Comments and proposals regarding SC-FEC sublayer lane alignment process

In support of comments: 52, 54, 62, 63, 66, 67, 68

Leon Bruckman (Huawei)

References

- 100GBASE ZR Draft 802.3ct_D1p1.pdf, Private Area
- ITU-T G.709 - Interfaces for the optical transport network
- ITU-T G.798 - Characteristics of optical transport network hierarchy equipment functional blocks
- trowbridge_3cn_01a_0119.pdf, IEEE P802.3cn Task Force, Long Beach, January 2019

Lane synchronization

- State machine
  - fas_valid
    - Boolean variable that is set to true if the received 6-octet sequence is a valid frame alignment signal. The frame alignment signal consists of 40 known bits and 8 variable bits. *The sequence is considered to be valid if four of the first five octets match the known bits of the pattern described in 153.2.3.2.4, and the 6th octet represents a numerical value in the range 0 to 239 with the most-significant bit transmitted first.*
  - FAS_COMPARE
    - This function compares the values of first_fecl and current_fecl to determine if a valid frame alignment sequence has been detected and returns the result of the comparison using the variable fas_match. fas_match is true if **fas_valid** is true for first_fecl and current_fecl, and the 6th octet of first_fecl (interpreted with the most significant bit transmitted first) modulo 20 is equal to the 6^{th} octet of current_fecl (interpreted with the most significant bit transmitted first) modulo 20. Otherwise, fas_match is false.

Lane alignment verification state machine

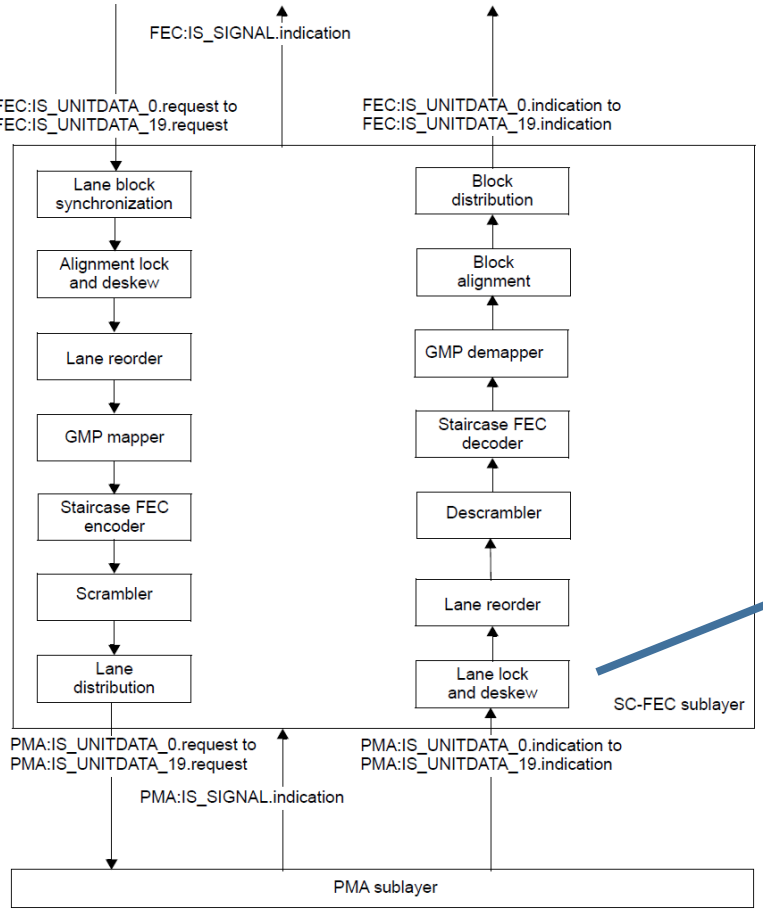
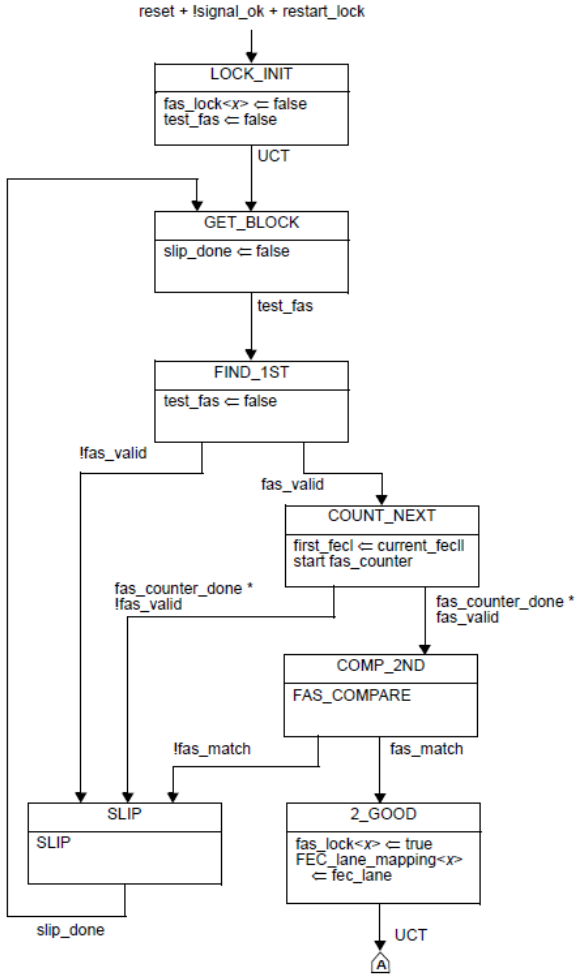


Figure 153–2—SC-FEC functional block diagram



Lane alignment loss verification state machine

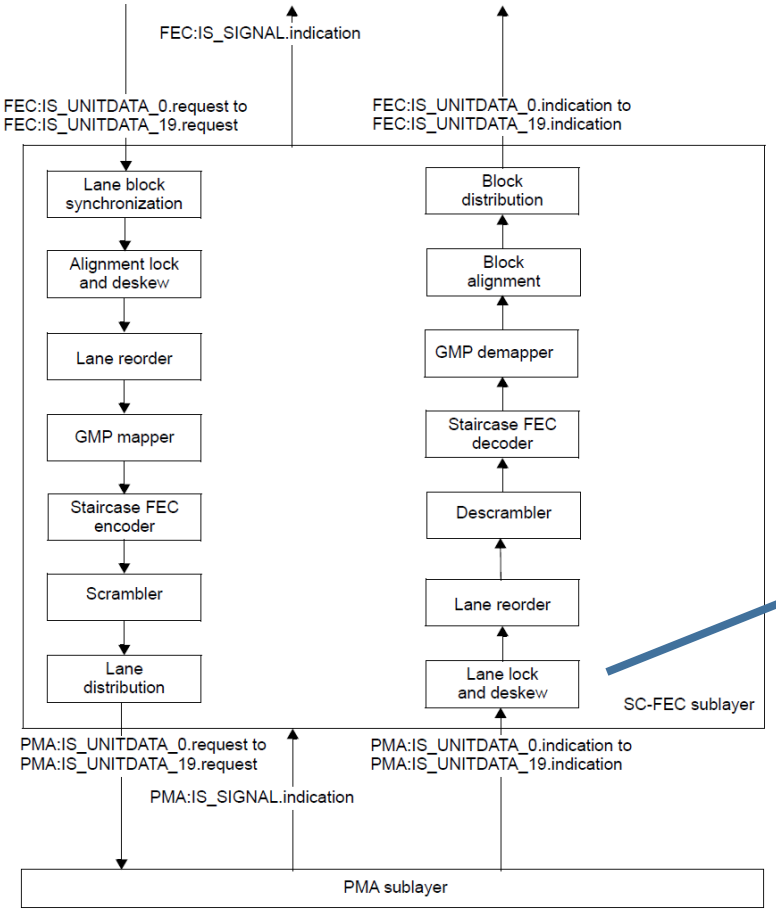
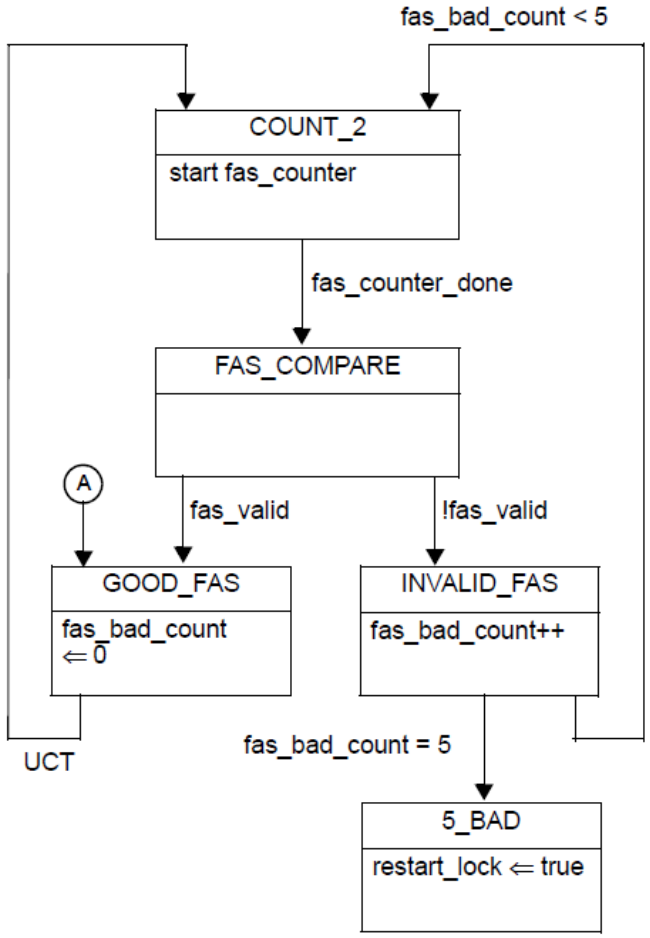


Figure 153–2—SC-FEC functional block diagram



Consequent actions

- The SIGNAL_OK parameter of the FEC:IS_SIGNAL.indication primitive can take one of two values: OK or FAIL. The value is set to OK when the FEC receive function has identified codeword boundaries as indicated by **fec_align_status** equal to true. That value is set to FAIL when the FEC receive function is unable to reliably establish codeword boundaries as indicated by fec_align_status equal to false. When SIGNAL_OK is FAIL, the rx_bit parameters of the FEC:IS_UNITDATA_i.indication primitives are **undefined**.

- **fec_align_status**: A variable set by the FEC alignment process to reflect the status of FEC lane-to-lane alignment. Set to true when all lanes are synchronized and aligned and set to false when the deskew process is not complete.

- This means that the FEC:IS_SIGNAL.indication is set FAIL if any of the lanes losses alignment and as a consequence the FEC:IS_UNITDATA_i.indication primitives become undefined.

Alignment procedures: 100GBASE-ZR vs. ITU-T G.798

Procedure	100GBASE-ZR	ITU-T G.798*
Alignment	Search for four octets that match four of the first five octets of the alignment (FAS) pattern + verify that the 6th octet value is <240. Count the bits to the next framing position candidate and verify again that four octets match four of the first five octets of the alignment (FAS) pattern and that the 6th octet value is the same as in the previous frame. If yes, then alignment is achieved.	In the OOF state (loss of alignment), the framing pattern searched for shall be a 4-byte subset of the FAS bytes. The IF state shall be entered if this subset is found and confirmed one frame period later.
Alignment loss	If for 5 consecutive frames there are more than four octets out of the first five octets of the FAS that do not match the pattern, OR the 6th octet value is not equal to the one detected during the alignment process, then alignment is lost.	The framing pattern checked for shall be the OA1OA2OA2 pattern (bytes 3, 4 and 5 of the FAS). The OOF state (loss of alignment) shall be entered if this subset is not found at the correct position in five consecutive frames.
Logical lane ID loss	Included in the alignment procedure	A new value of the logical lane marker is accepted when in five consecutive 16320 byte periods the same value is present in bits 7 and 8 of the MFAS byte (their equivalent to our lane identification).
Logical lane ID detection	Included in the alignment loss procedure	Recovery will be lost, when in each of five consecutive 16320-byte periods a value is received that is not the same as the accepted logical lane marker value

* ITU-T G.798 lane alignment requirements and procedures for OTU4-SC signal (the one our SC-FEC frame is based on) is for further study. Similar signals requirements and procedures are shown.

Alignment Related procedures: 100GBASE-ZR vs. ITU-T

Procedure	100GBASE-ZR	ITU-T G.709 and G.798
Frame start maintain	Not defined	The frame start shall be maintained during the OOF (alignment loss) state.
Lane marker counter	No correlation between MFAS and Lane marker counters	LLM = 0 (Logical Lane Marker) position shall be aligned with MFAS = 0 position every 3840 (the least common multiple of 240 and 256) frame periods.
Consequent actions	Immediate after anomaly (e.g. alignment loss) detection	Only for defects (anomaly that persists for an integration period), per lane integration timer

Proposal details

- Alignment detection based on 4 fixed FAS bytes OK
- Alignment loss detection based on: 3 fixed FAS bytes not OK
  - Configurable loss verification duration
- Separate Lane marker procedures from alignment procedures
  - Configurable detection and loss verification duration
- Maintain frame start position during loss of alignment
- Integrate anomaly before applying consequent actions
- Option to synchronize lane marker counter to MFAS
- Advantage:
  - Developers will be able to reuse the same functions/hardware they developed for other OTN similar signals.

Loss of synchronization probability

- According to D1.1:
  - Per Lane: On average there will be an alignment loss every: ~ 1.5 min
- With the new proposed loss of alignment procedure (Y is the number of consecutive verification failures to lose alignment):

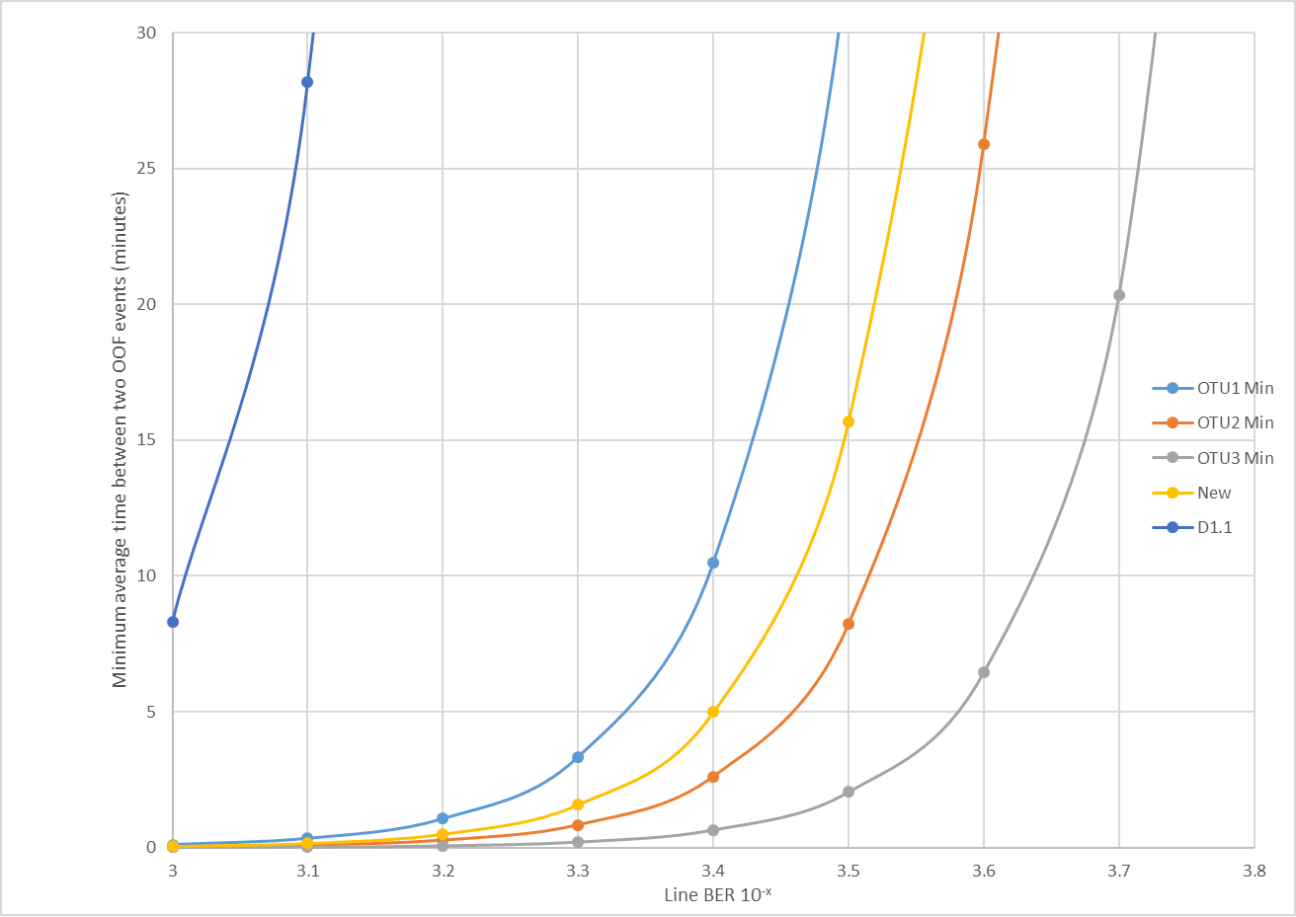
	Y=5	Y=6	Y=7
Per Lane [sec]	1.81	17.25	163.95

- In both cases, since the alarm is not integrated, the data path may be impaired.

Minimum average time between false out-of-frame events

- According to ITU-T G.798 Appendix III:
  - It is not possible to give the exact expression for the minimum average time between two out-of-frame events, due to it being a stochastic process. It is instead possible to give an approximate value for it.

Per Lane



Mean time to false frame acceptance (MTTFFA)

- According to ITU-T G.798 Appendix III:
  - The probability for false in-frame alignment can be obtained noting that the FAS is searched for up to one frame (FL bit long) with FL-1 possibilities for a false (simulated) FAS and confirmed the following δ frames.
  - The equation for computing MTTFFA is: $T_{frame}/(P_{fOOF} \times P_{fIF})$

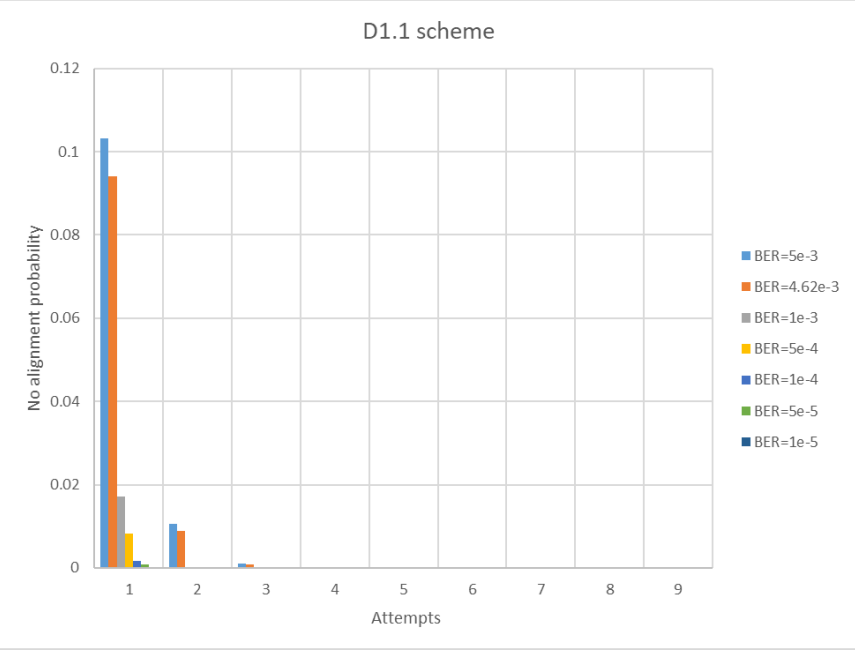
	OTU1	OTU2	OTU3	New	D1.1
MTTFFA (years) (BER = $5x10^{-3}$)	$1.173x10^{7}$	$2.920x10^{6}$	$7.268x10^{5}$	$5.593x10^{6}$	$1.144x10^{7}$
MTTFFA (years) (BER = $1x10^{-3}$)	$2.918x10^{10}$	$7.265x10^{9}$	$1.809x10^{9}$	$1.392x10^{10}$	$1.023x10^{11}$

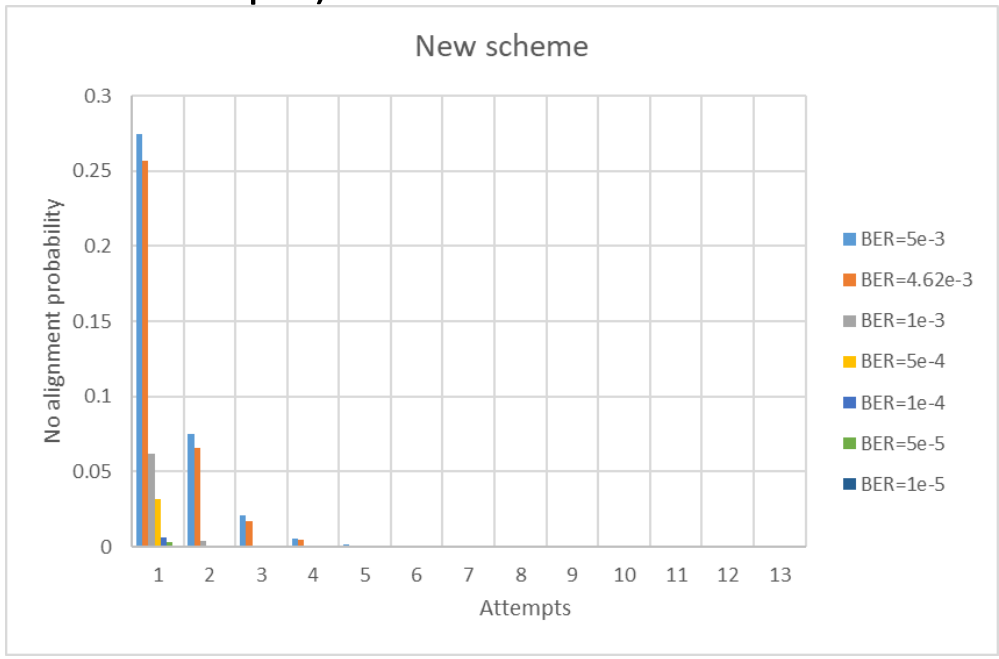
Frame lane alignment time

- According to ITU-T G.798 in our case:
  - The frame alignment time is computed using the following equation:
    - $T_{IF} = T_{frame} \times (1+ \delta + P_{fFAS} \times FAS_{Length})$
    - Where P_{fFAS} is the FAS emulation probability, FAS_{Length} is 32 and δ is 1 in our case

	OTU1	OTU2	OTU3	New
Alignment time [µsec]	97.94	24.38	6.07	46.71

- Taking BER into consideration (independent attempts):





New scheme adds two attempts: 46.71µsec

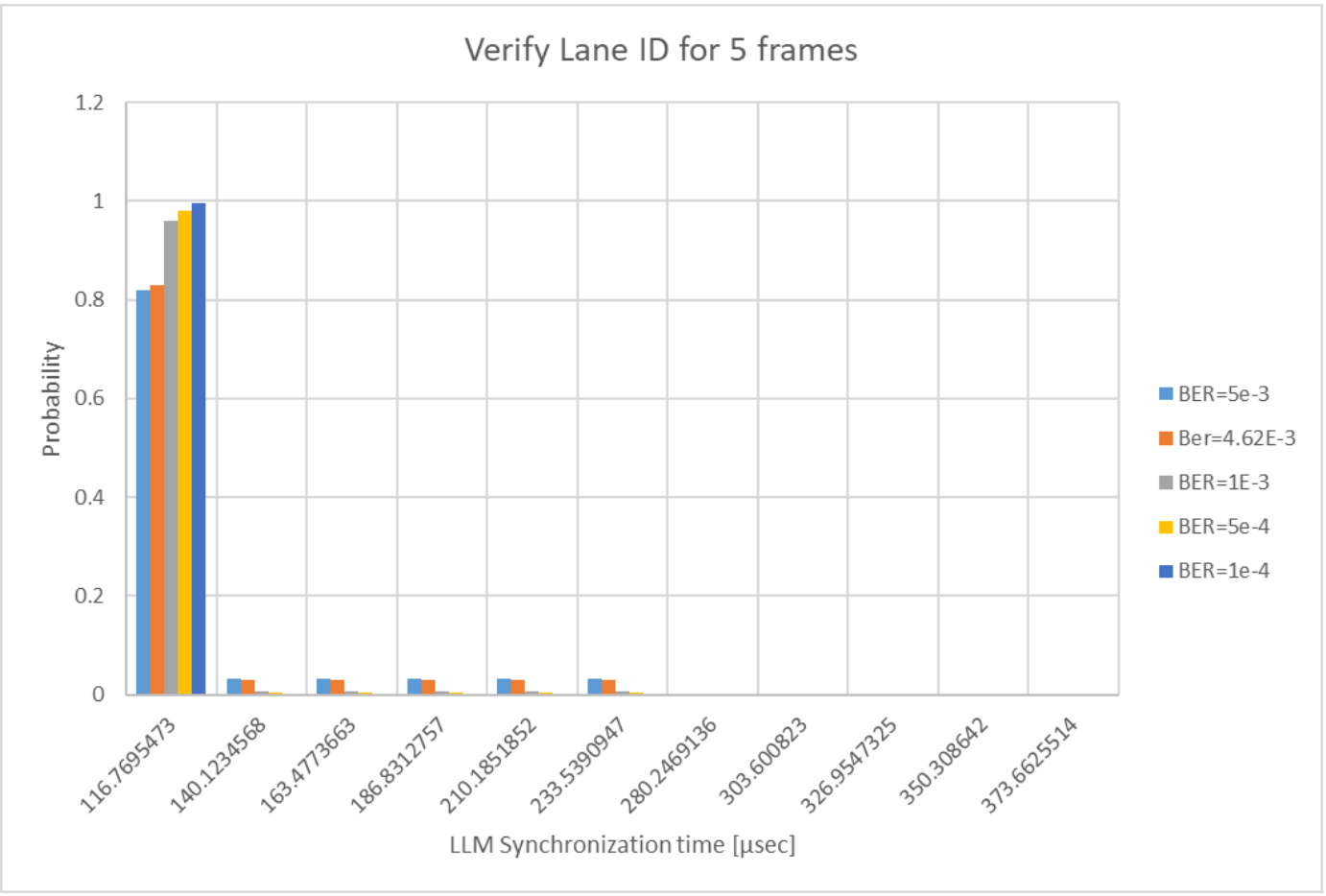
Alternative simpler alignment loss scheme

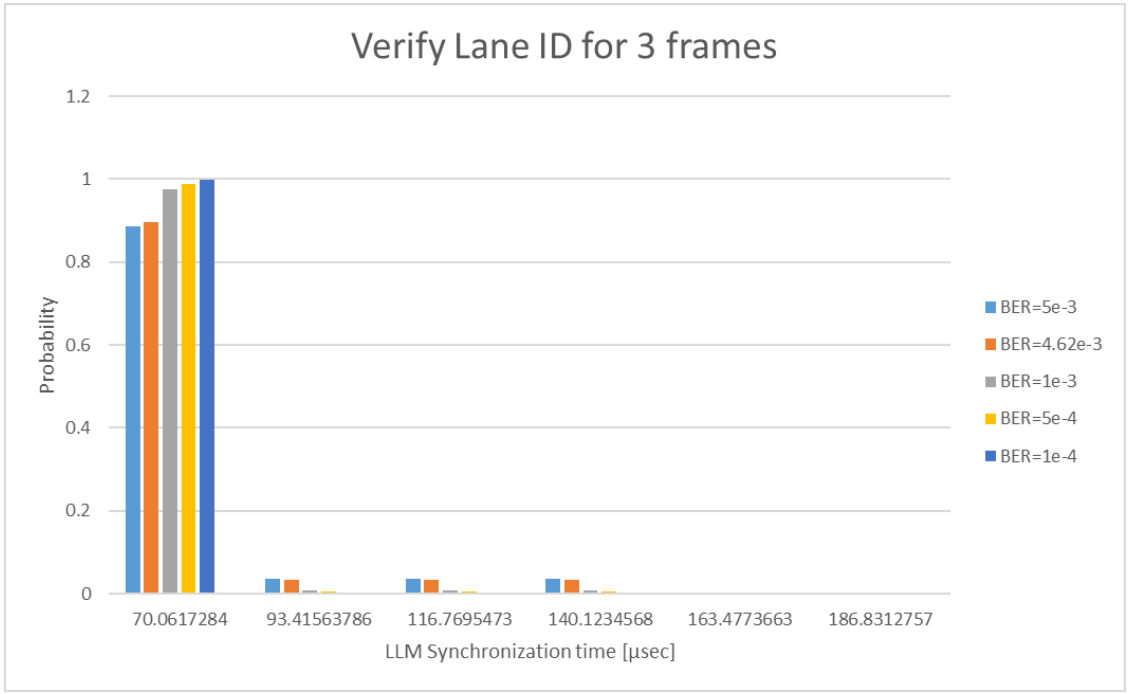
- fas_valid
  - Boolean variable that is set to true if the received 5-octet sequence is a valid frame alignment signal. The frame alignment signal consists of 40 known bits. The sequence is considered to be valid if a subset of 4 octets match the known bits of the pattern described in 153.2.3.2.4.
- FAS_COMPARE
  - This function compares the values of first_fecl and current_fecl to determine if a valid frame alignment sequence has been detected and returns the result of the comparison using the variable fas_match. fas_match is true if the third, fourth and fifth octets match the known bits of the pattern described in 153.2.3.2.4. Otherwise, fas_match is false.
- Option: Configurable fas_bad_count.

Lane identification proposed process

- Independent lane alignment process
  - Note that in section 82 (PCS for 64B/66B, type 40GBASE-R and 100GBASE-R) the Block synchronization and the alignment marker lock are separate processes (Figures 82-12 and 82-13 respectively)
- Lane identification:
  - Start after FAS alignment, verify that the value is stable for X frames
- Lane identification loss:
  - Declared after Y consecutive frames the detected value is different from the accepted value
- In my comment I suggested X=Y=5.
  - Option: Configurable X and Y.

Lane identification alignment time





Conclusion

- Proposal:
  - Lane alignment:
    - Fixed 4-octet subset of FAS searched for and verified
  - Lane alignment loss:
    - Fixed 3-octet subset of FAS verified
    - Option: Configurable verification duration
  - Lane identification:
    - Separate from lane alignment process
    - Option: Configurable verification duration
  - Fail indication:
    - Add 3 msec integration timers per lane (one for alignment loss and another for lane ID loss) before setting FEC:IS_SIGNAL.indication to FAIL

- Another option for Lane alignment/alignment-loss:
  - Do not define the process, just the requirements, for example:
    - Maximum alignment time X with a probability of better than Y
    - Minimum average time between alignment loss events
    - MTTFA

Backup

Loss of synchronization probability – D1.1

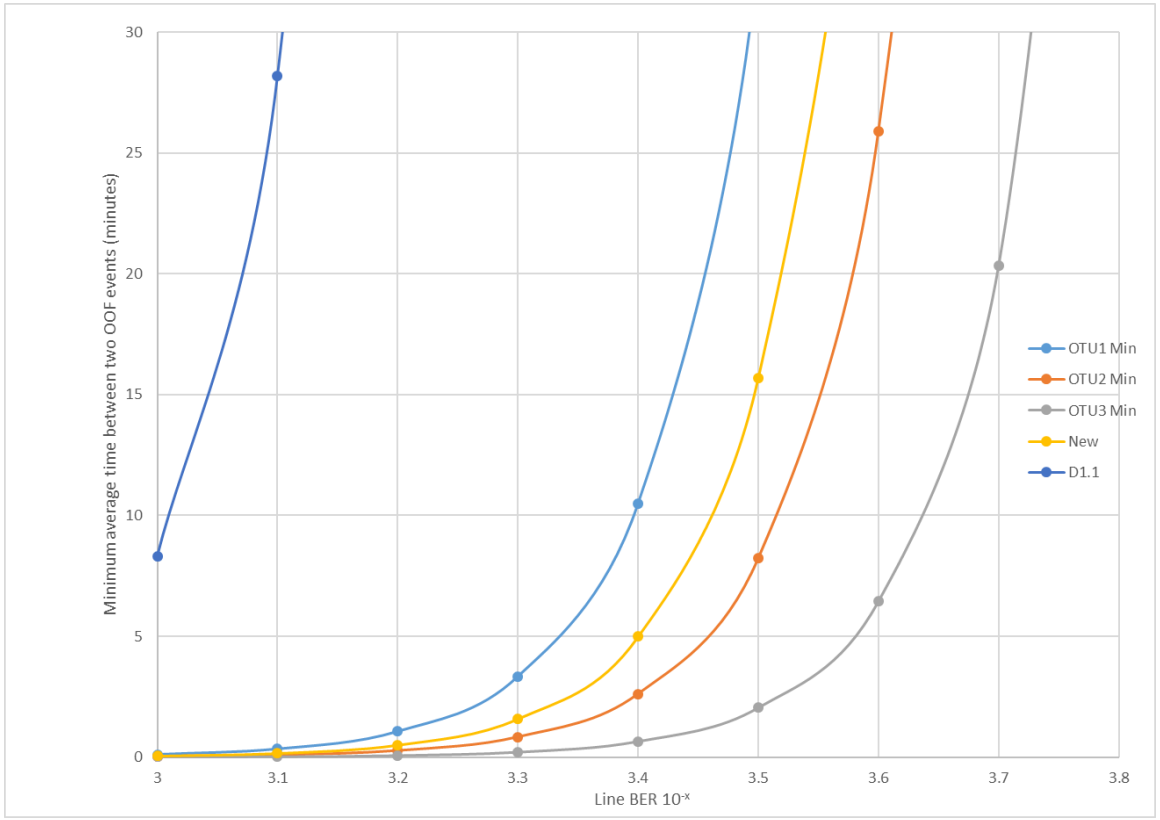
- FAS byte OK: $(1-4.62\text{x}10^{-3})^8 = 0.963632$
- FAS byte errored: = 1- 0.963632 = 0.036368
- Loss of synchronization happens if for 5 consecutive times, more than 4 out of 5 FAS bytes are errored and/or the lane ID byte is errored.
  - All FAS bytes OK and lane ID OK: $0.963632^5 \text{ x } 0.963632 = 0.800696$
  - 4 out of 5 FAS bytes OK and lane ID OK = C(5,4) x $(0.963632)^4$ x 0.036368 x 0.963632 = 0.951789
  - The probability of less than 4 out of 5 FAS bytes OK or lane ID error = 1 - 0.951789 = 0.048211
    - The probability that the above happens 5 consecutive times is: $0.048211^5 = 2.60455\text{x}10^{-7}$
- There are 4080 x 8 x 4 / ((255/227) x $(4.97664\text{ x}10^9)$) = 42819.38326 frames/sec
  - Per Lane: There will be an alignment loss every: 1 / $(2.60455\text{x}10^{-7}$ x 42819.38326) ~ 1.5 min
  - Per 20 Lanes: There will be an alignment loss every: ~4.48 sec
- With the new proposed loss of alignment procedure there will be an alignment loss every:

	Y=5	Y=6	Y=7
Per Lane [sec]	1.81	17.25	163.95
Per 20 Lanes [sec]	0.024	0.17	1.24

Minimum average time between false out-of-frame events

- According to ITU-T G.798 Appendix III:
  - It is not possible to give the exact expression for the minimum average time between two out-of-frame events, due to it being a stochastic process. It is instead possible to give an approximate value for it.

Per Lane



Per 20 Lanes