400GbE FEC Modes

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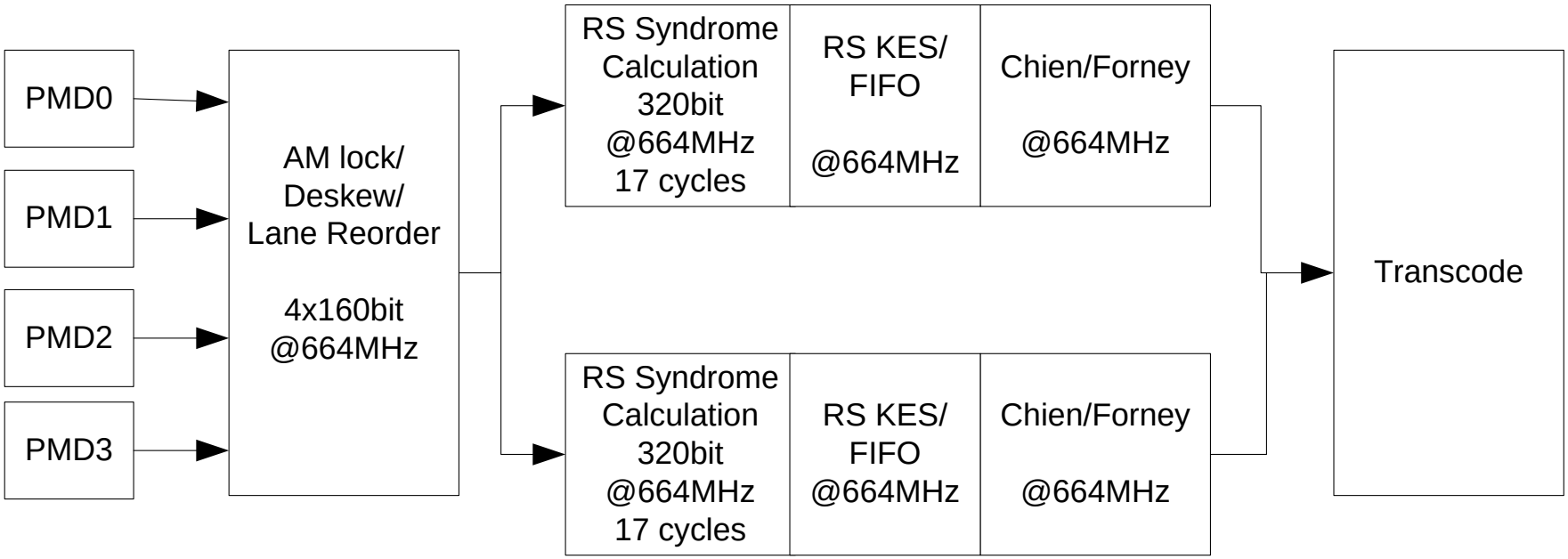
Potential FEC Modes

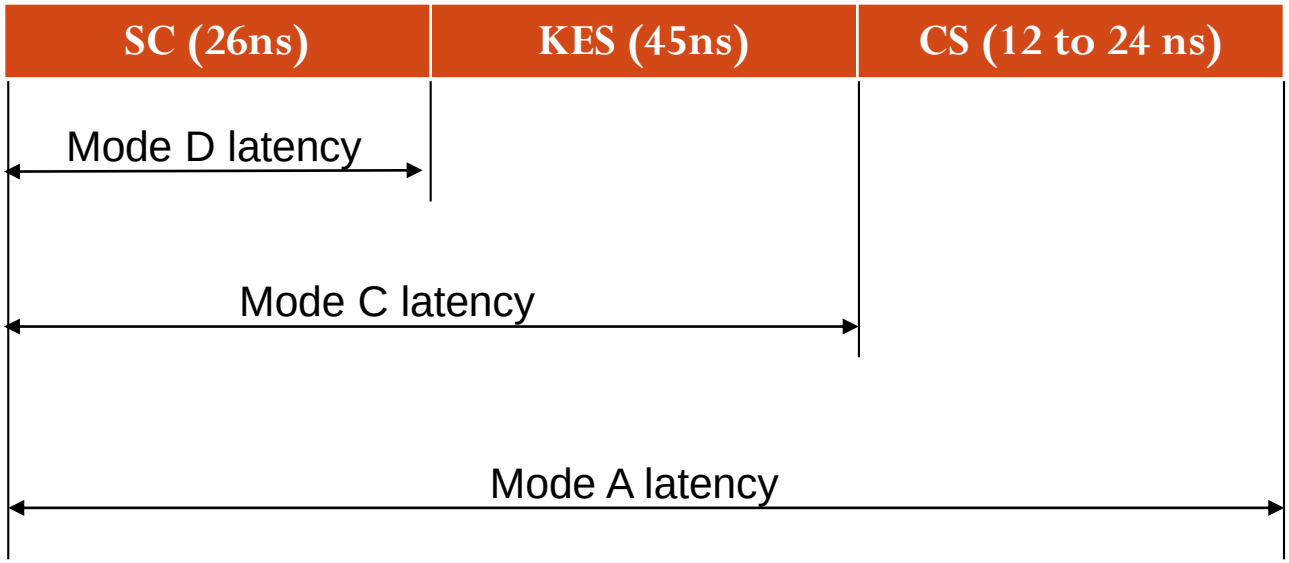
- Mode A: performs error correction and uncorrectable FEC block mark.
- Mode B: no error correction and no uncorrectable FEC block mark.
- Mode C: error correction but no uncorrectable FEC block mark.
- Mode D: no error correction but marks uncorrectable FEC block.

400G FEC Latency



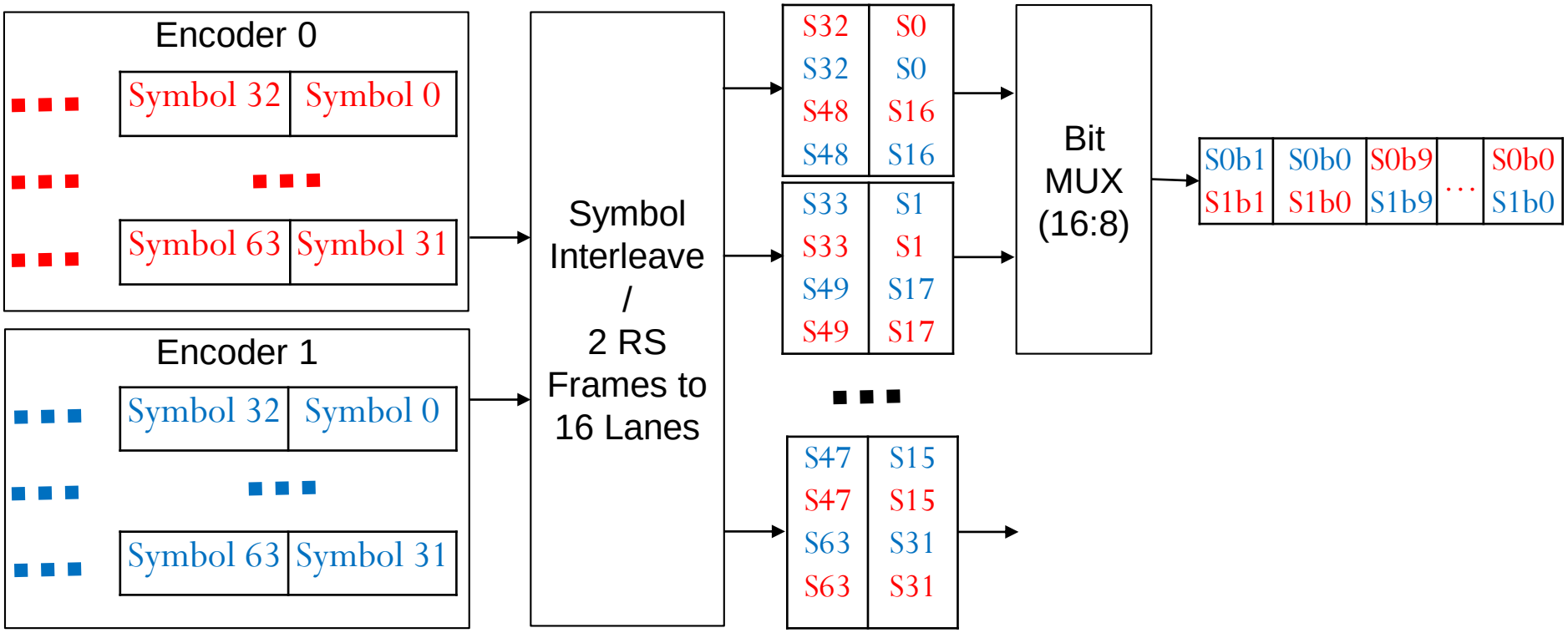
- "Typical" 2x200G FEC decoder latency : 17 cycles for syndrome calculation, 30 cycles for KES, and 8 cycles for CS. sun_3bs_01_0715.pdf
- No extra latency for interleaving. sun_3bs_01_0915.pdf

FEC Latency for Different Modes



- Mode C saves CS latency which is about 12 to 24 ns depending on implementation.
- Mode D latency is for syndrome calculation and takes about 26ns.

Error Distribution on 2 FEC

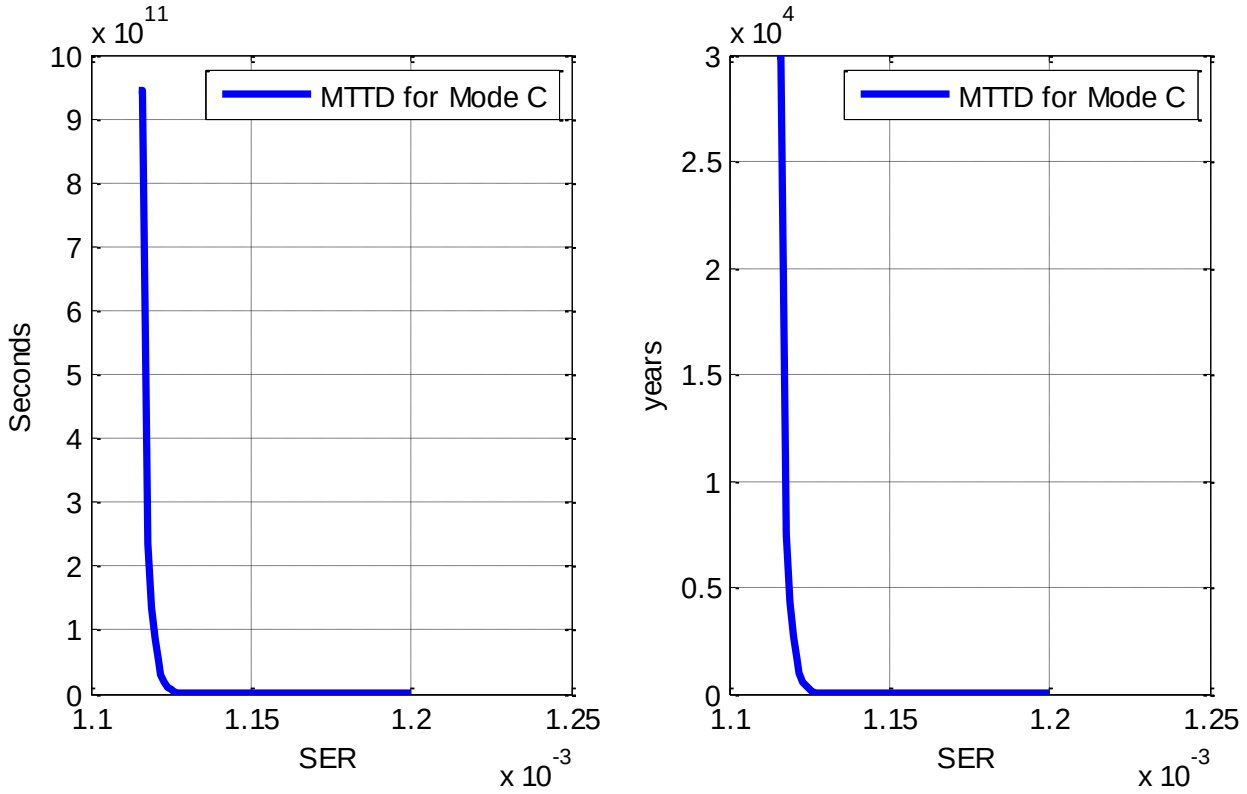


- Each FEC covers all 16 FEC lanes.
- If errors are random, error distribution on 2 FEC should be similar given current pre-interleaved scheme.

MTTFPA for Mode C with Random Errors

- A MTTFPA protection mechanism is needed as in 802.3bj. We count total symbol errors for 2^13 FEC frames. If the error counter exceeds a threshold K, we disconnect the link, and therefore prevents the risk of false packet acceptance. Mean time to disconnect (MTTD) is very sensitive to SER. Let K= 5560.
  - If SER=1.2e-3, MTTFPA= 5.25e9 years, MTTD = ~0.1 seconds.
  - If SER=1.1e-3, MTTFPA= 1.84e10 years, MTTD >> 1e4 years.

MTTD for Mode C



- The figures show MTTD in seconds and years.
- Window size is **2^13** FEC blocks and threshold K is **5560**.

Time to Lose Lock

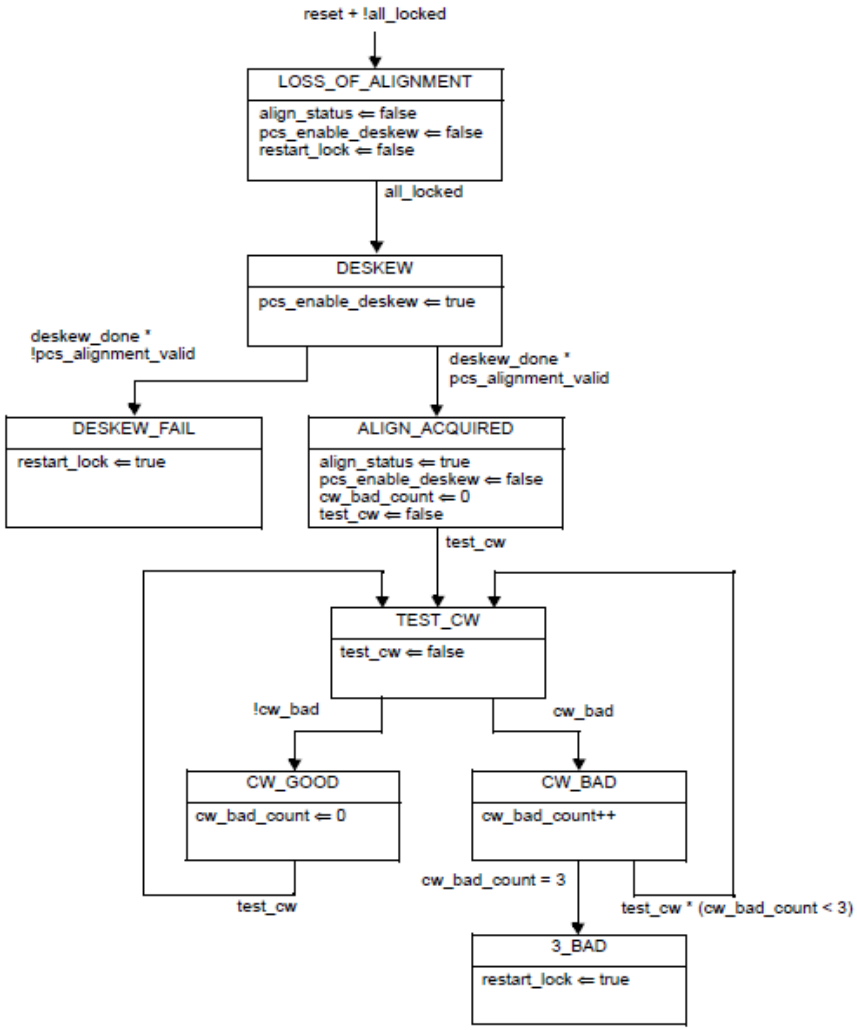
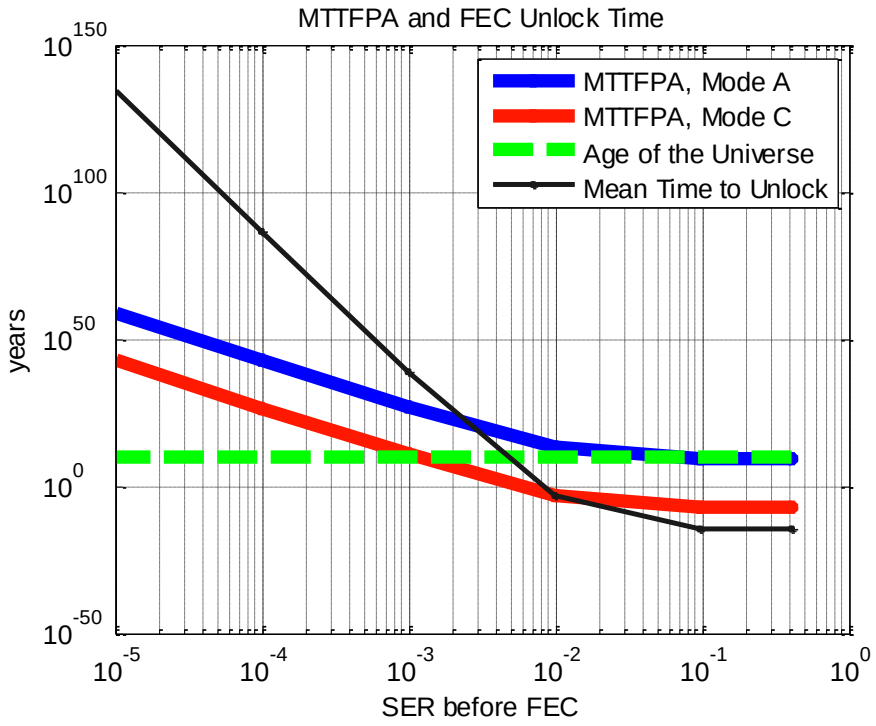
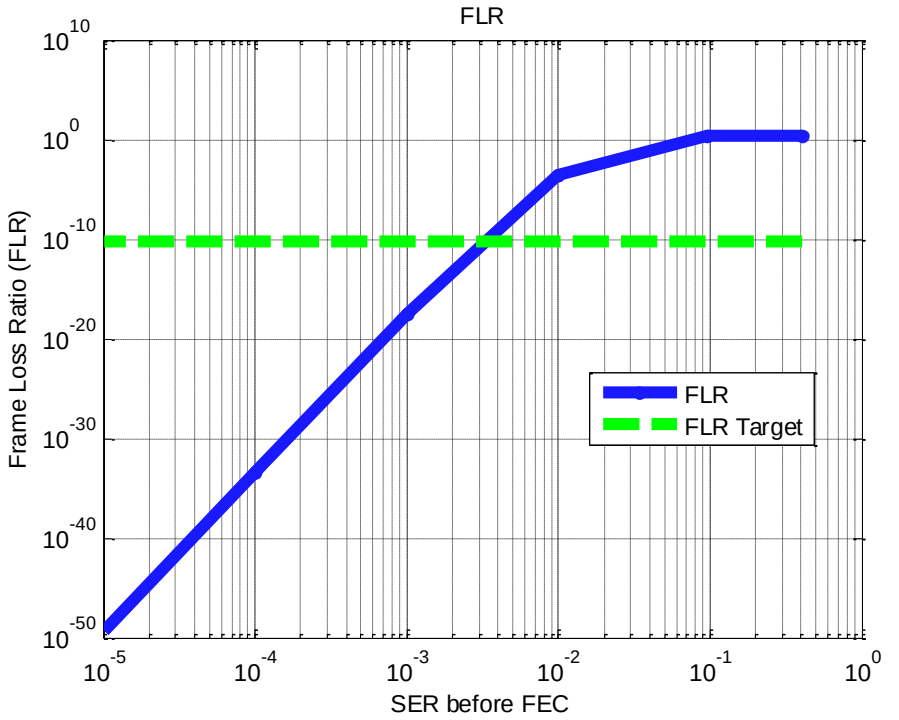


Figure 119–13—PCS synchronization state diagram

- FEC alignment is unlocked if there are 3 uncorrectable blocks in a row.
- Time to lose lock in case of misalignment should not be more than several FEC blocks.
- Here we analyze mean time to unlock when alignment is correct. We need to avoid false unlock when SER is OK.
- Time to lose lock in this presentation is calculated as the mean time to have 3 continuous uncorrectable blocks from one FEC.

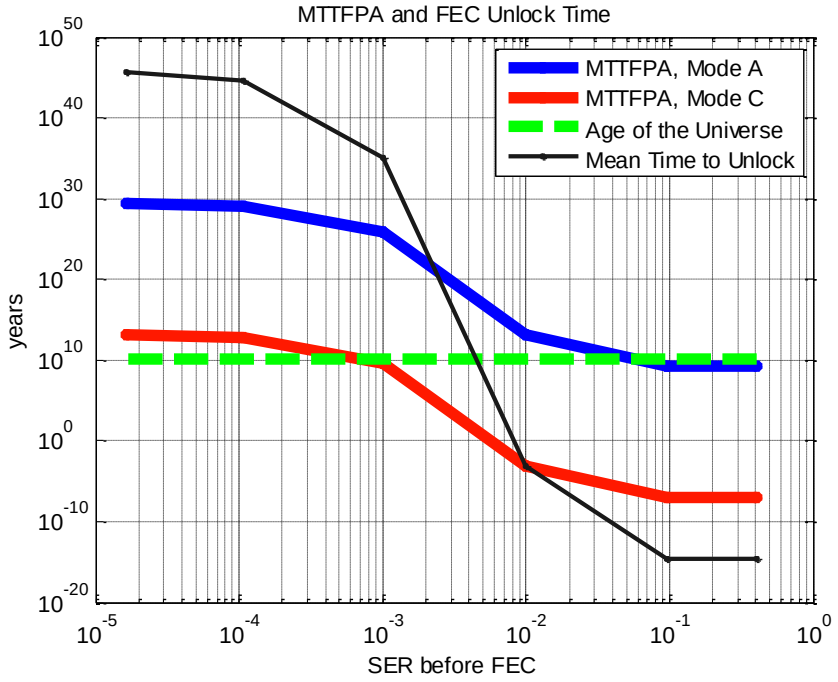
Mode C MTTFPA and FLR

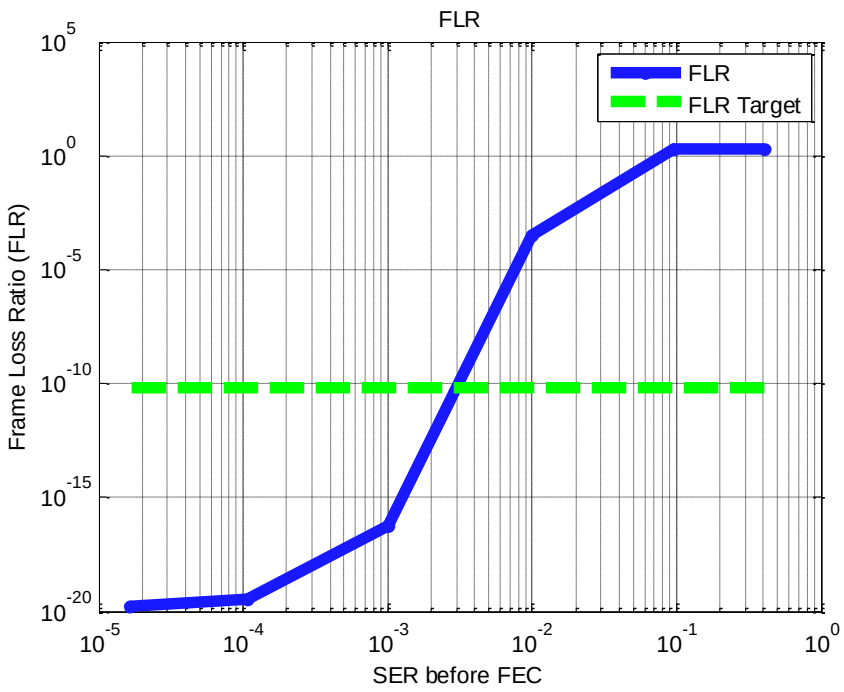




- Assuming random error case, e.g., C2M+optical link.
- For mode C, SER needed for MTTFPA (~1.13e-3) is lower than that for FLR (~3.06e-3).
- Mode A MTTFPA is estimated by assuming error patterns are random. When Mode A MTTFPA is less than AOU, mean time to unlock << 1ms.

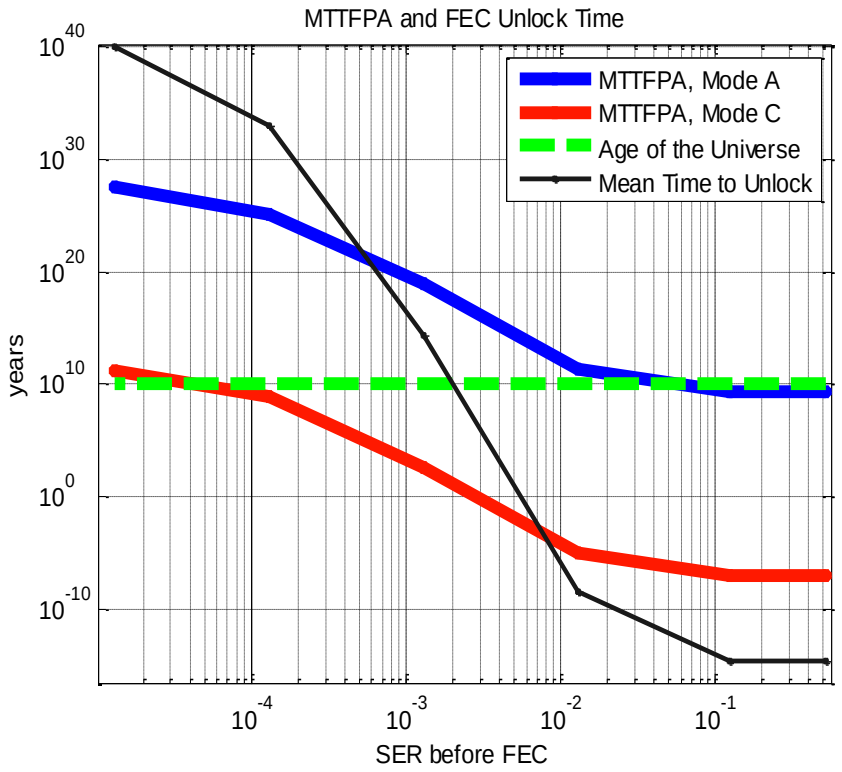
Mode C MTTFPA for Multi-Part Link

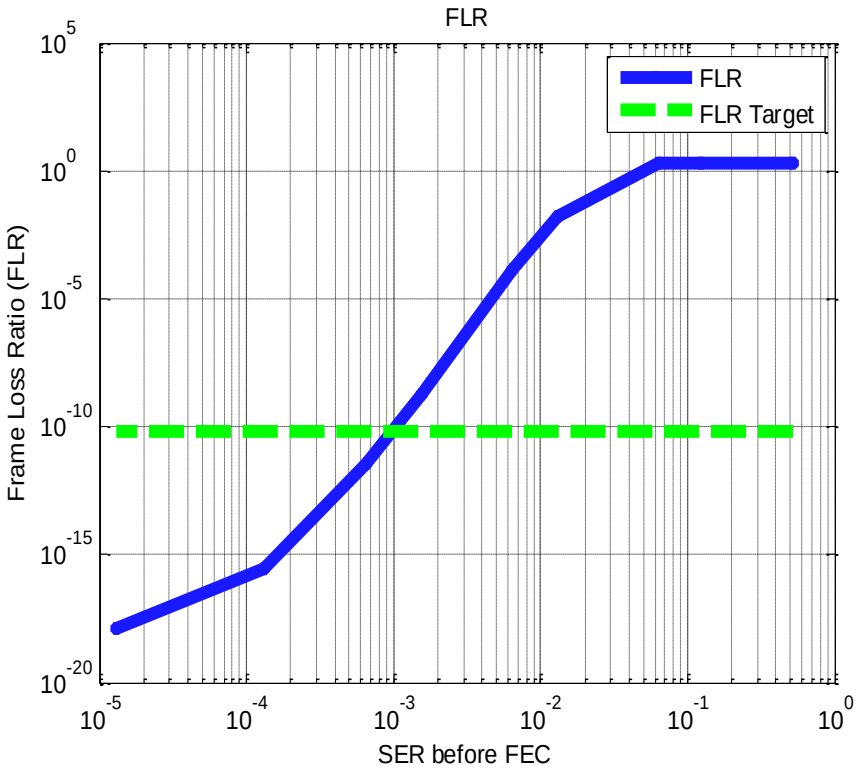




- Set electrical link BER as 1e-6 as an example to enable mode C for multi-part link.
- For electrical link DFE error propagation, a is set to 0.75.
- For SER=1.2e-3, MTTFPA is about 3.47e8 years. MTTD is ~0.1s.

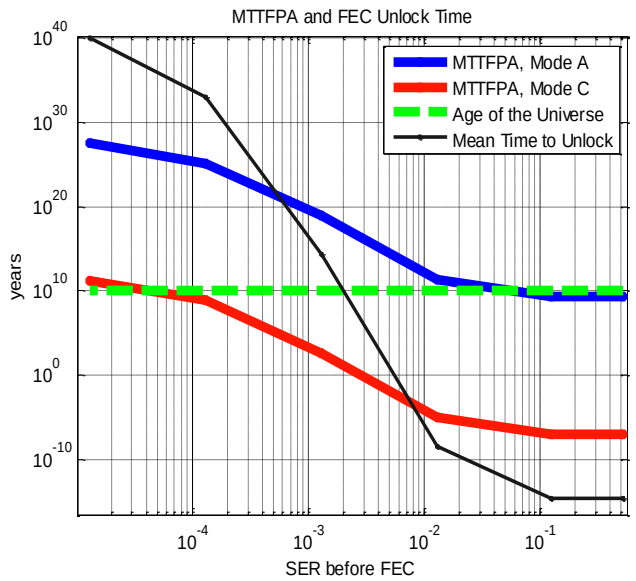
Mode C MTTFPA – Worst Case



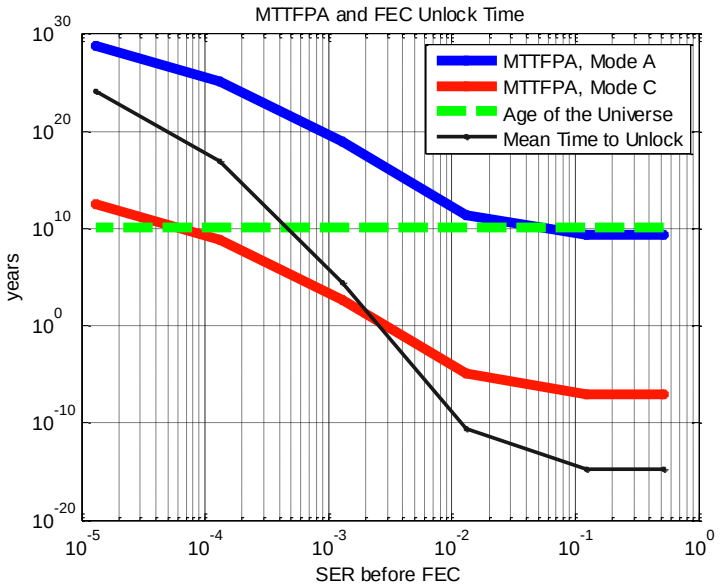


- Error distribution has impact on FLR and MTTFPA.
- a=0.75 is the theoretical worst case to check whether MTTFPA is OK.
- For SER=1.2e-3, MTTFPA is about 6.93e2 years. MTTD is ~0.1s.

Unlock Mechanism



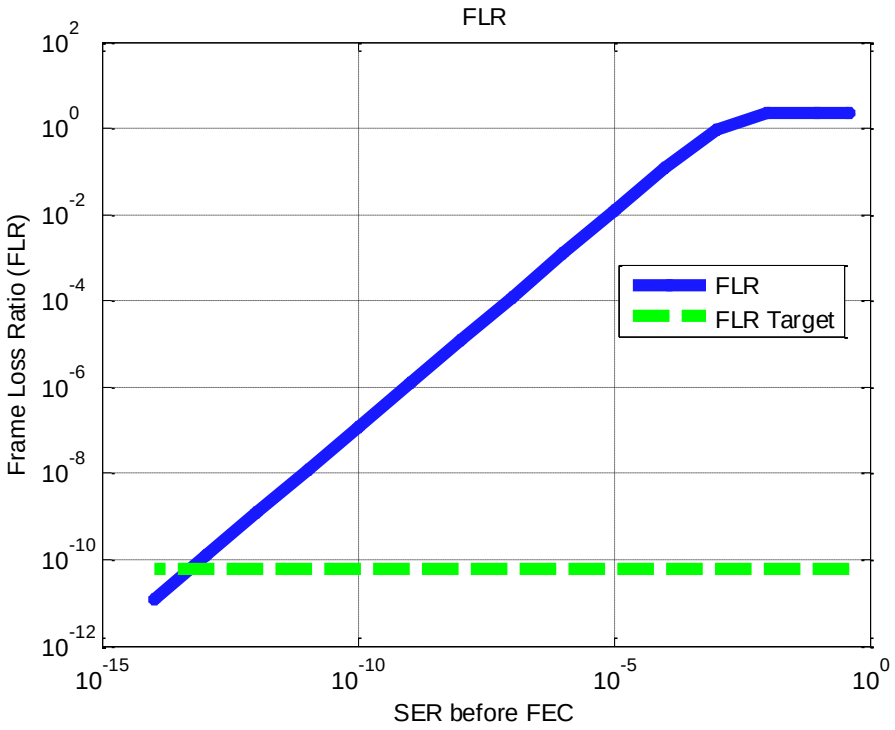
Unlock based on 3 Undecodable FEC blocks



Unlock based on 2 Undecodable FEC blocks

- Unlock based on how many consecutive undecodable FEC blocks?
- If based on 3 consecutive undecodable blocks from one FEC - mean time to false alignment unlock is much longer than AOU when FLR target is met. When SER is really low, FEC alignment will be unlocked within a few frames.
- If based on 2 consecutive undecodable blocks from one FEC - mean time to false alignment unlock is less than 7.94e4 years when FLR target is met.
- In case of false lock, unlock is triggered within a few FEC blocks for both cases.

Mode D (Detection only)



- Assume random errors. SER before FEC needs to be 5.07e-14 to meet 6.2e-11 FLR target.
- MTTFPA is not a problem.
- This mode is not practical for this project.

FEC Modes Summary

Modes	Error Correction	False Frames	Latency	FLR	MTTFPA
A	Yes	Mark	87 to 99 ns	Sufficient	Sufficient
Bypass	No	Pass through	0 ns	Low DER Required	Too short
Correct	Yes	Pass through	75 ns	Sufficient	Conditional
Detect	No	Mark	30 ns	Low DER Required	Sufficient

- Mode A achieves sufficient link efficiency and safety.
- Mode B requires better than 1E-13 raw BER to achieve efficient link. Even with this BER, it has MTTFPA risk. Mode B should not be used.
- Mode C has latency advantage (12 to 24 ns). MTTFPA depends on the ratio of uncorrectable RS frames.
- Mode D requires 5.07e-14 SER before FEC to meet 6.2e-11 FLR target.

Conclusions

- Mode A should be the default mode. MTTFPA can be protected by FEC frame alignment unlock mechanism when BER is high.
- Mode B should not be used.
- Mode C saves about 12 to 24 ns latency. It needs MTTFPA protection and a little lower BER before FEC. It may be good for applications like C2M+optical link.
- Mode D requires very low SER to meet FLR target and is not practical.