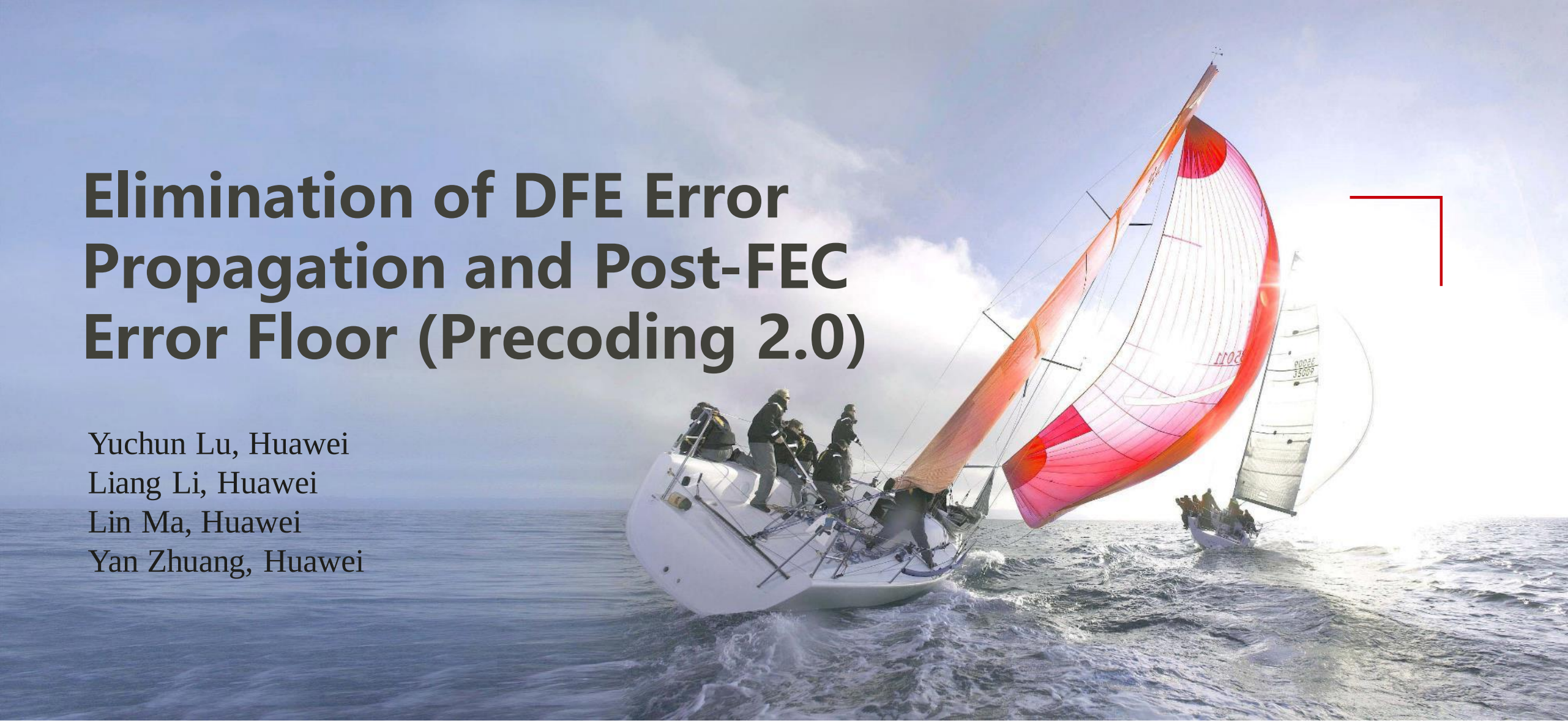
Elimination of DFE Error Propagation and Post-FEC Error Floor (Precoding 2.0)



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Background

Necessity of precoding is under discussion, it seems inevitable in IEEE 802.3ck scenarios.

Even with precoding, the performance concerns in certain scenarios have been raised (anslow_3ck_01_0918). The 2-way interleaved FEC was proposed for 100G KR/CR channels (gustlin_3ck_01_1118), which brings some system issues, such as compatibility difficulty, latency, complicated CDR, mandatory CDR, etc. (lu_3ck_adhoc_01_022719).

An enhanced precoding technology (a.k.a precoding 2.0) will be discussed in this deck. It can eliminate the DFE error propagation with minor penalty in performance and complexity. It is a generalized method that can be applied to both C2C and C2M interfaces, 1-tap DFE or n-tap DFE. This is an extended discussion of "Exploration on the Worst Case DFE Weight of DFE Error Propagation Effect (lu_3ck_adhoc_01a_010219)".

It can be used as long as precoding (let's say precoding 1.0) is supported, while precoding 1.0 is already in IEEE 802.3 spec and supported by most implementations.

Table of Contents

Insights of DFE error propagation

Underflow

(a)

Pos1/Main	1.0																				
1/(1+D) Encoder Input	1	0	1	3	3	0	3	2	0	1	3	3	0	0	0	0	2	3	0	3
1/(1+D) Encoder Output	1	3	2	1	2	2	1	1	3	2	1	2	2	2	2	2	0	3	1	2
After [1, Pos1] Channel	1	4	5	3	3	4	3	2	4	5	3	3	4	4	4	4	2	3	4	3
After DFE Equalizer	1	3	2	2	1	3	0	2	2	3	0	3	1	3	1	3	-1	3	1	2
DFE Slicer Output	1	3	1	2	1	3	0	2	2	3	0	3	1	3	1	3	0	3	1	2
DFE Error Pattern	0	0	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	0	0	0	0
(1+D) Decoder Output	1	0	0	3	3	0	3	2	0	1	3	3	0	0	0	0	3	3	0	3
Pre-Coding Error Pattern	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Symbol ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

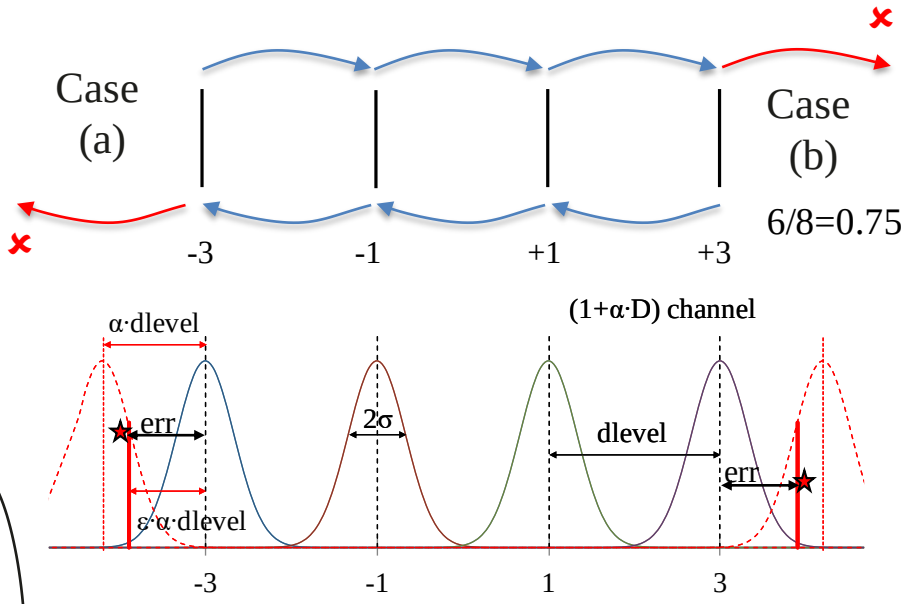
Random error that triggers the burst error

Correctable by burst error detection

(b)

Pos1/Main	1.0																				
1/(1+D) Encoder Input	1	0	1	3	3	0	3	2	0	1	3	3	0	2	1	3	0	1	0	3
1/(1+D) Encoder Output	1	3	2	1	2	2	1	1	3	2	1	2	2	0	1	2	2	3	1	2
After [1, Pos1] Channel	1	4	5	3	3	4	3	2	4	5	3	3	4	2	1	3	4	5	4	3
After DFE Equalizer	1	3	2	2	1	3	0	2	2	3	0	3	1	1	0	3	1	4	1	2
DFE Slicer Output	1	3	1	2	1	3	0	2	2	3	0	3	1	1	0	3	1	3	1	2
DFE Error Pattern	0	0	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	0	0	0
(1+D) Decoder Output	1	0	0	3	3	0	3	2	0	1	3	3	0	2	1	3	0	0	0	3
Pre-Coding Error Pattern	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0
Symbol ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Overflow



DFE burst errors terminate when equalized signal is out of range, It is possible to eliminate of DFE error propagation.

- Pre-coding 1.0 removes errors in the middle.
- Pre-coding 2.0 removes the error at the tail after precoding decoder.

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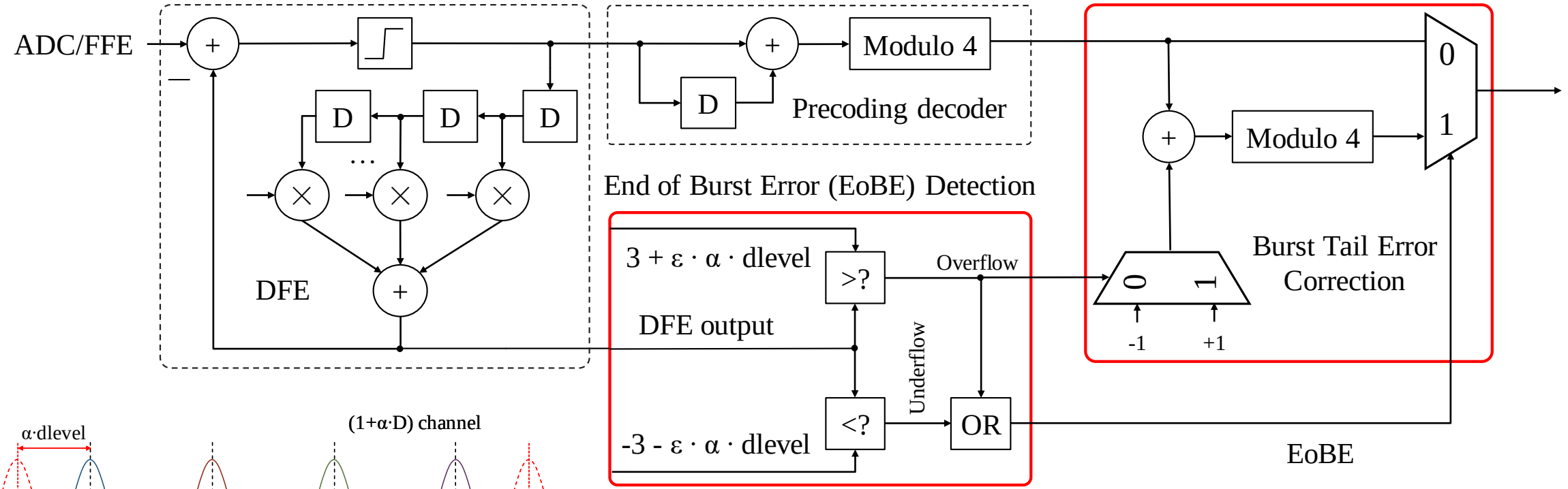
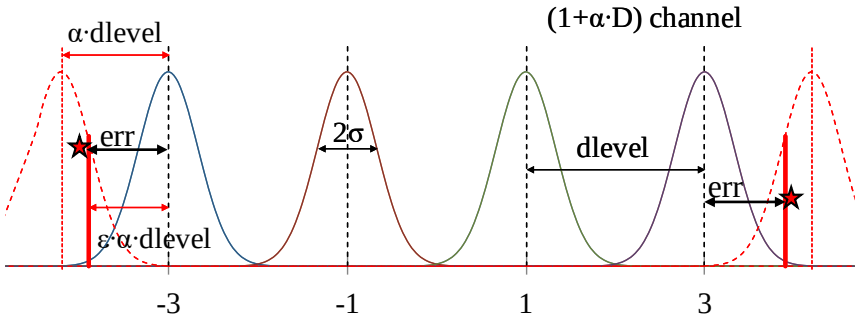
Complexity of DFE error propagation elimination





EoBE Detection: 2x comparator + 1x OR gate.

Burst Tail Error Correction: 2x “2-bit mux” , 1x “4-bit adder” and 1x “Mod 4 adder”.

The complexity of precoding 2.0 is minor and negligible!

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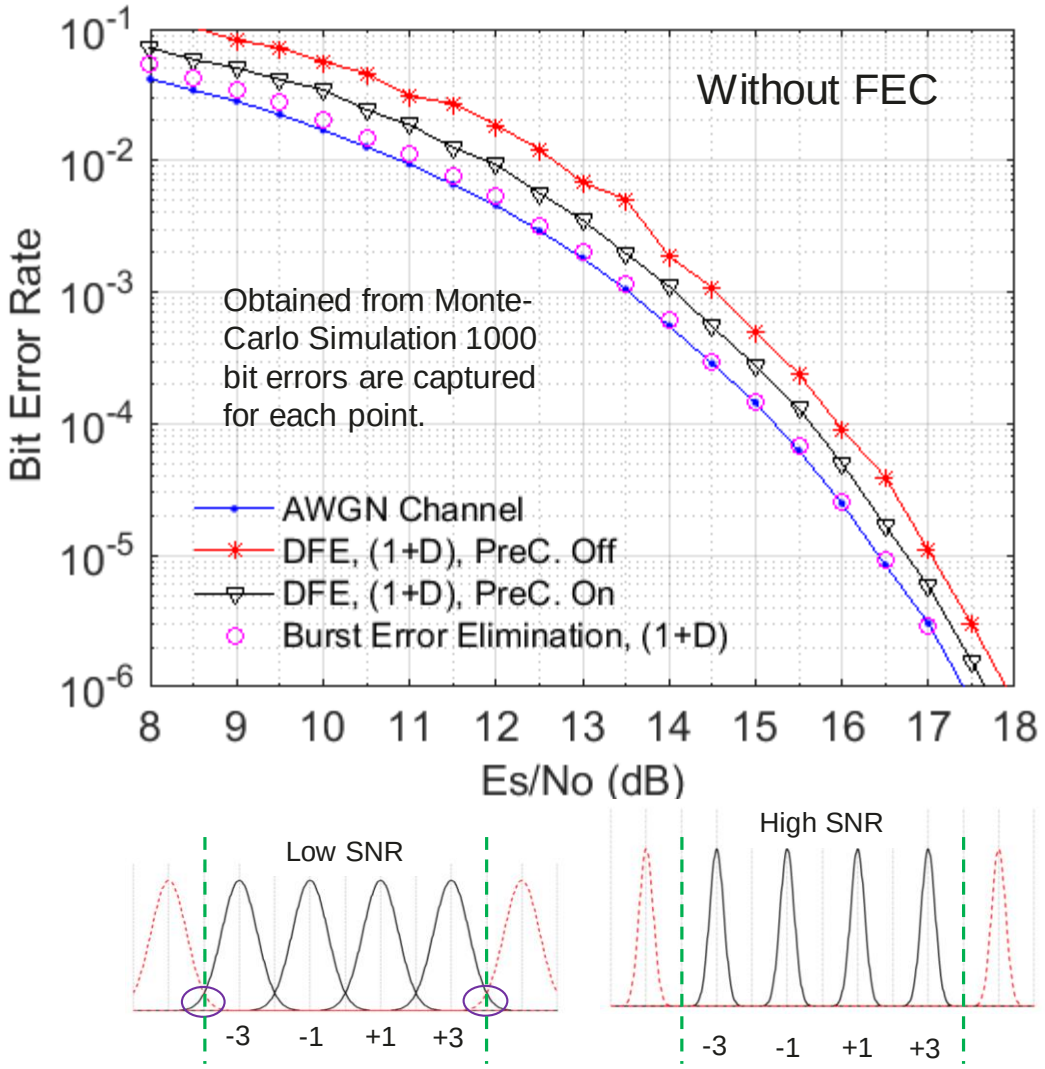
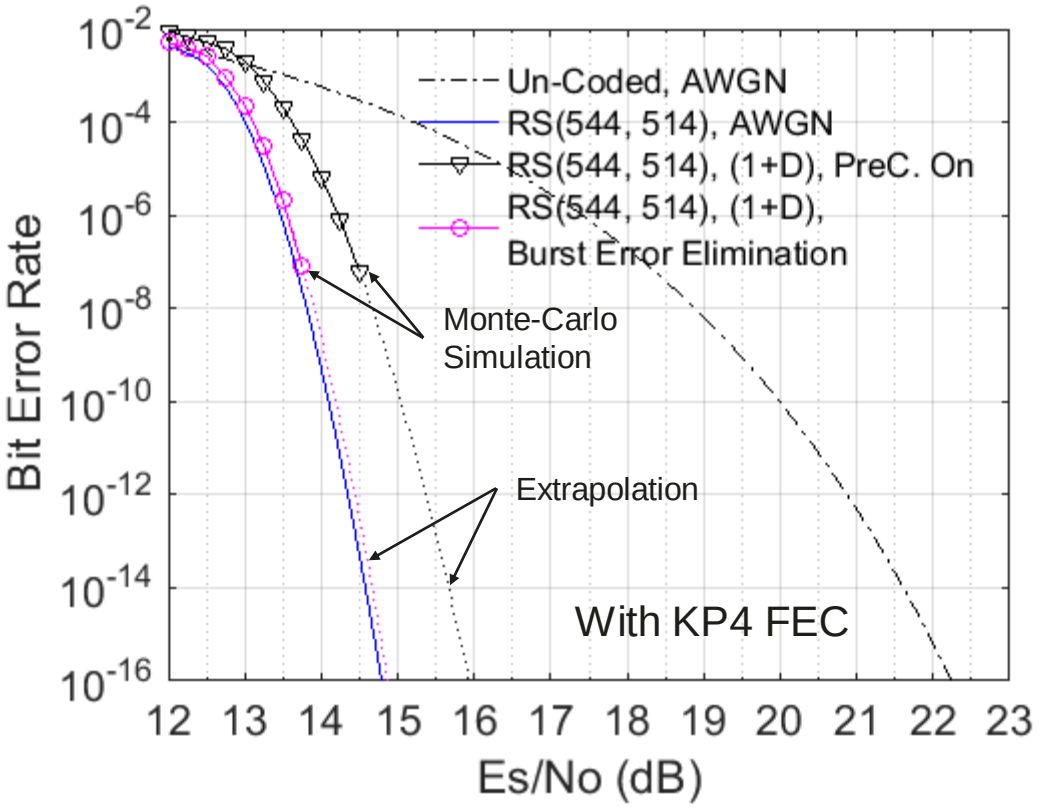
Simulation results (1+D) channel





The error propagation effect can be eliminated by precoding 2.0.
The post-FEC error floor effect can be removed.
Current Monte-Carlo simulation is sufficient, because low SNR case is the lower bound of the performance of high SNR case.

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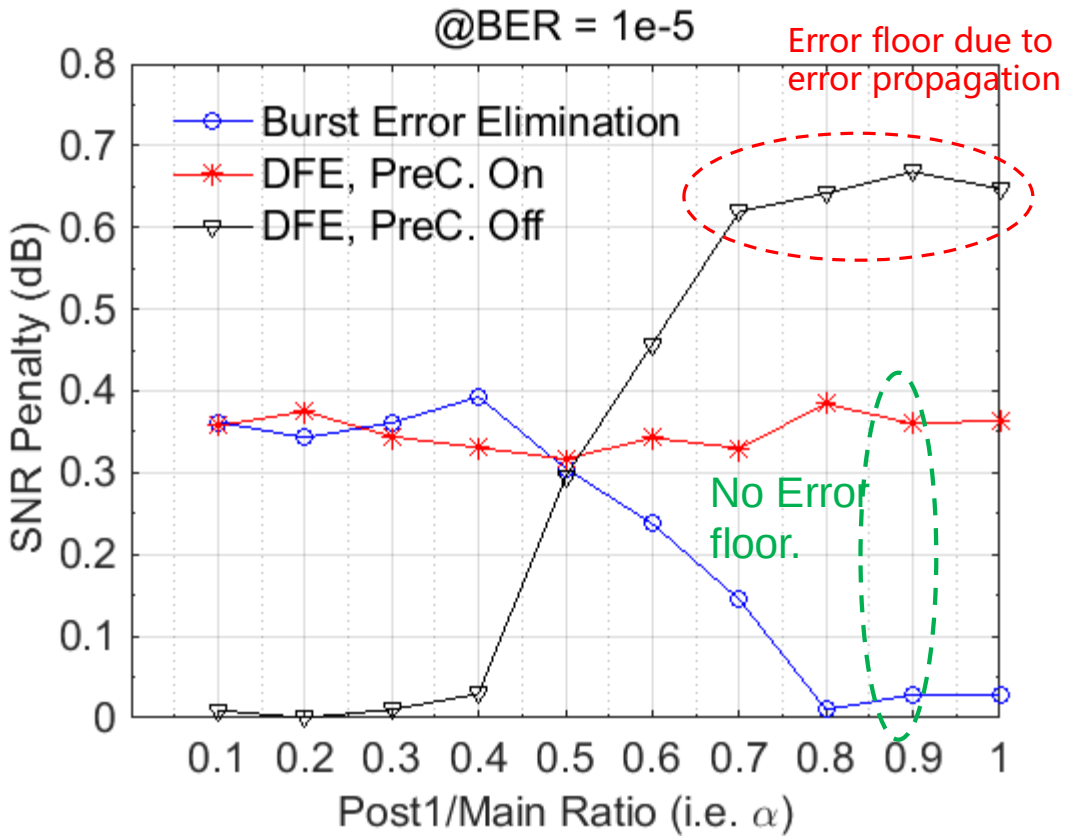
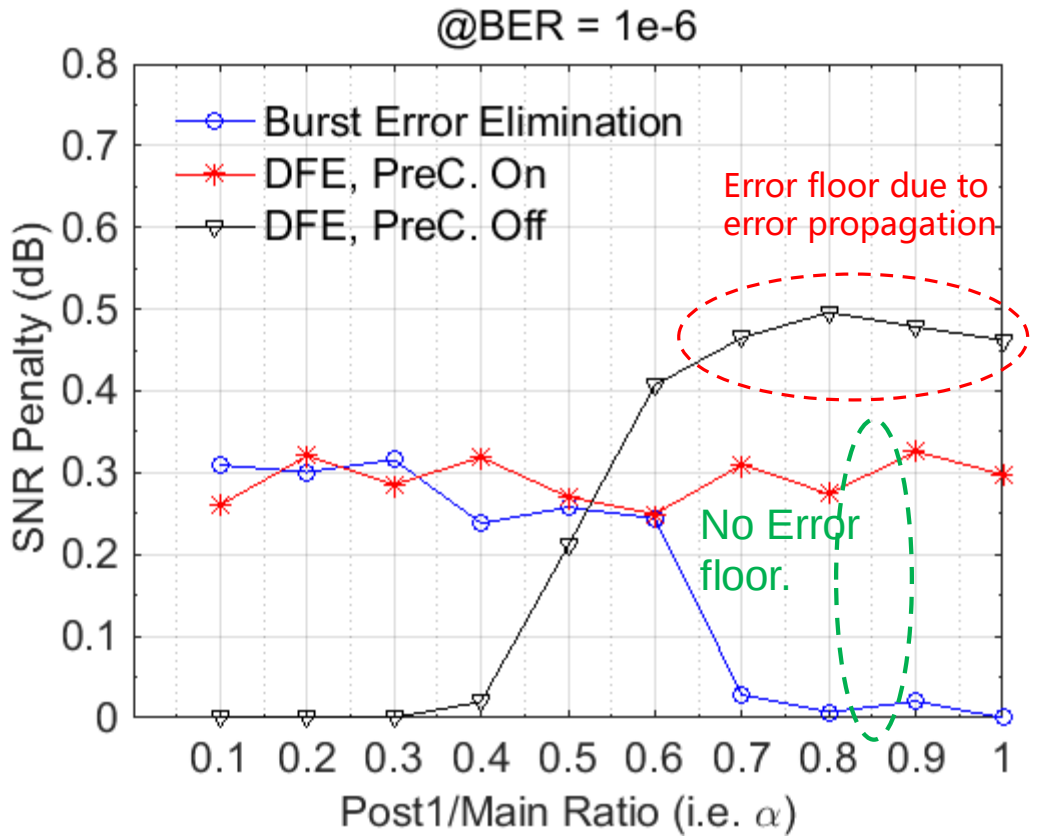
SNR penalty with respect to AWGN channel





The DFE error propagation can be eliminated by detection and correction of the tail of burst errors.
The post-FEC error floor can be removed by elimination of DFE error propagation.
The more serious the DFE error propagation is, the more effective Proceeding 2.0 will be!

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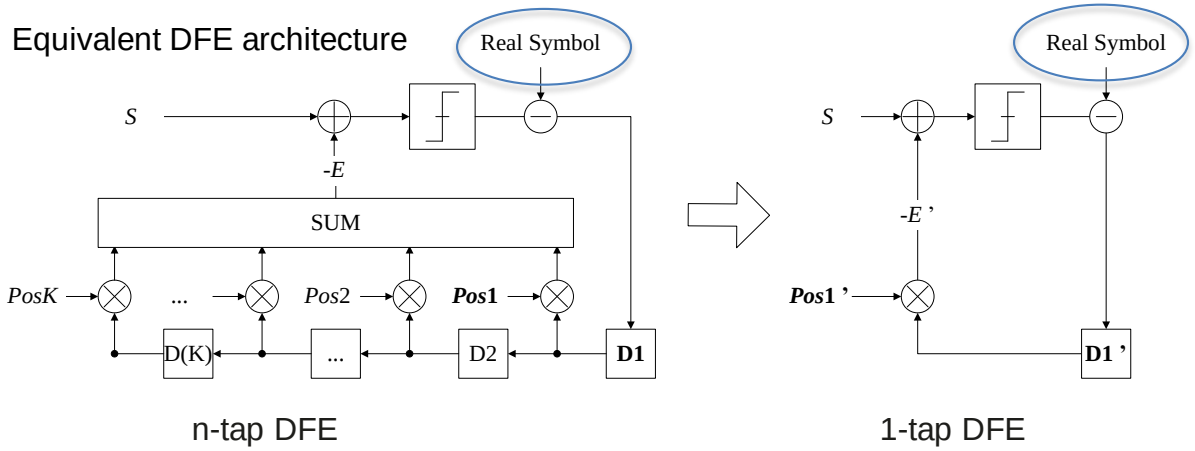
Generalization to n-tap DFE



Time	D_1	D_2	D_3	D_4	…	Pos1'
0	0	0	0	0	…	0
1	E_1	0	0	0	…	Pos1
2	E_2	E_1	0	0	…	Pos1-Pos2
3	E_3	E_2	E_1	0	…	Pos1-Pos2+Pos3
…	…	…	…	…	…	…
L+1	E_L	E_{L-1}	E_{L-2}	E_{L-3}	…	Pos1-Pos2+Pos3-Pos4+…

1. As discussed in lu_3ck_adhoc_01a_010219, the n-tap DFE can be viewed as 1-tap DFE with time-variant DFE weight.
2. The error propagation mechanism of n-tap DFE is identical to 1-tap DFE.
   - DFE burst errors exhibit "+1, -1" zig-zag patterns.
   - DFE burst errors terminate when equalized signal is out of range.
3. The equivalent DFE weight value is in the working zone of precoding 2.0, b1=0.7~1.0.
4. The more serious the DFE error propagation is, the more effective precoding 2.0 will be.

Y.C. Lu, et al "DFE Error Propagation Characteristics in Real 56Gbps PAM4 High-Speed Links with Pre-Coding and Impact on the FEC Performance", DesignCon 2017.

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Summary

An enhanced precoding technology (Precoding 2.0) is investigated. The DFE error propagation can be eliminated by detection and correction of the tail of burst errors. The post-FEC error floor can be removed by elimination of DFE error propagation.

1. Negligible SNR penalty with respect to the AWGN SNR when DFE weight is around 0.7~1.0.
2. Complexity of implementation is minor and negligible.
3. No standardization effort is needed, precoding is already in the IEEE standard.

DFE error propagation effect can be eliminated by Precoding 2.0 easily with negligible penalties both in performance and implementation. **The more serious the DFE error propagation is, the more effective Precoding 2.0 can be!**

Precoding is recommended for CR and KR channels. Precoding 2.0 may also benefit the C2M channel. Compared to 'precoding 1.0', it will provide >1dB SNR gain with negligible penalty, but not introduce any system issues.

Thank you !

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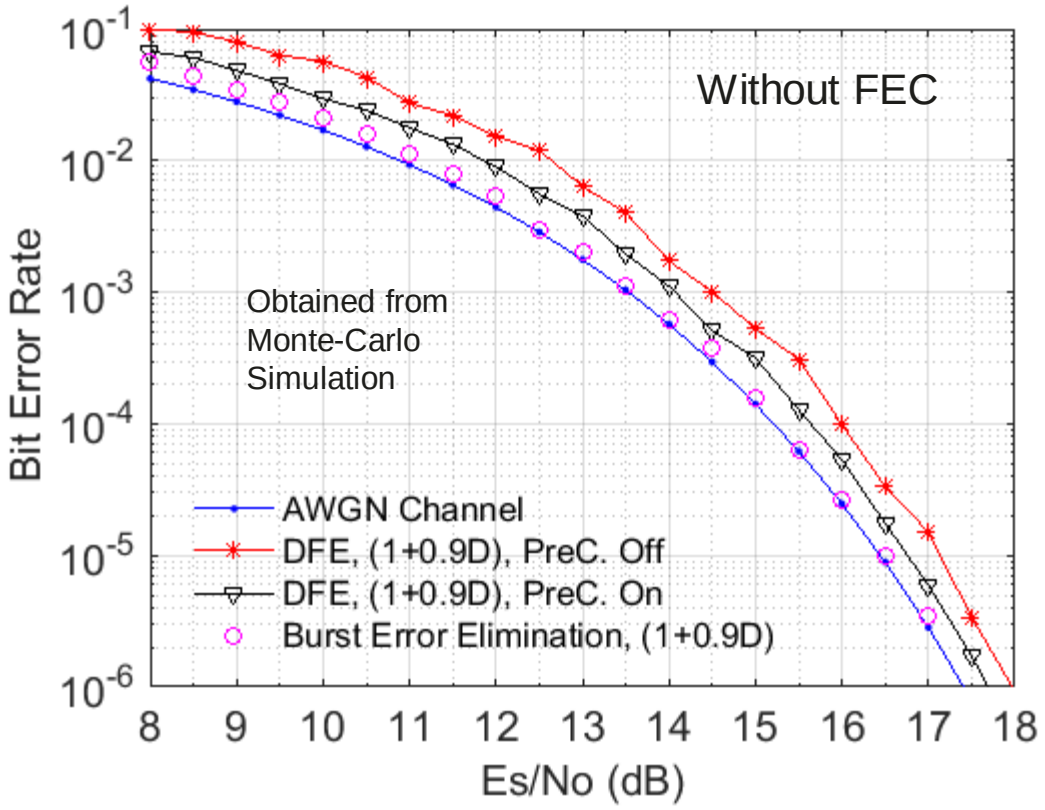
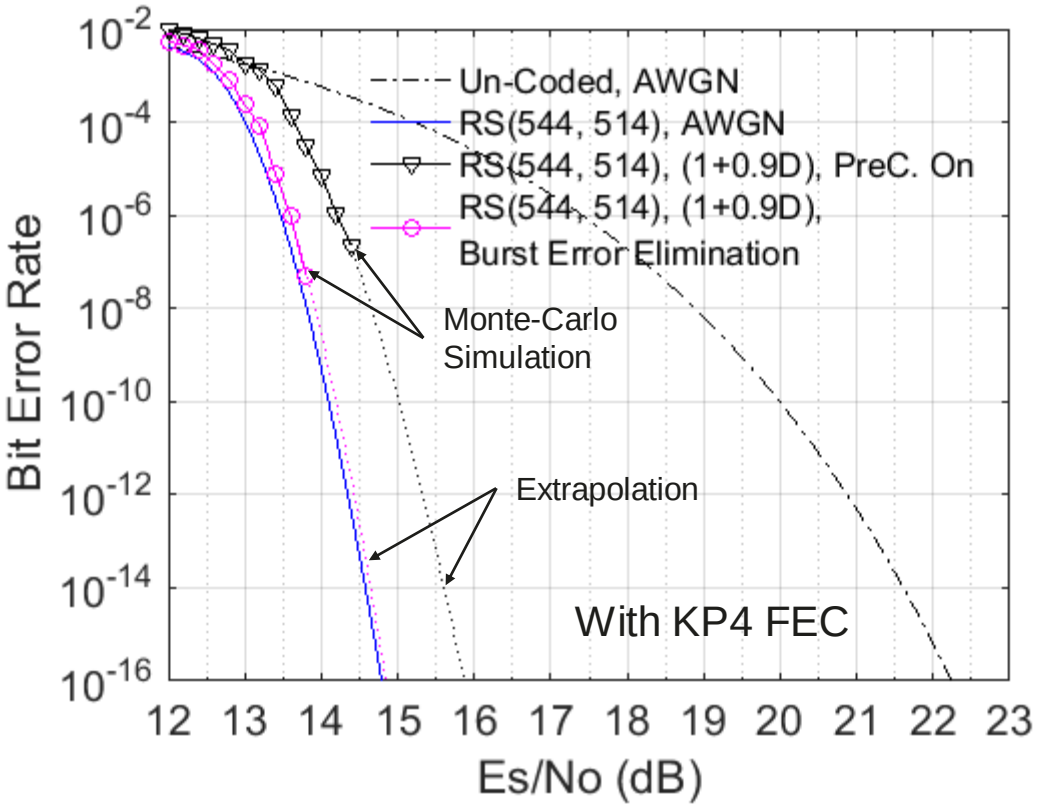
Simulation results (1+0.9D) channel





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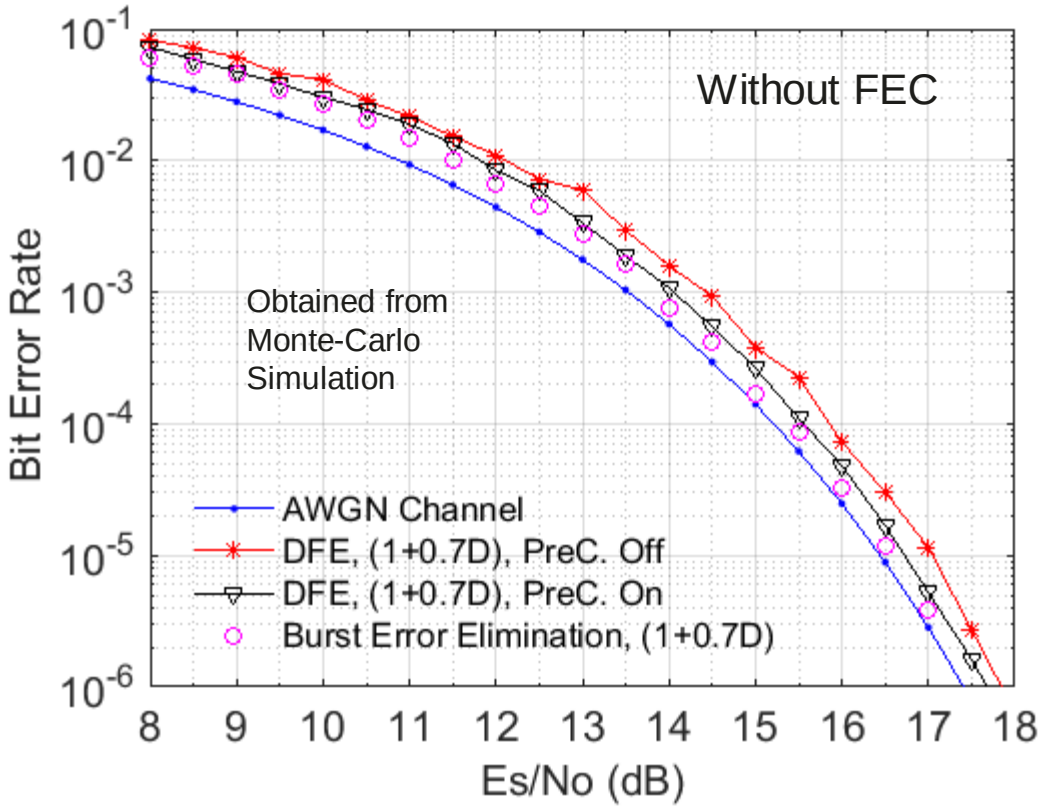
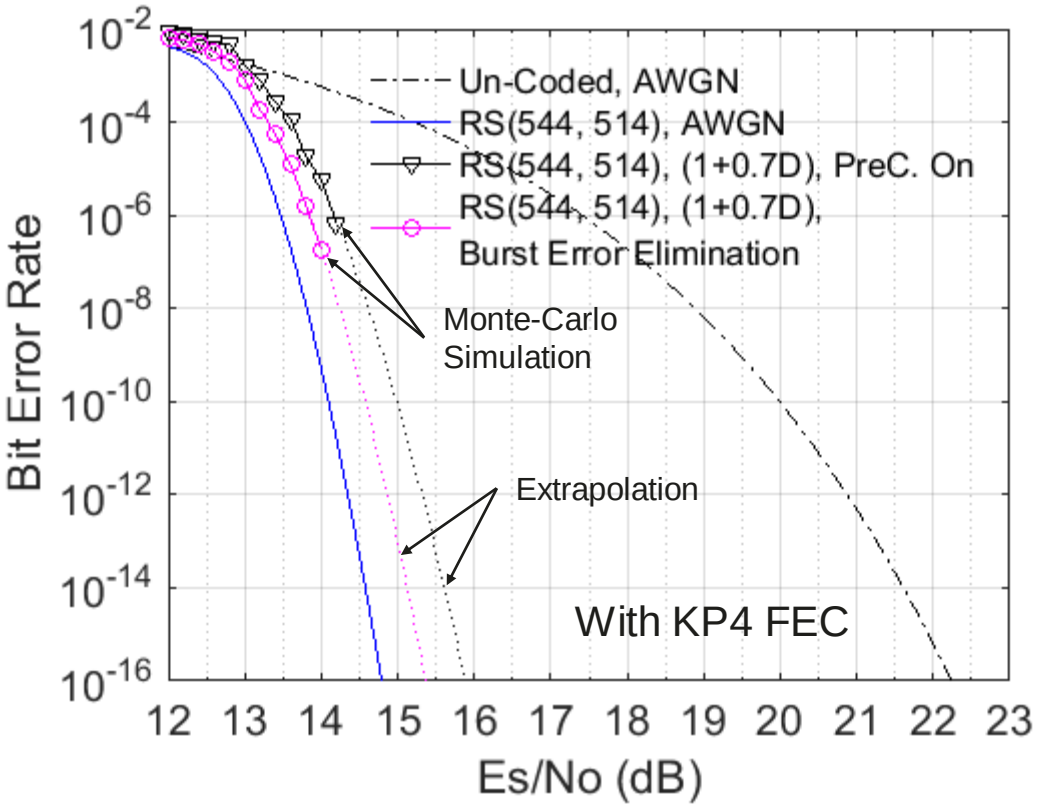
Simulation results (1+0.7D) channel





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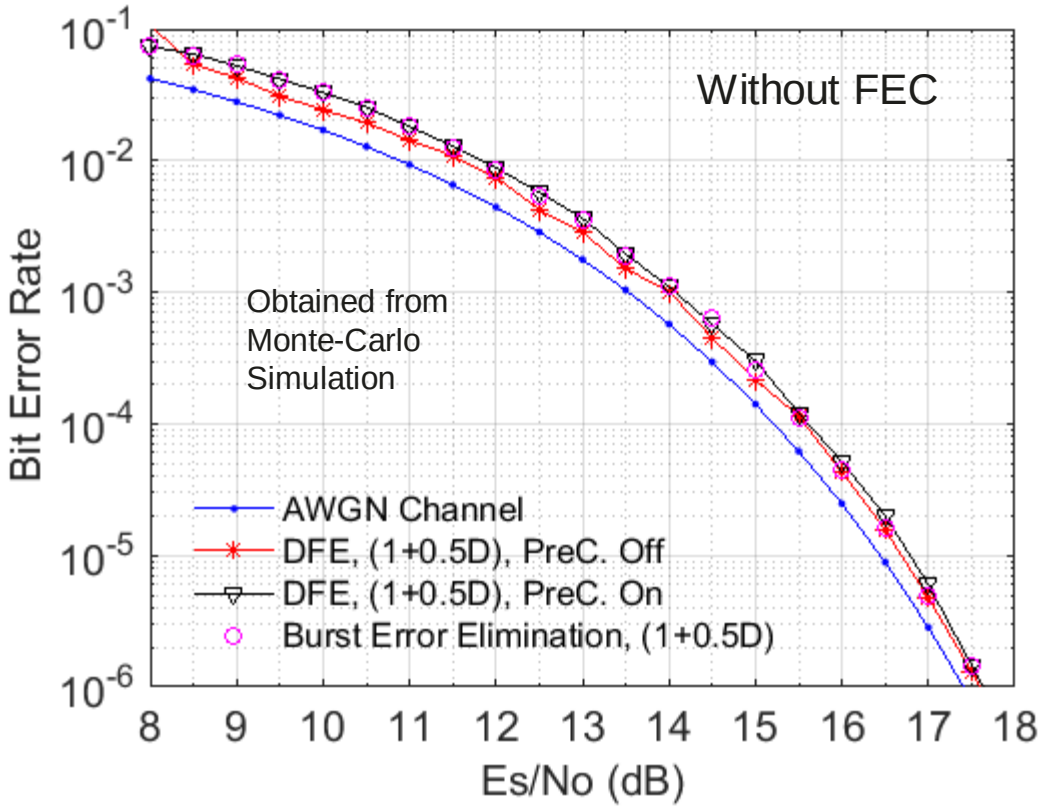
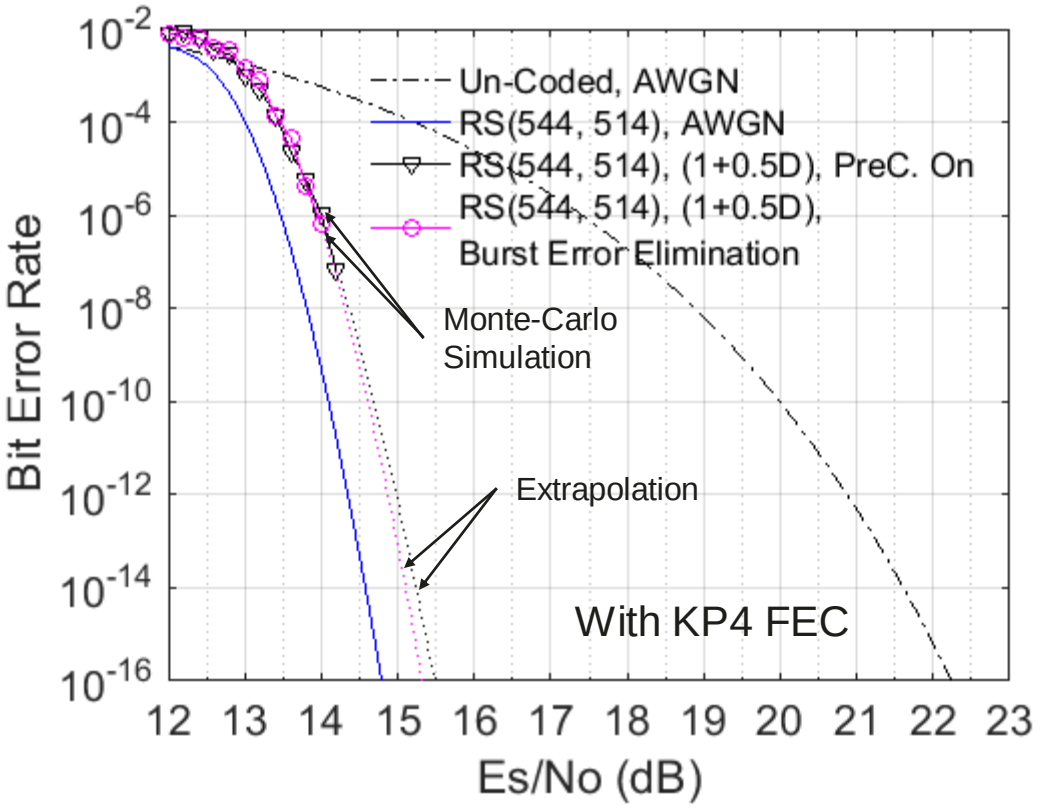
Simulation results (1+0.5D) channel





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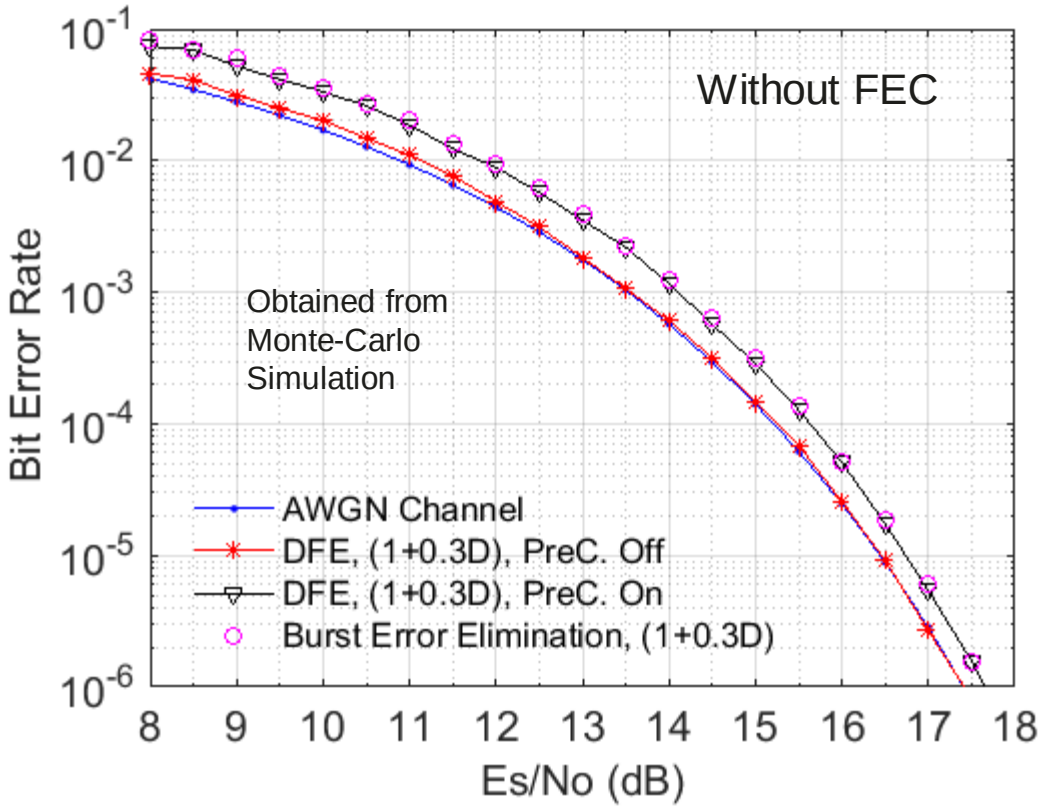
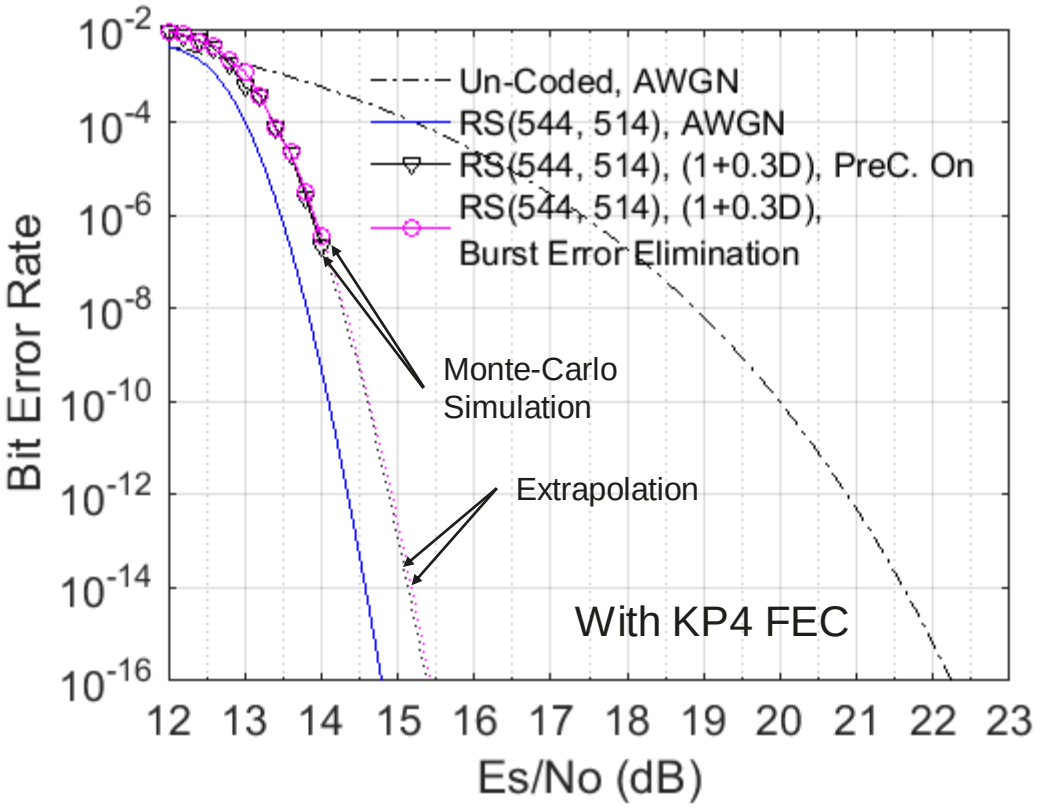
Simulation results (1+0.3D) channel





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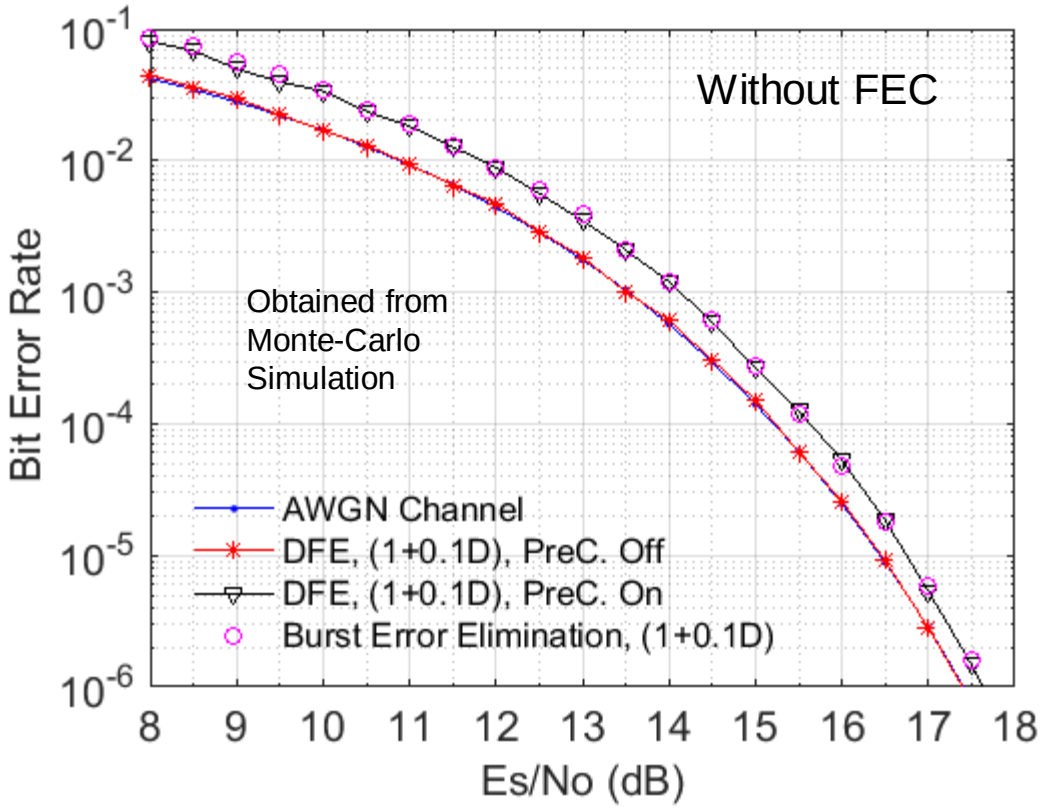
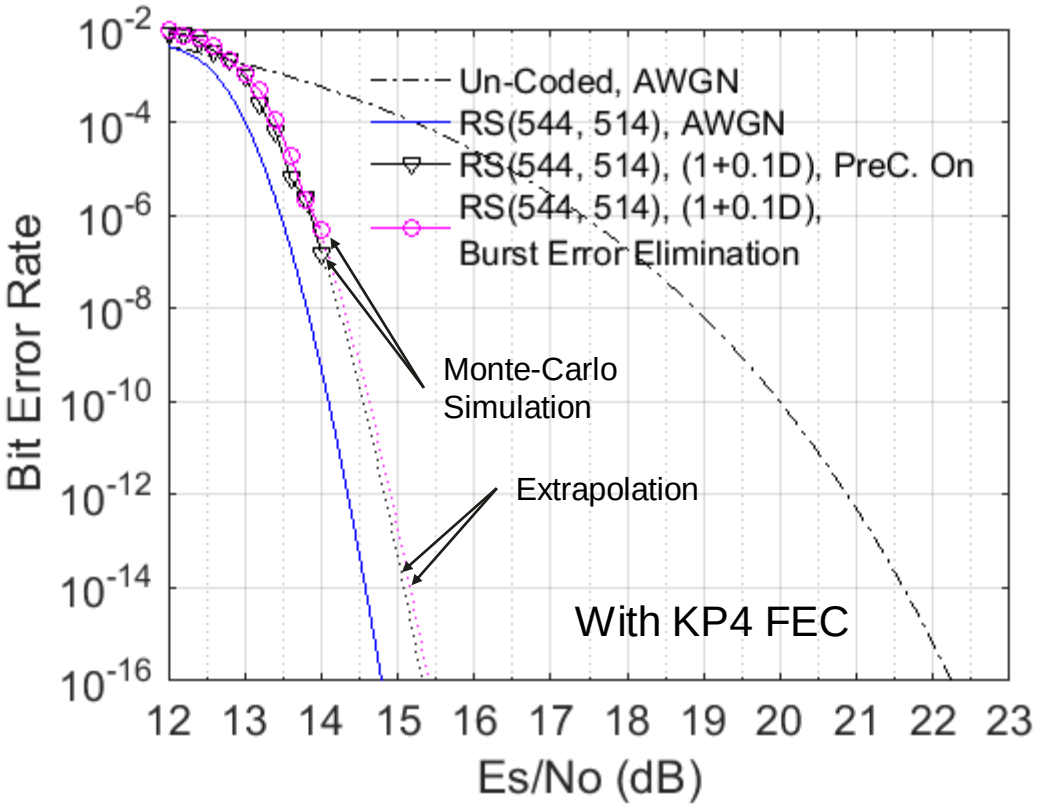
Simulation results (1+0.1D) channel





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