Error Statistics Analysis on Cable and Backplane Channels

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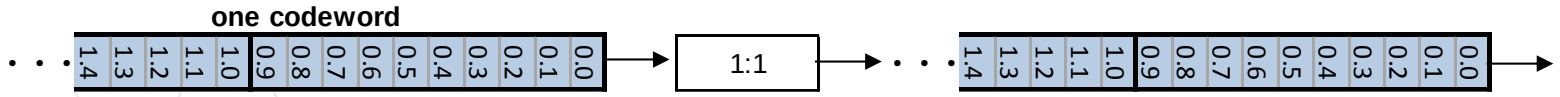
Introduction

- 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 analyzed error statistics based on one of the channels recommended in kochuparambil_3ck_01c_0119 ("CaBP_BGAVia_Opt2_28dB" from mellitz_3ck_adhoc_02_081518).
- As requested, we continued the work to a lower BER region on this channel, and tested how precoding may help in high-BER cases.
- We added simulation results for another recommended channel:
  - "Cable_BKP_28dB_0p575m_more_isi" from heck_3ck_01_1118.
- Error statistics analysis was performed on Case 1, to see how often consecutive errors occur on the channel and how long they may last.

Simulation Setup

- Two 28dB channels were simulated so far:
  - CH #1: CaBP_BGAVia_Opt2_28dB
  - CH #2: Cable_BKP_28dB_0p575m_more_isi
- **TX side:**
  - Matlab environment generates the RS(544,514) FEC codewords;
  - Modulates the signal stream and sends them over channels with insertion loss and cross talk.
- **RX side:**
  - ADC-based SerDes model
  - CTLE + long FFE + 1-tap DFE (tap value ~0.3)
- At least 5000 codewords per encoder is simulated for error statistics analysis in this presentation.
  - Simulations were based on Case 1 to study the error statistics in the channel under test.



Simulation Results – CH #1 to a lower BER region

- As BER goes lower to 1E-4, there is no sign of “probability of consecutive errors” going down.
  - Please refer to previous results (Page 10) to see higher BER cases.

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

Simulation Results – CH #1 with Precoding ON

- Precoding did help, lowering pre FEC BER and burst probability.
  - It did not clear longer burst cases though.
  - At Lower BER level, the burst probability is still high ~48.5%
- It is more effective at higher BER levels, as expected.

HIGH BER CASE			
Precoding OFF		Precoding ON	
BER_pre = 2.8079E-04		BER_pre = 2.2581E-04	
Burst Probability	**49.28%**	**Burst Probability**	**41.99%**
Consecutive Errors	**Occurrences**	**Consecutive Errors**	**Occurrences**
1	2213	1	2158
2	1200	2	881
3	828	3	554
4	80	4	84
5	36	5	37
6	3	6	3
7	3	7	3
8	0	8	0

LOW BER CASE			
Precoding OFF		Precoding ON	
BER_pre = 1.1256E-04		BER_pre = 1.0638E-4	
Burst Probability	**52.97%**	**Burst Probability**	**48.49%**
Consecutive Errors	**Occurrences**	**Consecutive Errors**	**Occurrences**
1	830	1	902
2	642	2	622
3	241	3	180
4	40	4	30
5	10	5	15
6	2	6	2
7	0	7	0
8	0	8	0

Simulation Results – CH #2 to a lower BER region

- This is another highlighted channel recommended for further study.
- Burst probability is also around 50%.
  - Even at 1.1569E-4 pre-FEC BER, there was still 1 uncorrectable codeword among 5000 codewords simulated.

BER_pre = 2.1898E-04		BER_pre = 1.1569e-04		BER_pre = 1.0660e-04	
Burst Probability	50.27%	Burst Probability	51.27%	Burst Probability	48.00%
Uncorrectable CWs	0	Uncorrectable CWs	1	Uncorrectable CWs	0
Consecutive Errors	Occurrences	Consecutive Errors	Occurrences	Consecutive Errors	Occurrences
1	1644	1	847	1	886
2	945	2	509	2	518
3	523	3	281	3	237
4	136	4	68	4	43
5	45	5	31	5	17
6	10	6	1	6	2
7	1	7	1	7	1
8	2	8	0	8	0

Source of Burst Errors

- It was proven that multi-tap DFE could cause burst errors.
  - It is NOT the only source of burst errors.

- In our case we saw high rate of burst errors within limited length of symbol streams, despite of 1-tap DFE architecture with low tap value.

Summary

- **Burst errors exist regardless of receiver architecture**
  - Whenever an error occurs, half of the time it will last more than 1 PAM4 symbol.
  - Bursts as long as 16 were observed in other channels simulated.
    - Longer simulations will exhibits even longer bursts.
  - DFE taps is only one cause for burst errors.

- **With 1:1 FEC symbol direct output, we observed uncorrectable codewords at low pre-FEC BER.**

THANK YOU

Backup

Previous results

he_3ck_01a_0119, CaBP_BGAVia_Opt2_28dB

BER_pre = 5.4334E-4	
Burst Probability	49.66%
Uncorrectable CWs	19
Consecutive Errors	Occurrences
1	4196
2	2345
3	1448
4	209
5	113
6	15
7	8
8	1
9	0

BER_pre = 4.2836E-4	
Burst Probability	49.33%
Uncorrectable CWs	9
Consecutive Errors	Occurrences
1	3352
2	1857
3	1156
4	158
5	79
6	10
7	4
8	0
9	0

BER_pre = 3.8419E-4	
Burst Probability	49.35%
Uncorrectable CWs	10
Consecutive Errors	Occurrences
1	3018
2	1700
3	1025
4	134
5	73
6	4
7	3
8	0
9	1

Additional Results for Other Channels

BER_pre = 3.4220E-04*	
Burst Probability	51.14%
Uncorrectable CWs	29
Consecutive Errors	Occurrences
1	4509
2	2701
3	1002
4	282
5	371
6	153
7	88
8	44
9	34
10	16
11	7
12	13
13	3
14	1
15	4
16	1

- **Bch2_a7p5_7_t**
  - Channel suffers ILD
  - Did not run to a lower BER level