Transcoding/FEC Options and Trade-offs for 100 Gb/s Backplane and Copper Cable

IEEE 802.3bj Task Force

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Motivation

- Reed-Solomon (RS) code words and transcoded blocks are assumed to extend across all four physical lanes to reduce latency
- There are various trade-offs for selecting a transcoding (TC) and FEC scheme
  - Total latency
  - Random and burst error correction capability
  - Overclocking
  - Ease of implementation
  - Factors affecting performance
- Investigate selected TC and FEC options for 100 Gb/s backplane and copper cable and discuss pros and cons of various options by considering trade-offs involved
- Presentation aims at facilitating the selection of a TC and FEC scheme by the IEEE P802.3bj Task Force

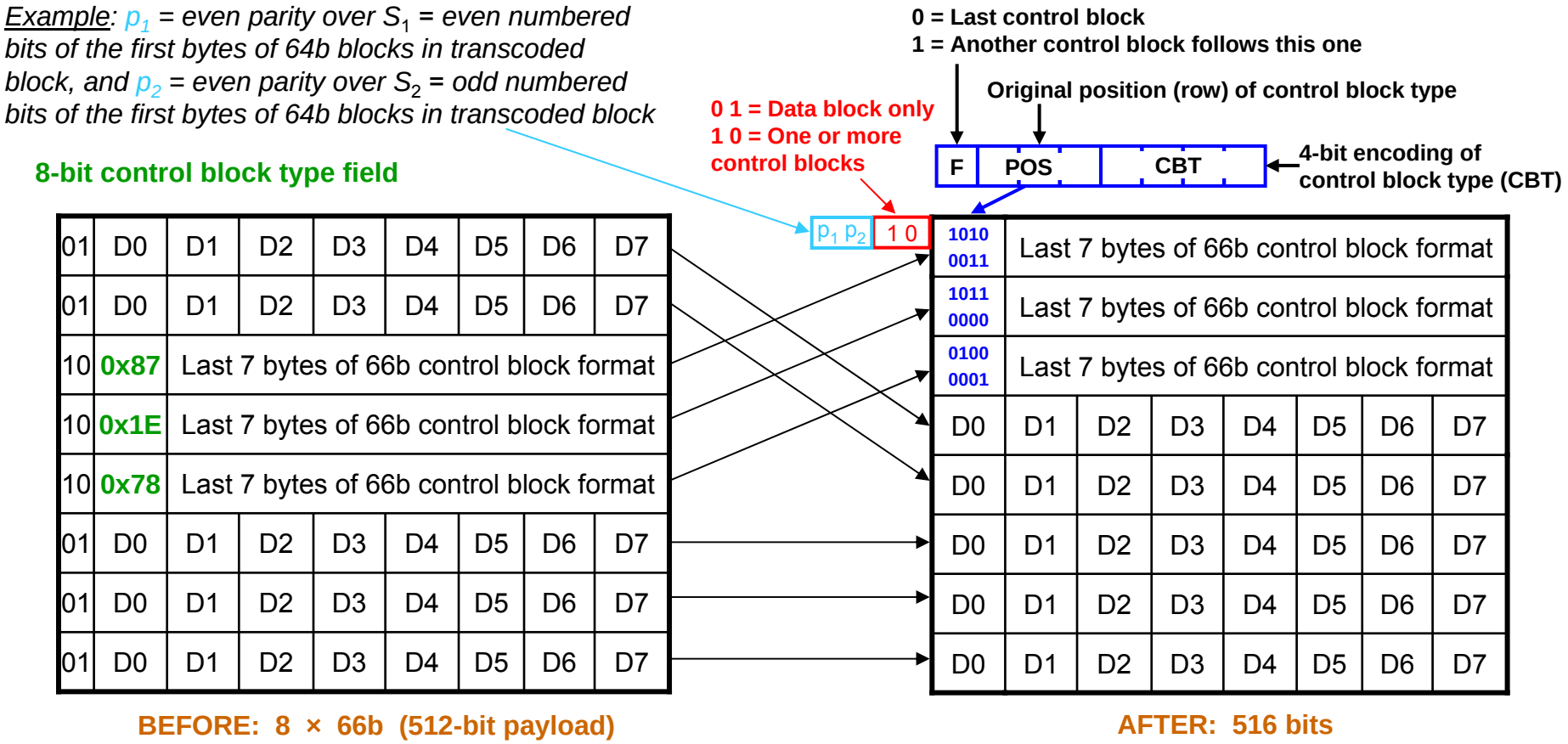
Trade-offs for Selecting Transcoding and FEC Scheme

- *Total latency* where RS decoding latency is the main contributor to total latency, e.g., 50 ns – 100 ns
- *Random and burst error correction capability* determined by RS correction power t and symbol size m
  - correct ≤ t random symbol errors
  - correct ≤ (t – 1) random symbol errors, 1-symbol decoding margin to reduce miscorrection probability and MTTFPA
  - correct cross-lane correlated c-bit burst errors where 1) c ≤ m+1 and 2) t=8 or t=9 w/ 1-symbol decoding margin
  - correct cross-lane correlated c-bit burst errors where 1) c ≤ 2m+1 and 2) t=12 or t=13 w/ 1-symbol decoding margin
- *Overclocking*
  - 0% overclocking: line rate = 25.78125 Gb/s, clock frequency = 165 fc where fc=10 GHz/64=156.25 MHz
  - 3% overclocking: line rate = 26.56250 Gb/s, clock frequency = 170 fc
- *Ease of implementation*
  - integer reference clock multiplier (RCM), e.g., 165 or 170
  - padding to an integer RCM ➔ Note: not all fractional RCM can be padded to the nearest integer
  - avoiding header bit rotation, e.g., 512b/516b transcoding
  - satisfying alignment criterion (AC) in gustlin_02a_0511 vs. insertion of sync patterns
- *Factors affecting performance*
  - protection of header bit and control block type (CBT) can impact mean time to false packet acceptance (MTTFPA)
  - data/parity striping can impact error correction performance as in gustlin_02_0911.pdf

Transcoding Schemes

- 512b/513b TC for 100 Gb/s backplane and copper cable: cideciyan_01a_0911.pdf
- 512b/514b TC has header protection similar to 64b/66b coding [1]
- 512b/516b TC w/ header protection and 2-bit parity p_1 and p_2 over a set of transcoded bits S_1 and S_2

Example: p_1 = even parity over S_1 = even numbered bits of the first bytes of 64b blocks in transcoded block, and p_2 = even parity over S_2 = odd numbered bits of the first bytes of 64b blocks in transcoded block



[1] Teshima et al. "Bit-Error-Tolerant (512*N)B/(513*N+1)B Code for 40Gb/s and 100Gb/s Ethernet Transport", INFOCOM 2008.

Selected Transcoding and FEC Schemes

RCM = Reference Clock multiplier

- 512b/513b transcoding, 0% overclocking w/ RCM = 165
  - RS(468,456), m=9, t=6
  - RS(528,513), m=10, t=7
  - RS(632,616), m=10, t=8
- 512b/514b transcoding, 0% overclocking w/ RCM = 165
  - RS(528,514), m=10, t=7 *
- 512b/516b transcoding, 0% overclocking w/ RCM = 165
  - RS(528,516), m=10, t=6
- 512b/513b transcoding, 0.6% overclocking w/ RCM = 165 15/16
  - RS(472,456), m=9, t=8
- 512b/514b transcoding, 0.6% overclocking w/ RCM = 166
  - RS(531,514), m=10, t=8 or RS(530,514), m=10, t=8

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Selected Transcoding and FEC Schemes (cont.)

- 512b/513b transcoding, 3% overclocking w/ RCM = 170
  - RS(544,513), m=10, t=15
  - RS(482,456), m=9, t=13
- 512b/514b transcoding, 3% overclocking w/ RCM = 170
  - RS(544,514), m=10, t=15
  - RS(272,257), m=10, t=7
  - RS(302,286), m=9, t=8
- 512b/516b transcoding, 3% overclocking w/ RCM = 170
  - RS(544,516), m=10, t=14
  - RS(272,258), m=10, t=7

Assumptions for transcoding and FEC schemes considered:

1) RS code words and transcoded blocks extend across all four physical lanes to reduce latency

2) TL = Total latency ~ Transcoding latency + 2x FEC block latency

Transcoding and FEC Schemes – 0% Overclocking

- 512b/513b transcoding, 0% overclocking, RS(468,456), m=9, t=6
  - Pro: TL=87 ns, data/parity symbols not split, RCM=165, satisfies AC
  - Con: t=6, does not correct cross-lane correlated bursts, header bit rotation
- 512b/516b transcoding, 0% overclocking, RS(528,516), m=10, t=6
  - Pro: data/parity symbols not split, RCM=165, satisfies AC, no header bit rotation, header/CBT protection
  - Con: TL=108 ns, t=6, does not correct cross-lane correlated bursts
- 512b/514b transcoding, 0% overclocking, RS(528,514), m=10, t=7
  - Pro: t=7, data/parity symbols not split, RCM=165, satisfies AC
  - Con: TL=108 ns, does not correct cross-lane correlated bursts, header bit rotation, no CBT protection
- 512b/513b transcoding, 0% overclocking, RS(528,513), m=10, t=7
  - Pro: t=7, data/parity symbols not split, RCM=165, satisfies AC, improved code distance (miscorr. prob.)
  - Con: TL=108 ns, does not correct cross-lane correlated bursts, header bit rotation, no header/CBT protection
- 512b/513b transcoding, 0% overclocking, RS(632,616), m=10, t=8
  - Pro: t=8, corrects cross-lane correlated 11-bit bursts, data/parity symbols not split, RCM=165
  - Con: TL=128 ns, header bit rotation, no header/CBT protection, does not satisfy AC

Transcoding and FEC Schemes – 0.6% Overclocking

- 512b/513b transcoding, 0.6% overclocking, RS(472,456), m=9, t=8
  - Pro: TL=87 ns, t=8, corrects cross-lane correlated 10-bit bursts, data/parity symbols not split, satisfies AC
  - Con: header bit rotation, no header/CBT protection, RCM=165 15/16
- 512b/514b transcoding, 0.6% overclocking, RS(530,514), m=10, t=8
  - Pro: t=8, corrects cross-lane correlated 11-bit bursts, parity symbols not split, RCM=166, satisfies AC, header protection
  - Con: TL=108 ns, header bit rotation, no CBT protection, data symbols split

Transcoding and FEC Schemes – 3% Overclocking

- 512b/514b transcoding, 3% overclocking, RS(544,514), m=10, t=15
  - Pro: corrects cross-lane correlated 21-bit bursts, data/parity symbols not split, RCM=170, satisfies AC
  - Con: TL=107 ns, header bit rotation, no CBT protection
- 512b/513b transcoding, 3% overclocking, RS(544,513), m=10, t=15
  - Pro: corrects cross-lane correlated 21-bit bursts, data/parity symbols not split, RCM=170, satisfies AC, improved code distance (miscorr. prob.)
  - Con: TL=107 ns, header bit rotation, no CBT protection, no header protection
- 512b/516b transcoding, 3% overclocking, RS(544,516), m=10, t=14
  - Pro: corrects cross-lane correlated 21-bit bursts, data/parity symbols not split, RCM=170, satisfies AC, no header bit rotation, header/CBT protection
  - Con: TL=107 ns
- 512b/513b transcoding, 3% overclocking, RS(482,456), m=9, t=13
  - Pro: TL=87 ns, corrects cross-lane correlated 19-bit bursts, data symbols not split, RCM=170, satisfies AC
  - Con: parity symbols split, header bit rotation, no header/CBT protection
- 512b/514b transcoding, 3% overclocking, RS(302,286), m=9, t=8
  - Pro: TL=56 ns, parity symbols not split, RCM=170, satisfies AC, header protection
  - Con: t=8, corrects cross-lane correlated 10-bit bursts, data symbols split, header bit rotation, no CBT protection

Code Search for RS(n,k,t) over GF(2^m) – Setup

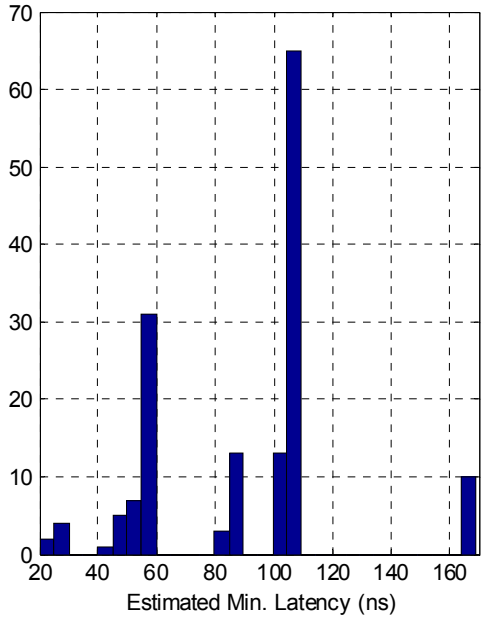
- Search for possible codes of the form RS(n,k,t) over GF(2^m)
  - Parameter space: k = 64:720, t = 4:16, m = 8:12,
    transcoding = { 64b/65b, 512b/513b, 512b/514b, 512b/516b}, NRZ signaling
  - Alignment marker criteria satisfied
  - Code can be padded to the nearest integer multiple of a 156.25MHz reference clock
  - FEC block size divisible by 4
  - FEC message contains an integer number of transcoded blocks
  - Clocking overhead ≤ 6%
- Latency estimates
  - Estimate #1: (2x – 3x)*FEC block latency *(bhoja_01_0911.pdf and cideciyan_01_0911.pdf)*
  - Estimate #2: FEC block latency + (2t + n/p + 2) cycles *(wang_01_0511.pdf)*
  - Add latency for 512b/51xb transcoding: 512b block latency for TX + 2 cycles latency for RX
- Results
  - 154 possible choices meet criteria
  - Metrics computed:
    - Random error coding gain
    - Burst error coding gain (1-tap DFE model with H1=1)
    - Total Coding Gain TCG (36dB channel loss at 0% over-clocking, at BER=1e-15)

Code Search for RS(n,k,t) over GF(2^m) – Results

Total Coding Gain	Estimated Latency (min. ns)	Estimated Latency (max. ns)	t	n	k	m	Padded Clk Rate	Raw Clk Rate	Random Coding Gain	Burst Coding Gain	Overhead IL Penalty	Trans code In	Trans code Out	Comments
5.79	82	123	16	448	416	10	175	175.000	7.33	6.88	-1.09	64	65	Best 64b/65b – best overall
5.71	87	128	15	372	342	12	175	174.375	7.22	6.80	-1.09	512	513	Best 512b/513b
5.57	87	128	14	372	344	12	175	174.375	7.10	6.66	-1.09	512	516	Best 514b/516b
5.21	56	81	11	280	257	10	175	175.000	6.94	6.30	-1.09	512	514	Best 512b/514b
5.83	107	158	16	462	430	12	174	173.250	7.20	6.81	-0.98	512	516	Best 512b/516b – best overall
5.28	56	82	11	308	285	9	174	173.250	6.94	6.27	-0.98	512	513	Best 512b/513b
5.10	56	82	10	278	257	10	174	173.750	6.76	6.08	-0.98	512	514	Best 512b/514b
4.83	51	77	9	278	260	10	174	173.750	6.55	5.81	-0.98	64	65	Best 64b/65b
5.89	102	154	16	552	520	10	173	172.500	7.20	6.76	-0.87	64	65	Best 64b/65b – best overall
5.81	107	158	15	460	430	12	173	172.500	7.09	6.69	-0.87	512	516	Best 512b/516b
4.94	56	82	9	276	257	10	173	172.500	6.56	5.82	-0.87	512	514	Best 512b/514b
6.00	107	158	16	548	516	10	172	171.250	7.20	6.76	-0.76	512	516	Best 512b/516b – best overall
5.87	102	154	15	550	520	10	172	171.875	7.09	6.63	-0.76	64	65	Best 64b/65b
4.76	56	82	8	274	257	10	172	171.250	6.33	5.53	-0.76	512	514	Best 512b/514b
6.11	107	158	16	546	513	10	171	170.625	7.21	6.77	-0.65	512	513	Best 512b/513b – best overall
6.11	107	158	16	546	514	10	171	170.625	7.21	6.77	-0.65	512	514	Best 512b/514b
5.98	107	158	15	546	516	10	171	170.625	7.10	6.64	-0.65	512	516	Best 512b/516b
5.69	102	154	13	546	520	10	171	170.625	6.85	6.35	-0.65	64	65	Best 64b/65b
6.09	107	158	15	544	513	10	170	170.000	7.10	6.64	-0.55	512	513	Best 512b/513b – best overall
6.09	107	158	15	544	514	10	170	170.000	7.10	6.64	-0.55	512	514	Best 512b/514b
5.96	107	158	14	544	516	10	170	170.000	6.98	6.50	-0.55	512	516	Best 512b/516b
5.64	102	154	12	544	520	10	170	170.000	6.71	6.18	-0.55	64	65	Best 64b/65b
5.92	107	158	13	540	513	10	169	168.750	6.86	6.35	-0.44	512	513	Best 512b/513b – best overall
5.92	107	158	13	540	514	10	169	168.750	6.86	6.35	-0.44	512	514	Best 512b/514b
5.75	107	158	12	538	513	10	169	168.125	6.72	6.19	-0.44	512	513	Best 512b/513b
5.35	102	154	10	540	520	10	169	168.750	6.40	5.79	-0.44	64	65	Best 64b/65b
5.67	107	158	11	536	513	10	168	167.500	6.57	6.00	-0.33	512	513	Best 512b/513b – best overall
5.67	107	158	11	536	514	10	168	167.500	6.57	6.00	-0.33	512	514	Best 512b/514b
5.46	107	158	10	536	516	10	168	167.500	6.40	5.79	-0.33	512	516	Best 512b/516b
4.95	102	154	8	536	520	10	168	167.500	6.01	5.28	-0.33	64	65	Best 64b/65b
5.57	107	159	10	534	513	10	167	166.875	6.41	5.79	-0.22	512	513	Best 512b/513b – best overall
5.57	107	159	10	534	514	10	167	166.875	6.41	5.79	-0.22	512	514	Best 512b/514b
5.33	107	159	9	534	516	10	167	166.875	6.22	5.55	-0.22	512	516	Best 512b/516b
4.72	102	154	7	534	520	10	167	166.875	5.76	4.94	-0.22	64	65	Best 64b/65b
5.18	107	159	8	530	513	10	166	165.625	6.01	5.28	-0.11	512	513	Best 512b/513b – best overall
5.18	107	159	8	530	514	10	166	165.625	6.01	5.28	-0.11	512	514	Best 512b/514b
4.83	107	159	7	530	516	10	166	165.625	5.77	4.94	-0.11	512	516	Best 512b/516b
3.94	102	154	5	530	520	10	166	165.625	5.14	4.05	-0.11	64	65	Best 64b/65b
5.66	169	251	10	704	684	12	165	165.000	6.17	5.66	0.00	512	513	512b/513b – latency >> 100ns
5.18	169	251	8	704	688	12	165	165.000	5.80	5.18	0.00	512	516	512b/516b – latency >> 100ns
4.94	107	159	7	528	513	10	165	165.000	5.77	4.94	0.00	512	513	Best 512b/513b – best overall
4.94	107	159	7	528	514	10	165	165.000	5.77	4.94	0.00	512	514	Best 512b/514b
4.59	107	159	6	528	516	10	165	165.000	5.48	4.59	0.00	512	516	Best 512b/516b
3.51	102	154	4	528	520	10	165	165.000	4.72	3.51	0.00	64	65	Best 64b/65b

Code Search for RS(n,k,t) over GF(2^m) – Observations (1/2)

- No 0% overhead codes exist with t ≥ 8
  - t = 8 code exists with 0.6% clocking overhead
- RS(528,514,t=7), GF(2^{10}), 512b/514b proposal* is the best 0% overclocking
- No GF(2^8) codes exist with t > 5
  - RS(140,130,t=5), GF(2^8), 64b/65b, TCG ~ 3.11dB, 6% overclocking
- Latency estimate #1: clusters into 4 groups
  - <~60ns, ~80ns, ~100ns, >>100ns
- ~100ns latency: 3% overclocking looks best
- ~80ns latency: 6% overclocking offers more options
  - RS(362,344,t=9), GF(2^{12}), 512b/516b, 3% overclocking, TCG ~ 5.15dB is an option
- < 60ns latency: 6% overclocking looks best



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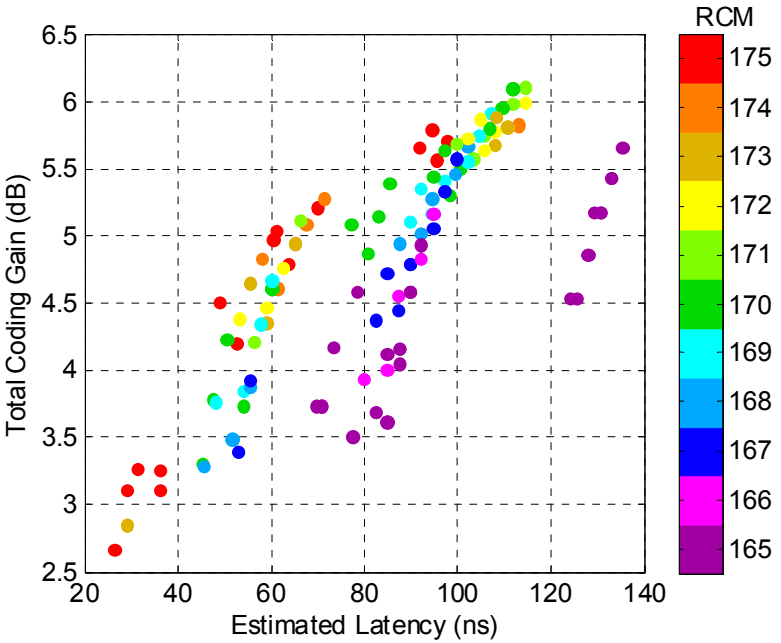
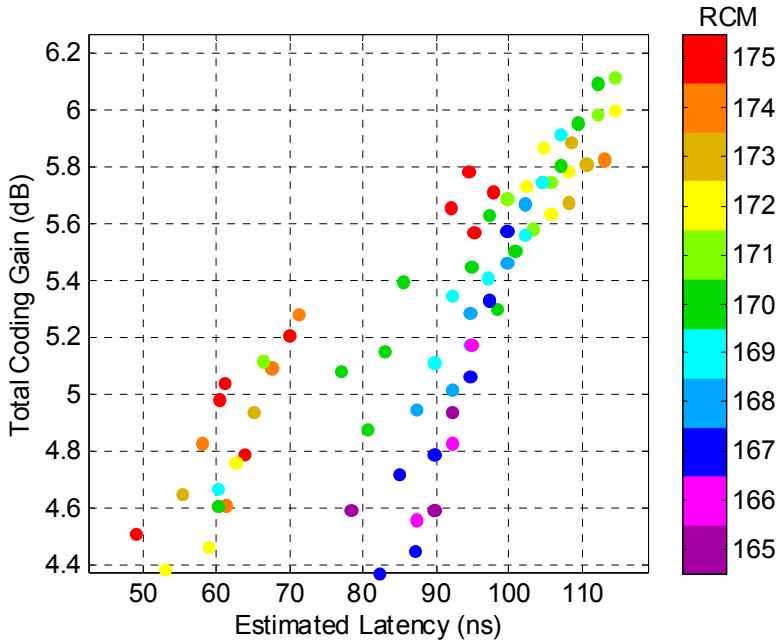
Code Search for RS(n,k,t) over GF(2^m) – Observations (2/2)

- Latency estimate #2
  - Impact of t on latency included explicitly → better view of code strength vs. latency
  - Now see results fall into three broad clusters
    - Latency > 120ns with strong TCG and 0% overclocking
    - Latency 80 – 100 ns with strong TCG and 0.6% – 6% overclocking

      Relaxing limit to ~110ns could buy ~0.5dB TCG with 3% overclocking
    - Latency < 80ns with very good TCG and 4% – 6% overclocking





Summary

- Introduced a new transcoding scheme 512b/516b to avoid header bit rotation and to increase MTTFPA by providing additional protection to a preselected set of transcoded bits
- Discussed selected transcoding and FEC schemes and the trade-offs involved in terms of latency, random error correction capability, overclocking, ease of implementation and factors affecting performance
- Padded encoded data such that a fractional reference clock multiplier becomes an integer equal to the ceiling of the fractional reference clock multiplier whenever possible
- Correction of burst errors correlated across four physical lanes
  - achievable at 0% overclocking for a total latency > 100 ns
  - achievable at 0.6% overclocking for a total latency < 100 ns
  - achievable at 3% overclocking for a total latency ~ 60 ns
- Searched for codes to explore trade-offs between latency, overclocking and error correction power

802.3bj Task Force must agree on 1) max. latency

2) max. overclocking

3) min. error correction capability

Backup

RS(n,k,t), GF(2^m) Code Options – Results (latency 40ns – 60ns)

Total Coding Gain	Estimated Latency (min. ns)	Estimated Latency (max. ns)	t	n	k	m	Padded Clk Rate	Raw Clk Rate	Random Coding Gain	Burst Coding Gain	Overhead IL Penalty	Trans code In	Trans code Out	Comments
5.21	56	81	11	280	257	10	175	175.000	6.94	6.30	-1.09	512	514	Best 512b/514b
5.21	56	81	11	280	258	10	175	175.000	6.94	6.30	-1.09	512	516	
5.04	46	66	10	248	228	9	175	174.375	6.88	6.13	-1.09	512	513	
4.98	51	77	10	280	260	10	175	175.000	6.75	6.07	-1.09	64	65	
4.79	56	81	9	233	215	12	175	174.750	6.55	5.88	-1.09	512	516	
4.51	41	61	8	224	208	10	175	175.000	6.43	5.60	-1.09	64	65	
4.21	46	66	7	186	171	12	175	174.375	6.16	5.30	-1.09	512	513	
4.21	46	66	7	186	172	12	175	174.375	6.16	5.30	-1.09	512	516	
5.28	56	82	11	308	285	9	174	173.250	6.94	6.27	-0.98	512	513	Best 512b/513b
5.10	56	82	10	278	257	10	174	173.750	6.76	6.08	-0.98	512	514	Best 512b/514b
5.10	56	82	10	278	258	10	174	173.750	6.76	6.08	-0.98	512	516	
4.83	51	77	9	278	260	10	174	173.750	6.55	5.81	-0.98	64	65	Best 64b/65b
4.61	56	82	8	231	215	12	174	173.250	6.32	5.59	-0.98	512	516	
4.61	56	82	8	232	215	12	174	174.000	6.32	5.59	-0.98	512	516	
4.94	56	82	9	276	257	10	173	172.500	6.56	5.82	-0.87	512	514	Best 512b/514b
4.94	56	82	9	276	258	10	173	172.500	6.56	5.82	-0.87	512	516	
4.65	51	77	8	276	260	10	173	172.500	6.33	5.52	-0.87	64	65	
4.36	56	82	7	230	215	12	173	172.500	6.06	5.23	-0.87	512	516	
4.76	56	82	8	274	257	10	172	171.250	6.33	5.53	-0.76	512	514	Best 512b/514b
4.76	56	82	8	274	258	10	172	171.250	6.33	5.53	-0.76	512	516	
4.47	56	82	7	229	215	12	172	171.750	6.06	5.23	-0.76	512	516	
4.39	51	77	7	274	260	10	172	171.250	6.06	5.15	-0.76	64	65	
5.12	56	82	9	304	285	9	171	171.000	6.56	5.77	-0.65	512	513	
4.21	56	82	6	227	215	12	171	170.250	5.76	4.87	-0.65	512	516	
4.21	56	82	6	228	215	12	171	171.000	5.76	4.87	-0.65	512	516	
4.61	56	82	7	272	257	10	170	170.000	6.07	5.16	-0.55	512	514	
4.61	56	82	7	272	258	10	170	170.000	6.07	5.16	-0.55	512	516	
4.24	51	77	6	272	260	10	170	170.000	5.76	4.78	-0.55	64	65	
3.79	46	66	5	181	171	12	170	169.688	5.48	4.33	-0.55	512	513	
3.73	56	82	5	226	215	12	170	169.500	5.39	4.28	-0.55	512	516	
3.31	46	66	4	181	172	12	170	169.688	5.01	3.86	-0.55	512	516	
4.67	56	82	7	300	285	9	169	168.750	6.07	5.11	-0.44	512	513	
4.35	56	82	6	270	257	10	169	168.750	5.76	4.79	-0.44	512	514	
4.35	56	82	6	270	258	10	169	168.750	5.76	4.79	-0.44	512	516	
3.84	56	82	5	225	215	12	169	168.750	5.39	4.28	-0.44	512	516	
3.77	51	77	5	270	260	10	169	168.750	5.39	4.21	-0.44	64	65	
3.88	56	82	5	268	257	10	168	167.500	5.39	4.21	-0.33	512	514	
3.88	56	82	5	268	258	10	168	167.500	5.39	4.21	-0.33	512	516	
3.49	56	82	4	223	215	12	168	167.250	4.94	3.82	-0.33	512	516	
3.49	56	82	4	224	215	12	168	168.000	4.94	3.82	-0.33	512	516	
3.29	51	77	4	268	260	10	168	167.500	4.94	3.62	-0.33	64	65	
3.93	56	82	5	296	285	9	167	166.500	5.40	4.15	-0.22	512	513	
3.40	56	82	4	266	257	10	167	166.250	4.94	3.62	-0.22	512	514	
3.40	56	82	4	266	258	10	167	166.250	4.94	3.62	-0.22	512	516	

RS(n,k,t), GF(2^m) Code Options – Results (latency ~80ns)

Total Coding Gain	Estimated Latency (min. ns)	Estimated Latency (max. ns)	t	n	k	m	Padded Clk Rate	Raw Clk Rate	Random Coding Gain	Burst Coding Gain	Overhead IL Penalty	Trans code In	Trans code Out	Comments
5.79	82	123	16	448	416	10	175	175.000	7.33	6.88	-1.09	64	65	Best 64b/65b – best overall
5.71	87	128	15	372	342	12	175	174.375	7.22	6.80	-1.09	512	513	Best 512b/513b
5.71	87	128	15	373	342	12	175	174.844	7.22	6.80	-1.09	512	513	
5.66	82	123	15	446	416	10	175	174.219	7.22	6.75	-1.09	64	65	
5.57	87	128	14	372	344	12	175	174.375	7.10	6.66	-1.09	512	516	Best 512b/516b
5.57	87	128	14	373	344	12	175	174.844	7.10	6.66	-1.09	512	516	
5.40	87	128	10	362	342	12	170	169.688	6.52	5.94	-0.55	512	513	
5.15	87	128	9	361	342	12	170	169.219	6.32	5.70	-0.55	512	513	
5.15	87	128	9	362	344	12	170	169.688	6.32	5.70	-0.55	512	516	
5.09	82	123	9	434	416	10	170	169.531	6.32	5.63	-0.55	64	65	
4.88	87	128	8	361	344	12	170	169.219	6.11	5.42	-0.55	512	516	
4.59	87	128	6	468	456	9	165	164.531	5.58	4.59	0.00	512	513	
4.17	87	128	5	352	342	12	165	165.000	5.23	4.17	0.00	512	513	
3.73	87	128	4	350	342	12	165	164.063	4.79	3.73	0.00	512	513	
3.73	87	128	4	351	342	12	165	164.531	4.79	3.73	0.00	512	513	
3.73	87	128	4	352	344	12	165	165.000	4.79	3.73	0.00	512	516	

RS(n,k,t), GF(2^m) Code Options – Results (0% - 3% overclocking)

Total Coding Gain	Estimated Latency (min. ns)	Estimated Latency (max. ns)	t	n	k	m	Padded Clk Rate	Raw Clk Rate	Random Coding Gain	Burst Coding Gain	Overhead IL Penalty	Trans code In	Trans code Out	Comments
6.09	107	158	15	544	513	10	170	170.000	7.10	6.64	-0.55	512	513	Best 512b/513b – best overall
6.09	107	158	15	544	514	10	170	170.000	7.10	6.64	-0.55	512	514	Best 512b/514b
5.96	107	158	14	544	516	10	170	170.000	6.98	6.50	-0.55	512	516	Best 512b/516b
5.64	102	154	12	544	520	10	170	170.000	6.71	6.18	-0.55	64	65	Best 64b/65b
5.92	107	158	13	540	513	10	169	168.750	6.86	6.35	-0.44	512	513	Best 512b/513b – best overall
5.92	107	158	13	540	514	10	169	168.750	6.86	6.35	-0.44	512	514	Best 512b/514b
5.75	107	158	12	538	513	10	169	168.125	6.72	6.19	-0.44	512	513	Best 512b/513b
5.35	102	154	10	540	520	10	169	168.750	6.40	5.79	-0.44	64	65	Best 64b/65b
5.67	107	158	11	536	513	10	168	167.500	6.57	6.00	-0.33	512	513	Best 512b/513b – best overall
5.67	107	158	11	536	514	10	168	167.500	6.57	6.00	-0.33	512	514	Best 512b/514b
5.46	107	158	10	536	516	10	168	167.500	6.40	5.79	-0.33	512	516	Best 512b/516b
4.95	102	154	8	536	520	10	168	167.500	6.01	5.28	-0.33	64	65	Best 64b/65b
5.57	107	159	10	534	513	10	167	166.875	6.41	5.79	-0.22	512	513	Best 512b/513b – best overall
5.57	107	159	10	534	514	10	167	166.875	6.41	5.79	-0.22	512	514	Best 512b/514b
5.33	107	159	9	534	516	10	167	166.875	6.22	5.55	-0.22	512	516	Best 512b/516b
4.72	102	154	7	534	520	10	167	166.875	5.76	4.94	-0.22	64	65	Best 64b/65b
5.18	107	159	8	530	513	10	166	165.625	6.01	5.28	-0.11	512	513	Best 512b/513b – best overall
5.18	107	159	8	530	514	10	166	165.625	6.01	5.28	-0.11	512	514	Best 512b/514b
4.83	107	159	7	530	516	10	166	165.625	5.77	4.94	-0.11	512	516	Best 512b/516b
3.94	102	154	5	530	520	10	166	165.625	5.14	4.05	-0.11	64	65	Best 64b/65b
5.66	169	251	10	704	684	12	165	165.000	6.17	5.66	0.00	512	513	512b/513b – latency >> 100ns
5.18	169	251	8	704	688	12	165	165.000	5.80	5.18	0.00	512	516	512b/516b – latency >> 100ns
4.94	107	159	7	528	513	10	165	165.000	5.77	4.94	0.00	512	513	Best 512b/513b – best overall
4.94	107	159	7	528	514	10	165	165.000	5.77	4.94	0.00	512	514	Best 512b/514b
4.59	107	159	6	528	516	10	165	165.000	5.48	4.59	0.00	512	516	Best 512b/516b
3.51	102	154	4	528	520	10	165	165.000	4.72	3.51	0.00	64	65	Best 64b/65b

RS(n,k,t), GF(2^m) Code Options – Results (3.6% - 6% overclocking)

Total Coding Gain	Estimated Latency (min. ns)	Estimated Latency (max. ns)	t	n	k	m	Padded Clk Rate	Raw Clk Rate	Random Coding Gain	Burst Coding Gain	Overhead IL Penalty	Trans code In	Trans code Out	Comments
5.79	82	123	16	448	416	10	175	175.000	7.33	6.88	-1.09	64	65	Best 64b/65b – best overall
5.71	87	128	15	372	342	12	175	174.375	7.22	6.80	-1.09	512	513	Best 512b/513b
5.57	87	128	14	372	344	12	175	174.375	7.10	6.66	-1.09	512	516	Best 514b/516b
5.21	56	81	11	280	257	10	175	175.000	6.94	6.30	-1.09	512	514	Best 512b/514b
5.83	107	158	16	462	430	12	174	173.250	7.20	6.81	-0.98	512	516	Best 512b/516b – best overall
5.28	56	82	11	308	285	9	174	173.250	6.94	6.27	-0.98	512	513	Best 512b/513b
5.10	56	82	10	278	257	10	174	173.750	6.76	6.08	-0.98	512	514	Best 512b/514b
4.83	51	77	9	278	260	10	174	173.750	6.55	5.81	-0.98	64	65	Best 64b/65b
5.89	102	154	16	552	520	10	173	172.500	7.20	6.76	-0.87	64	65	Best 64b/65b – best overall
5.81	107	158	15	460	430	12	173	172.500	7.09	6.69	-0.87	512	516	Best 512b/516b
4.94	56	82	9	276	257	10	173	172.500	6.56	5.82	-0.87	512	514	Best 512b/514b
6.00	107	158	16	548	516	10	172	171.250	7.20	6.76	-0.76	512	516	Best 512b/516b – best overall
5.87	102	154	15	550	520	10	172	171.875	7.09	6.63	-0.76	64	65	Best 64b/65b
4.76	56	82	8	274	257	10	172	171.250	6.33	5.53	-0.76	512	514	Best 512b/514b
6.11	107	158	16	546	513	10	171	170.625	7.21	6.77	-0.65	512	513	Best 512b/513b – best overall
6.11	107	158	16	546	514	10	171	170.625	7.21	6.77	-0.65	512	514	Best 512b/514b
5.98	107	158	15	546	516	10	171	170.625	7.10	6.64	-0.65	512	516	Best 512b/516b
5.69	102	154	13	546	520	10	171	170.625	6.85	6.35	-0.65	64	65	Best 64b/65b