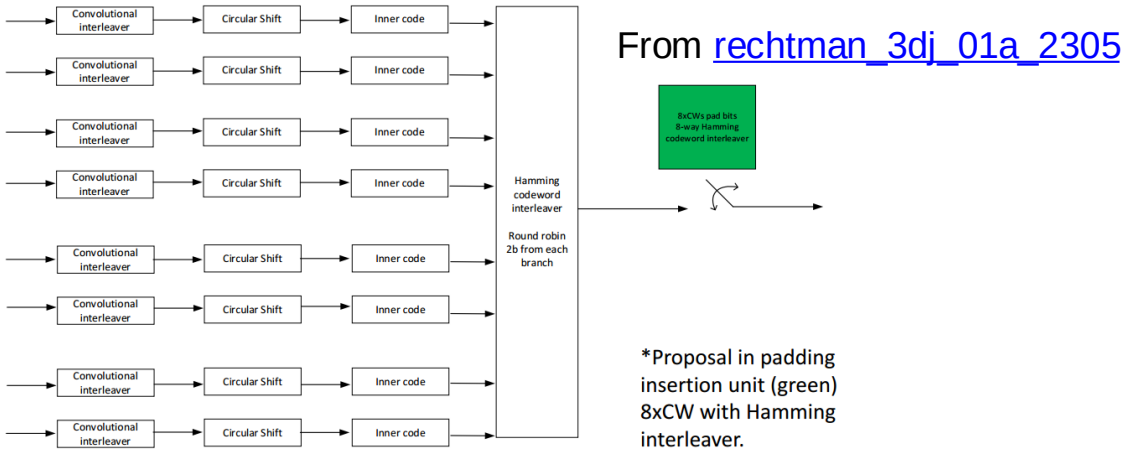
- Two padding insertion methods were proposed
  - 3 inner FEC CWs padding was proposed in farhood_3dj_01a_230206; and
  - 8 inner FEC CWs (interleaved) padding was proposed in rechtman_3dj_01a_2305.
- Self-sync method can be applied to both padding insertion methods.
  - 8x CWs padding could simplify the self-sync process because paddings and payloads are both 8:1 PAM4 symbol interleaved.

From farhood_3dj_01a_230206



3 inner FEC CWs for every 3264 CWs

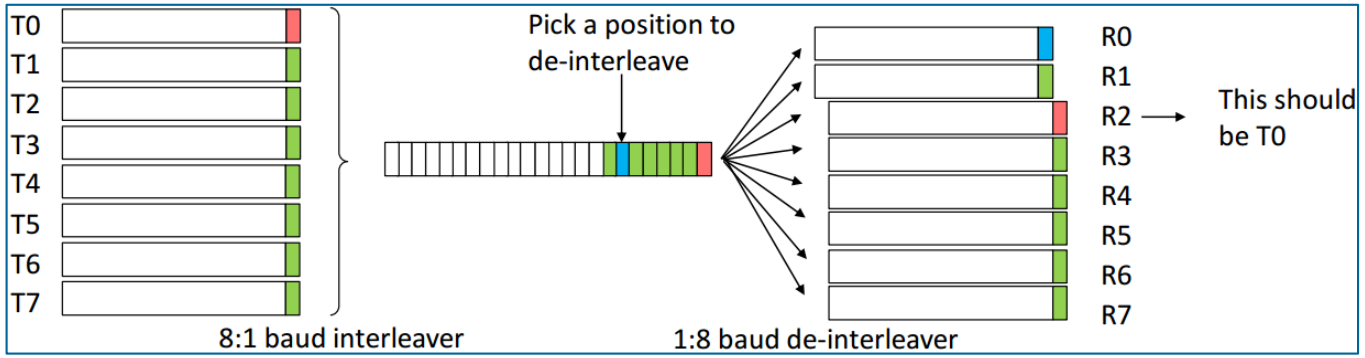
From rechtman_3dj_01a_2305



8 inner FEC CWs (interleaved) for every 8704 CWs

Proposed self-sync method

- Self-sync uses the intrinsic feature of inner FEC code.
  - Self-sync is performed on each of the de-interleaved inner FEC codeword streams.
  - **Steps:**
    1. **Search and Test**: Start the search from any candidate position, check ***N*** codewords, see if at least ***n*** of them are good.
       - If so, go to "Validate". If not, shift potential start to next position (PAM4 symbol) and try again.
    2. **Validate**: See if at least ***p*** in the following ***P*** codewords are also good.
       - If so, sync established. If not, go back to "Search and Test".
    3. **Monitor and Drop**: When there are at least ***m*** invalid codewords in the following ***M*** codewords, drop sync and restart from 1.

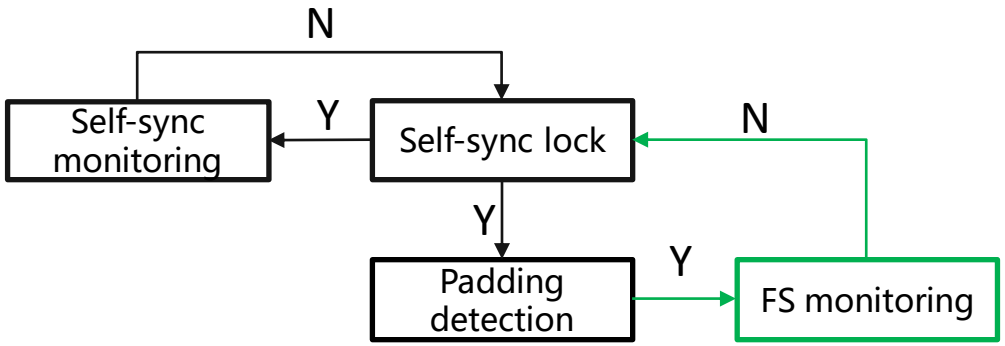


he_3dj_03b_2307

- De-interleaving can be done at any position.
  - After each de-interleaved FEC codeword streams are synced, the correct de-interleaving position can be resolved.

Locating padding codewords

- After self-sync is done, padding can be located based on codeword boundaries.
  - Padding can be confirmed by identifying ***x*** successive valid FS with fixed intervals.
    - If ***t*** or more nibbles in the candidate FS block match, it is recognized as a valid FS.
  - FS comparison is recommended to be performed on 200G data streams to avoid complicated definition of padding.
    - See example FS definition in rechtman_3dj_01_2309.
  - The reliability of locating the padding codewords at known boundaries is sufficiently high as shown in he_3dj_optx_01_230815.
- Once in FS lock state, an FS lock monitoring state diagram may be kept to improve robustness and interoperability if one chooses to use FS sync instead of self-sync.
    - When there are ***y*** successive invalid FS, restart self-sync lock.



Proposed self-sync parameters

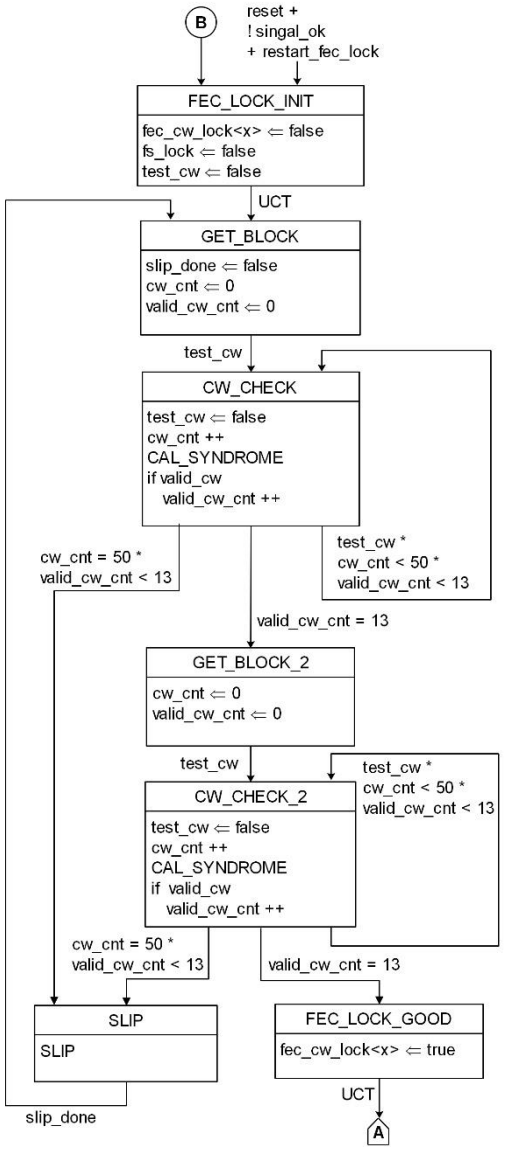
- For self-sync lock and monitoring process, we can choose N = P = 50, n = p = 13, M = 150, m = 140.
  - Self-sync performance will not degrade with burst error when measured BER is limited.

N=P=50, n=p=13, M=150, m=140. AWGN channel				
Parameters	**BER = 2E-3**	**BER = 3E-3**	**BER = 4E-3**	**BER = 5E-3**
Mean time to false-lock (MTTFL) (years)	6.66E+22	6.66E+22	6.66E+22	6.66E+22
Mean time to false-unlock (MTTFU) (years)	6.99E+60	1.99E+41	1.86E+28	3.26E+18
Mean time to lock (MTTL) (μs)	<1	<1	<1	<1
Mean time to unlock (MTTU) (μs)	<1	<1	<1	<1

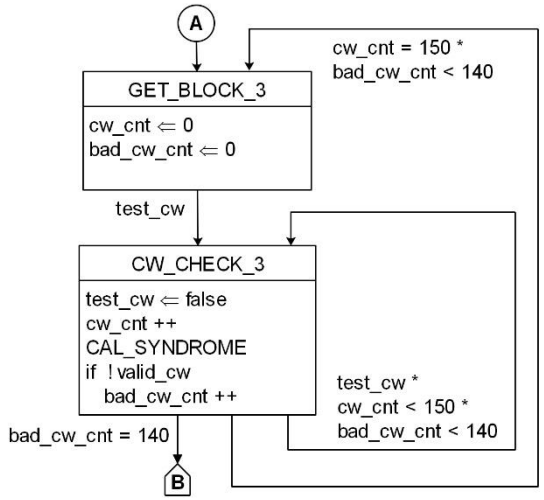
- For padding detection and FS monitoring process, we propose to use t = 9, x = 3, y = 12 as discussed in he_3dj_optx_01_230815.
  - Due to known codeword boundaries, x=3 is sufficient for MTTFL. (2.2E+10 years)
  - Considering burst errors, y=12 is a good choice for a sufficient MTTFU. (1.8E+11 years)

State diagram for self-sync

- Self-sync state diagram to get inner FEC codeword boundaries.
- Self-sync lock is performed on each of the 8 de-interleaved codeword streams on each 200G lane.
- “CAL_SYNDROME” function calculates the syndrome vector of each candidate codeword. If the result is zero, valid_cw is true.



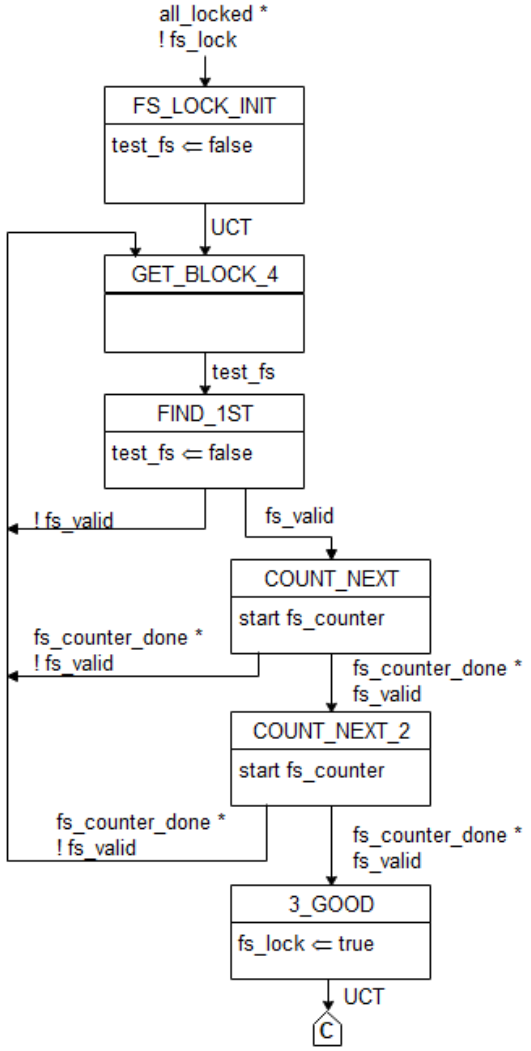
Search and Test + Validate



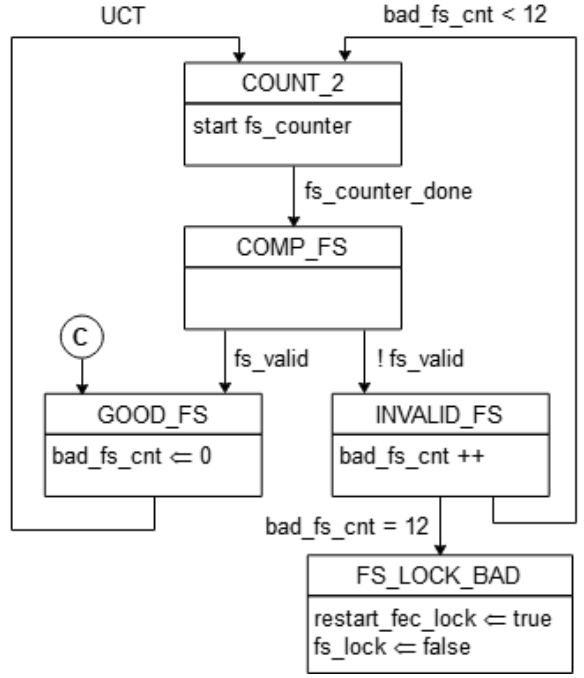
Monitor

State diagrams for FS identifying and monitoring

- "all_locked" is set to true when self-sync lock are achieved on all 8 de-interleaved codeword streams.
- If FS monitoring is implemented, 12 consecutive invalid FS's will restart the self-sync lock process.
- FS monitoring may be performed based on the decoded data stream, to further improve the reliability.
  - Most errors are corrected, which will greatly increase MTTFU.
  - Fewer than 12 invalid FS can be used to restart lock.



Padding Detection



FS Monitoring

- Similar state diagrams as in clause119.

Summary

- A complete proposal of self-sync is presented for inner FEC synchronization.
- FS pattern comparison is still needed to locate padding CWs after self-sync is established.
- It still allows FS sync method with the proposed FS state diagrams.

Thank you!