Error Statistics Study for 802.3ck Channels

- a brief study of short-bursts observed

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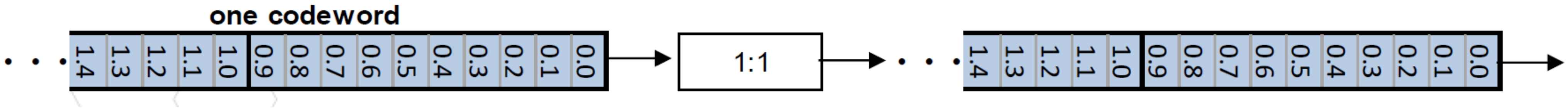
Background

- he_3ck_01a_0119 simulated four different FEC architectures, showing the benefit of symbol interleaving.
  - Case 1 – 1 codeword, 1 lane, direct symbol output
  - Case 2 – 1 codeword, 2 lanes, bit mux
  - Case 3 – 2 codewords, 1 lane, symbol mux
  - Case 4 – 2 codewords, 2 lanes, bit mux
- he_3ck_01a_0319 and he_3ck_01a_0519 analyzed error statistics based on some of the channels recommended in kochuparambil_3ck_01c_0119.
- Simulation was conducted from a higher raw BER down to ~1e-4.
- Error statistics analysis was performed on Case 1, in order to see the behavior of the channel without any data manipulation, and a large amount of short-burst errors were observed (~50% of the time).



- Questions were received on the large number of 2-consecutive symbol errors, and why longer bursts still exists after precoding is turned on.
- We will provide some raw data of the symbol streams with short bursts, and address the cause for longer bursts.

Previous Discussions

Pre-FEC BER HIGH to LOW →

BER_pre = 3.3441E-04		BER_pre = 2.8079E-04		BER_pre = 2.5895E-04		BER_pre = 1.1256E-04	
Burst Probability	49.90%	Burst Probability	49.28%	Burst Probability	49.90%	Burst Probability	52.97%
Uncorrectable CWs	8	Uncorrectable CWs	1	Uncorrectable CWs	2	Uncorrectable CWs	0
Consecutive Errors	Occurrences	Consecutive Errors	Occurrences	Consecutive Errors	Occurrences	Consecutive Errors	Occurrences
1	2565	1	2213	1	1998	1	830
2	1391	2	1200	2	1110	2	642
3	985	3	828	3	756	3	241
4	110	4	80	4	70	4	40
5	61	5	36	5	47	5	10
6	4	6	3	6	4	6	2
7	3	7	3	7	2	7	0
8	0	8	0	8	0	8	0
9	1	9	0	9	1	9	0

From Page 4, he_3ck_01a_0519.

One big concern is the large number of two-consecutive errors.

- As pre-FEC BER goes down to 1e-4, the probability of consecutive errors did not go down.
  - ~50% of total errors were in the form of short bursts.

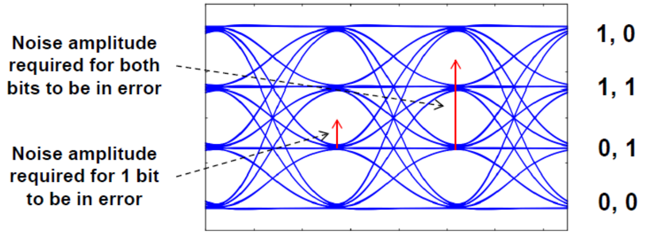
Example Data for Single Errors

Sym #	in	out	Sym #	in	out
1593	-3	-3	197	-3	-3
1594	-1	-1	198	1	1
1595	-1	-1	199	-1	-1
1596	1	1	200	-3	-3
1597	1	1	201	-3	-3
1598	3	3	202	1	1
1599	-1	-1	203	-1	-1
1600	1	1	204	-3	-3
1601	-3	-3	205	3	3
1602	-3	-3	206	-3	-3
1603	-3	**-1**	207	-3	**-1**
1604	3	3	208	3	3
1605	-3	-3	209	-1	-1
1606	3	3	210	3	3
1607	1	1	211	-3	-3
1608	-1	-1	212	3	3
1609	3	3	213	-3	-3
1610	-1	-1	214	3	3
1611	1	1	215	1	1
1612	-3	-3	216	-1	-1
1613	-1	-1	217	1	1

Gray coding

anslow_3ck_01_0918

Assume the use of Gray coding (see IEEE Std 802.3-2018 120.5.7) as illustrated below:



If noise causes any of the 4 levels to be mistaken for an adjacent level, this causes one of the two bits to be in error.

If there is just enough Gaussian noise to cause a BER of 3.8E-4* due to single level errors, then the probability of that noise causing both bits to be in error is 2.8E-23.

This analysis therefore assumes that only one of the two bits is in error.

* FLR = 6.2E-10 (equivalent to BER = 1E-12 with random errors) after RS(544,514) FEC

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- All errors observed in our simulation are single level errors.

Example Data for 2-Symbol Errors

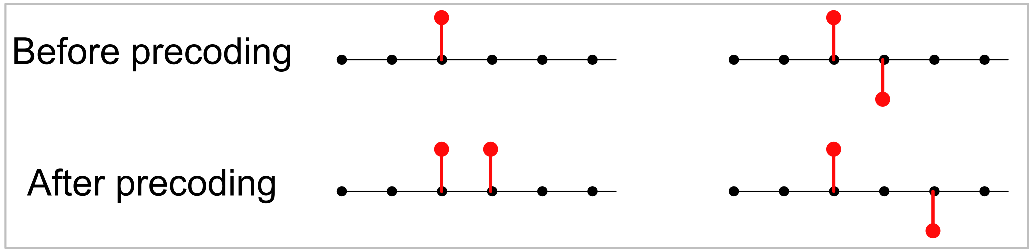
Sym #	in	out	Sym #	in	out	Sym #	in	out	Sym #	in	out	Sym #	in	out	Sym #	in	out	Sym #	in	out
1327	1	1	485	-1	-1	1095	3	3	1684	-1	-1	1919	-1	-1	1866	3	3	1142	-1	-1
1328	-1	-1	486	-1	-1	1096	1	1	1685	-3	-3	1920	1	1	1867	-1	-1	1143	-1	-1
1329	1	1	487	3	3	1097	-3	-3	1686	-1	-1	1921	1	1	1868	3	3	1144	1	1
1330	-1	-1	488	-1	-1	1098	1	1	1687	-1	-1	1922	3	3	1869	-1	-1	1145	3	3
1331	3	3	489	-1	-1	1099	-1	-1	1688	-1	-1	1923	3	3	1870	-1	-1	1146	1	1
1332	-3	-3	490	-1	-1	1100	-3	-3	1689	-3	-3	1924	-3	-3	1871	3	3	1147	3	3
1333	-3	-3	491	1	1	1101	1	1	1690	-1	-1	1925	-1	-1	1872	3	3	1148	-3	-3
1334	-3	-3	492	-3	-3	1102	1	1	1691	-1	-1	1926	-3	-3	1873	-1	-1	1149	-3	-3
1335	-1	-1	493	1	1	1103	-3	-3	1692	-3	-3	1927	3	3	1874	-3	-3	1150	-3	-3
1336	3	3	494	3	3	1104	3	3	1693	-3	-3	1928	-3	-3	1875	3	3	1151	-3	-3
1337	-3	**-1**	495	1	**-1**	1105	-1	**-3**	1694	1	**3**	1929	1	**3**	1876	-1	**-3**	1152	-3	**-1**
1338	-1	**-3**	496	-3	**-1**	1106	-3	**-1**	1695	1	**-1**	1930	3	**1**	1877	-3	**-1**	1153	1	**-1**
1339	3	3	497	3	3	1107	1	1	1696	-3	-3	1931	-3	-3	1878	3	3	1154	3	3
1340	-1	-1	498	-1	-1	1108	-3	-3	1697	-3	-3	1932	-1	-1	1879	-3	-3	1155	-1	**-3**
1341	-3	-3	499	3	3	1109	3	3	1698	-3	-3	1933	-3	-3	1880	3	3	1156	-1	-1
1342	-1	**-3**	500	1	1	1110	3	**1**	1699	3	3	1934	3	3	1881	3	3	1157	-3	-3
1343	3	3	501	1	1	1111	-3	**-1**	1700	1	1	1935	3	3	1882	-1	-1	1158	-3	-3
1344	-3	-3	502	-3	-3	1112	3	3	1701	-1	-1	1936	3	3	1883	1	1	1159	1	1
1345	3	3	503	3	3	1113	-3	-3	1702	-3	-3	1937	3	3	1884	1	1	1160	3	3
1346	3	3	504	1	1	1114	3	3	1703	-3	-3	1938	-3	-3	1885	-1	-1	1161	3	3
1347	-1	-1	505	1	1	1115	1	1	1704	3	3	1939	-3	-3	1886	-1	-1	1162	3	3

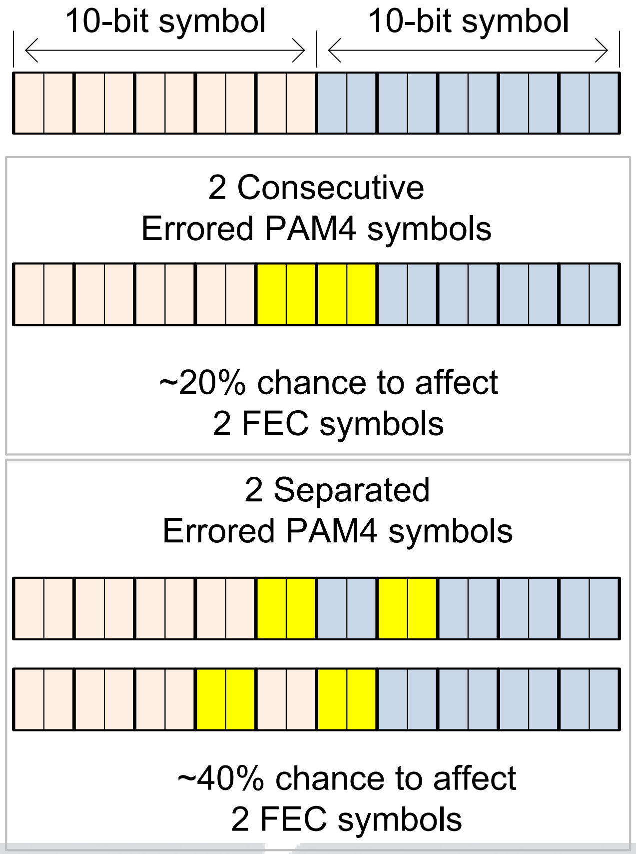
- The table above shows some sections of the input PAM4 symbol streams that suffered 2-consecutive errors.
- Low weight DFE could cause these errors, but there could be other sources like crosstalk, jitter, etc…

Precoding Effect on Single and Short Bursts

- Precoding could not help single or two errors in a row.
  - Precoding will turn single error into two.
  - Precoding will turn two-consecutive errors into two separate errors.

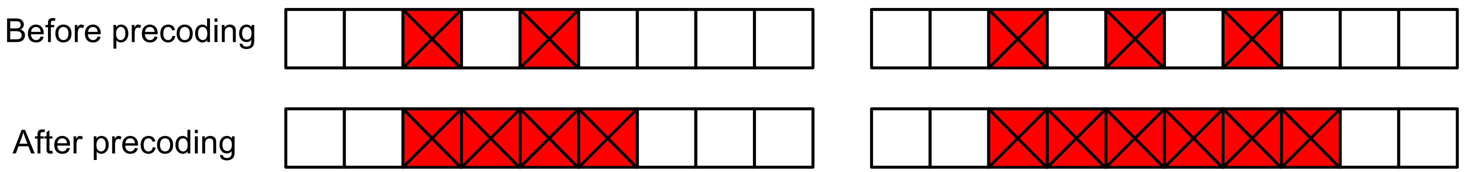
- Effect on FEC symbol errors
  - Under Case 1 situation, assuming PAM 4 symbols and FEC symbols are aligned for easier analysis.
  - Two consecutive PAM4 symbol errors could affect two FEC symbols, the chance is 20%.
  - Two PAM4 symbol errors separated by one correct PAM4 symbol have a higher chance to affect two FEC symbls.





Cause for Longer Bursts

- **Another question raised is why there are bursts as long as 6 after precoding is turned on.**
- **Closely located separated errors could cause longer consecutive errors after precoding.**
  - For example, 2 separated errors could become 3 consecutive errors after precoding.
  - Similarly, 3 separated errors could become 6 consecutive errors.



  - There are more complicated combinations of error patterns that could generate different length of consecutive errors.

- **Not all errors are following the continuous zig-zag pattern which can be effectively cleared by precoding.**

Summary

- Error statistics were further displayed, showing some example raw data flow running through the channels where errors occurred.

- The cause for longer bursts after precoding is briefly explained.

Thank you