800GBASE-LR1 synchronization state diagram parameters

In support of comment #307

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Supporters

Outline

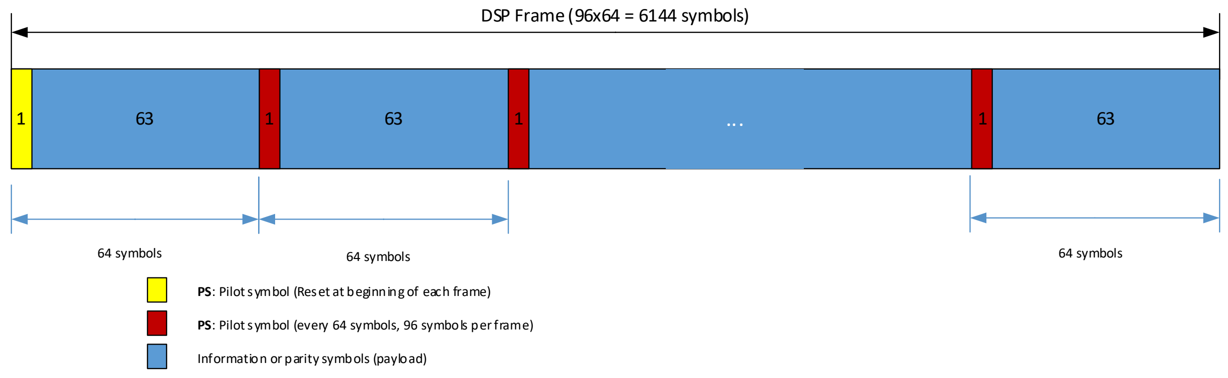
- General principles
- D1.0 synchronization method
- Select values for N and M
- Other options

General principles

- Define simplest test machine that can provide high synchronization probability and low wrong synchronization probability
- Low synchronization time, very low synchronization loss probability
- Fast wrong synchronization detection
- Assume SER = $5e^{-2}$ for evaluation
- Synchronization scheme based on QPSK
- Implementations with better performance is compliant

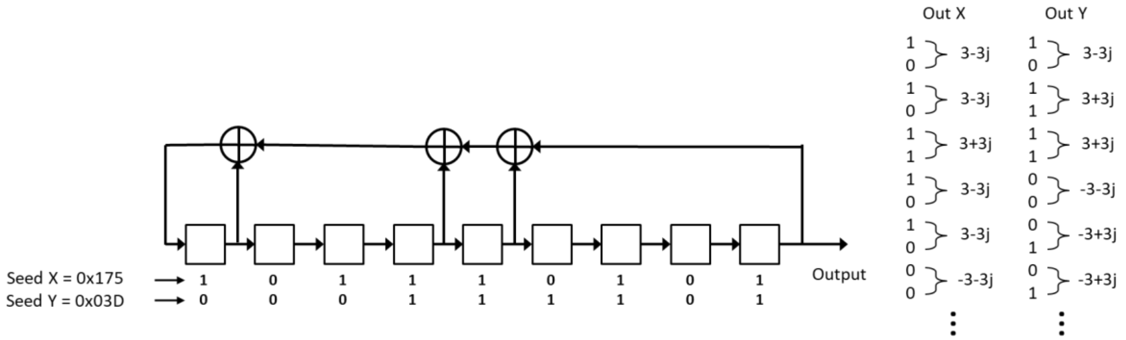
Background

- The 800GBASE-LR1 DSP frame is defined as a set of 96x64=6144 4–bit blocks
  - 4–bit pilot symbols (PS) are inserted every 64 4-bit blocks (1 pilot 4–bit symbol, 63 message 4–bit blocks)
- Two 800GBASE-LR1 DSP frames are generated by the Inner FEC sublayer
  - The 4–bit blocks for DSP frame_0 are constructed from two consecutive bits from output_0 (to be mapped to X_I) and two consecutive bits from output_1 (to be mapped to X_Q)
  - The 4–bit blocks for the DSP frame_1 are constructed from two consecutive bits from output_2 (to be mapped to Y_I) and two consecutive bits from output_3 (to be mapped to Y_Q)

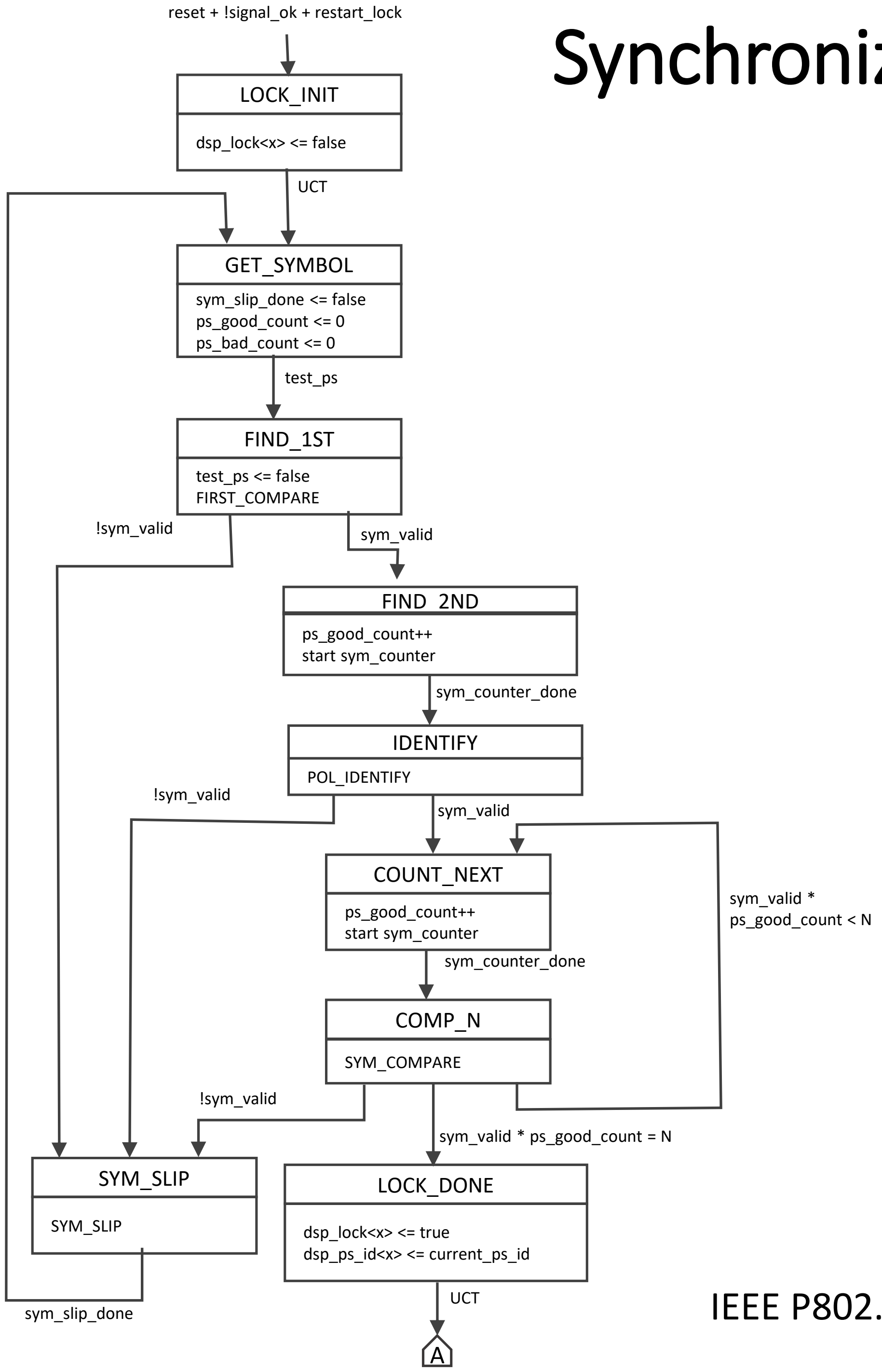


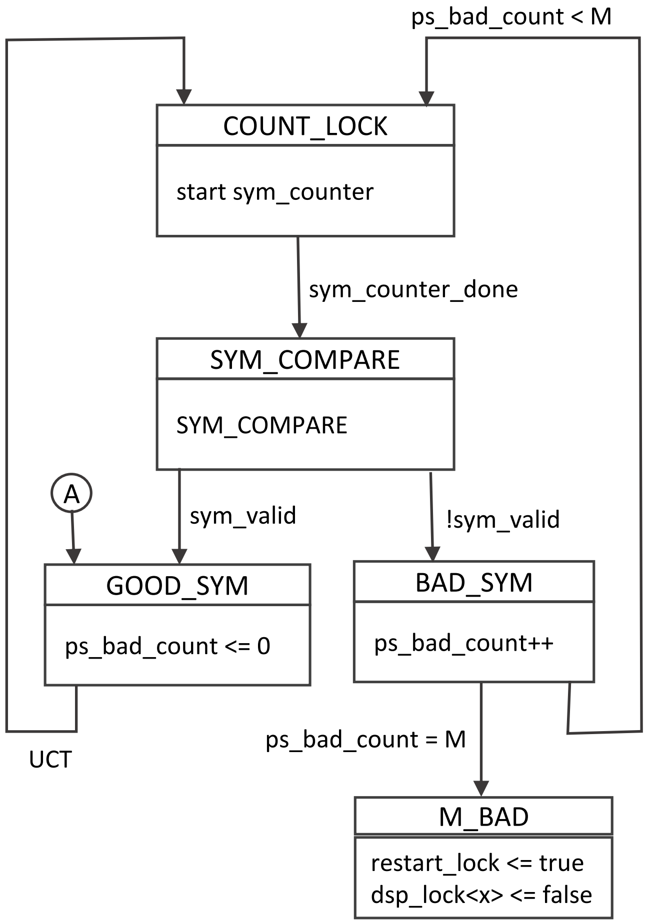
Pilot Sequences (PSs)

- The pilot sequence is a fixed PRBS9 sequence with different seed values for DSP frame_0 and for DSP frame_1
  - The seeds are selected so that the pilot sequences are DC balanced.
- The generator is initialized using the seed at the start of every DSP frame, so that the same 96 PS symbols, [P0,...,P95] are inserted into every DSP frame PS field
- For each one of DSP frame_0 and DSP frame_1, the generator produces 192 bits PRBS[191:0] that are complemented by zeros to generate the 4–bit PS symbols.
  - These 4–bit PS symbols are mapped to outer symbols of the 16QAM constellation, allowing robust framing to the 16QAM constellation
- The pilot sequence bits are used to synchronize to the each of the two DSP frames and to identify DSP frame_0 and DSP frame_1
  - Note that the first symbol of both PSs is the same



Synchronization state diagrams D0.2





N and M - Synchronization

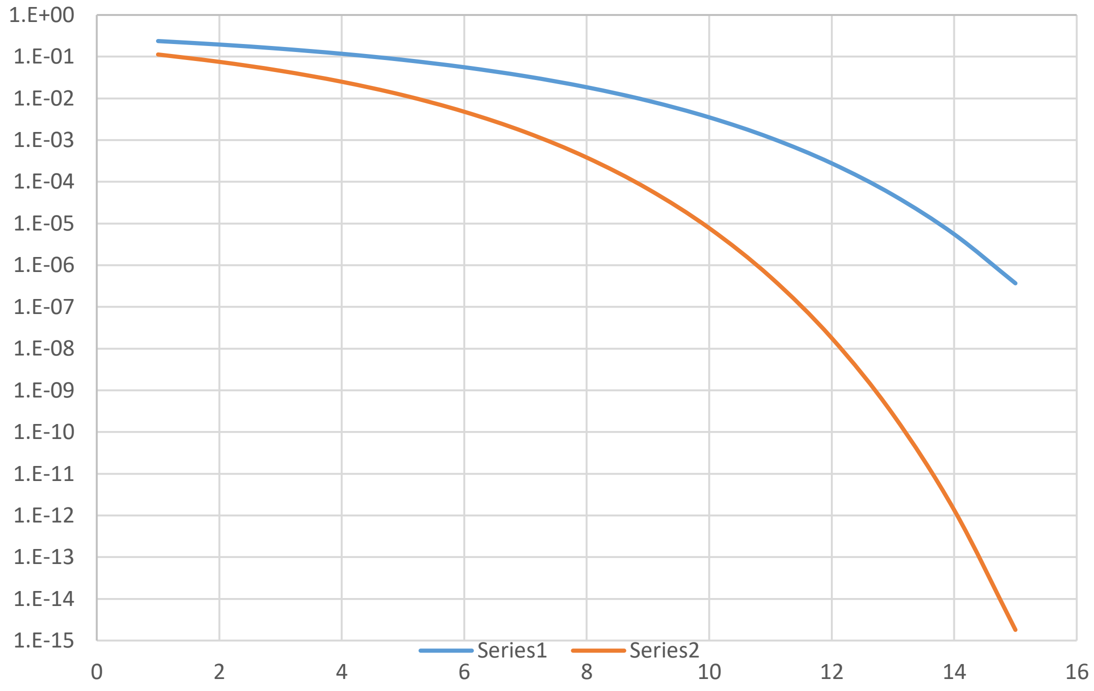
- Method:
  - Scan received symbols
  - Every time a received symbol = P0 wait 64 symbols and verify if it is = P1, and so on
  - Continue until N is reached or verification fails
  - If verification fails test next symbol
- Once start of PS is identified the probability of synchronization for each polarity is:
  - $P_s = (1 - SER)^N$
  - And for the whole signal (2 polarities): $P_{ST} = P_S^2$
- Time to synchronization first try is approximaltely:
  - AvSyT = FrameTime x N + MultiFrameTime/2 + (FrameTime x $\sum_{k=1}^{N-1} \frac{1}{Emul^k}$ + LossTime /$Emul^N$) x 96/2
  - MaxSyT = FrameTime x N + MultiFrameTime + (FrameTime x $\sum_{k=1}^{N-1} \frac{1}{Emul^k}$ + LossTime /$Emul^N$) x 96
  - Emul = 4 for QPSK, Emul = 16 for 16QAM
  - LossTime: Time to lose false synchronization, M dependent
- If we missed synchronization, every new attempt A, will result in:
  - Average: A x MaxSyT + AvSyT
  - Maximum: (A+1) x MaxSyT
- The probability of false synchronization for each polarity is:
  - $P_F = (1/Emul)^N$
  - And for the whole signal (2 polarities): $P_{FT} = P_F^2$

N and M – Synchronization loss

- Once synchronized, the probability of false (due to errors) synchronization-loss for each polarization is:
  - $P_L = SER^M$
  - And for the whole signal (2 polarities): $P_{LT} = 1 - (1-P_L)^2$
- Average false losses per year is (approximately):
  - AvFLYr = P_{LT} x 3600 x 24 x 365 x Baudrate/(M x 64)
  - Years to false loss (YtFL) is the inverse of the above
- The probability of not identifying a false synchronization for each polarity is:
  - $P_{NL} = 1 - (1-1/4)^M$
  - And for the whole signal (2 polarities): $P_{NLT} = P_{NL}^2$
  - Every new verification V, will reduce the probability approximately by: $(P_{NLT})^V$
- Loss time for false synchronization is:
  - LossTime = FrameTime x M x V

Synchronization using QPSK

- SER for 16QAM is: $P_S = 3/4 \times \text{erfc}(\sqrt{(4xE_b/5xN_o)}/\sqrt{2})$
- SER for QPSK is: $P_S = \text{erfc}(\sqrt{(2xE_b/N_o)}/\sqrt{2})$
- 16QAM SER = $5e^{-2}$
- For the same SNR: QPSK SER ~ $4e^{-3}$
- Note: for 16QAM SER = $1.2e^{-2,}$ QPSK SER ~ $1.4e^{-4}$



N – Selection, Emul = QPSK, SER = $5e^{-2}$, M=6, V=32

N	7	8	9	10	11	12
P_{ST}, A=0	0.999277924	0.999060525	0.99881557	0.998543385	0.998244294	0.997918619
P_{ST}, A=1	0.999467436	0.999277924	0.999060525	0.99881557	0.998543385	0.998244294
AvSyT, A=0 [sec]	0.006412396	0.001603127	0.00040081	0.000100231	2.50866E-05	6.30089E-06
MaxSyT, A=0 [sec]	0.012824788	0.003206249	0.000801615	0.000200457	5.01675E-05	1.25956E-05
AvSyT, A=1 [sec]	0.019237184	0.004809376	0.001202425	0.000300688	7.52541E-05	1.88965E-05
MaxSyT, A=1 [sec]	0.025649577	0.006412498	0.00160323	0.000400913	0.000100335	2.51912E-05
P_{FT}	3.72529E-09	2.32831E-10	1.45519E-11	9.09495E-13	5.68434E-14	3.55271E-15

SER = $1.2e^{-2}$

N	7	8	9	10	11	12
P_{ST}, A=0	0.999013417	0.998872557	0.998731715	0.998590894	0.998450093	0.998309312
P_{ST}, A=1	0.999999027	0.999998729	0.999998391	0.999998014	0.999997598	0.999997142

M – Selection, Emul = QPSK, SER = $5e^{-2}$

M	4	5	6	7	8	9
P_{LT}	4.5502E-10	1.76718E-12	6.86327E-15	2.66552E-17	1.03522E-19	4.02051E-22
AvFLYr	6930164.27	21531.9659	69.6871341	0.231982905	0.000788341	2.72152E-06
YtFL	1.443E-07	4.64426E-05	0.014349851	4.310662466	1268.486349	367441.4559
P_{NL}, V=29	1.6186E-05	0.000387419	0.003401041	0.015686377	0.046930216	0.103981752
P_{NLT}, V=29	2.6199E-10	1.50094E-07	1.15671E-05	0.000246062	0.002202445	0.010812205
LossTime, V=29 [sec]	6.0047E-08	7.50588E-08	9.00706E-08	1.05082E-07	1.20094E-07	1.35106E-07
P_{NL}, V=30	1.1065E-05	0.000295483	0.002795729	0.013592498	0.042231895	0.096174315
P_{NLT}, V=30	1.2243E-10	8.73101E-08	7.8161E-06	0.000184756	0.001783533	0.009249499
LossTime, V=30 [sec]	6.2118E-08	7.76471E-08	9.31765E-08	1.08706E-07	1.24235E-07	1.39765E-07
P_{NL}, V=31	7.5638E-06	0.000225363	0.002298149	0.011778119	0.038003937	0.088953097
P_{NLT}, V=31	5.7211E-11	5.07887E-08	5.28149E-06	0.000138724	0.001444299	0.007912653
LossTime, V=31 [sec]	6.4188E-08	8.02353E-08	9.62824E-08	1.12329E-07	1.28376E-07	1.44424E-07
P_{NL}, V=32	5.1706E-06	0.000171884	0.001889128	0.01020593	0.034199252	0.082274081
P_{NLT}, V=32	2.6735E-11	2.9544E-08	3.5688E-06	0.000104161	0.001169589	0.006769024
LossTime, V=32 [sec]	6.6259E-08	8.28235E-08	9.93882E-08	1.15953E-07	1.32518E-07	1.49082E-07

SER = $1.2e^{-2}$

M	4	5	6	7	8	9
P_{LT}	7.9051E-16	1.11462E-19	1.57161E-23	2.21597E-27	3.12452E-31	4.40557E-35
AvFLYr	12.0398011	0.00135809	1.59576E-07	1.92858E-11	2.37939E-15	2.98217E-19
YtFL	0.08305785	736.3284641	6266625.226	51851508965	4.20276E+14	3.35326E+18

N and M proposed values

- N = 12, M = 8
- Time to synchronization will be less than 25 µsec with:
  - 99.82% probability under SER = $5e^{-2}$
- Time to False loss:
  - 1268 years for SER = $5e^{-2}$
  - 4.2×10^{14} years for SER = $1.2e^{-2}$

Other option

- The PMD needs to detect the pilot location for its own functions
- The PMD could indicate the pilot location to the Inner FEC sublayer
  - No need for the Inner FEC to detect the pilot location
  - The Inner FEC sublayer needs only to detect the PS value for X/Y I/Q identification
- The PMD sublayer does not have such an indication today
- The Inner FEC synchronization is not independent from the PMD implementation

Thanks