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Impact of pre-coding and high gain FEC on 25, 50 &100G EPON

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Pre-coding

Why do we need pre-coding?

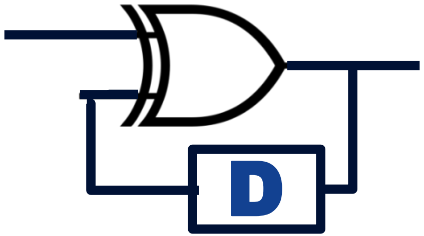
- Deployment of bandwidth limited systems might be needed for the 25G in the near-medium term to ensure lowest cost
- For proper detection in bandwidth limited systems it will be beneficial to apply differential encoding (pre-coding) at the transmitter
- Pre-coding also mitigates burst errors in conventional NRZ based receivers
- Pre-coding is achieved by using an XOR gate at the transmitter, which can be implemented in (digital) electronics

Differential Encoding (pre-coding)

Pre-coder

0 0 1 1 0 1 0 1 1 1 0 0 0

Input data



0 0 1 0 0 1 1 0 1 0 0 0 0

Output data

The transmitted data depends not only on the current bit, but also on the previous output value

Pre-coding

- Desired for EDB
- Might be beneficial for DSP-aided NRZ detection
- Not ideal for conventional NRZ detection, since it roughly doubles the raw bit error rate. However, it does mitigate burst errors, and for symbol-oriented RS-FEC codes, most “twin errors” result in single symbol errors

The impact of pre-coding on the performance of EDB, NRZ, and NRZ-NFC under various conditions has already been studied:

- V. Houtsma, D. van Veen and E. Harstead, “Unified Evolution-Ready 25/50/100 Gbps-EPON Architecture Proposal”, houtsma_3ca_1_0516.pdf
- S. Yao, X. Liu and D. Liu, “The Impact of Differential Pre-coding on 25-Gb/s EDB, NRZ, and NRZ-NFC”, liu_3ca_5_0716.pdf

Prior conclusions from both presentations on pre-coding :

- Pre-coding is necessary for EDB for significant performance improvement
- Pre-coding results in a 0.15 dB improvement with bandwidth limited NRZ using MLSE under dispersive transmission
- Pre-coding causes a 0.1 dB penalty for NRZ with MLSE at FEC threshold when dispersion effects are small (O-band)
- Pre-coding results in a 0.3 dB penalty for conventional NRZ detection

The largest penalty observed was for conventional NRZ of 0.3 dB

(These results were obtained on **"before FEC curves"** with an FEC threshold of 10^{-3}).

In this presentation we will study high gain FECs and its impact on pre-coding for conventional NRZ detection

High gain FEC

Why do we need high gain FEC ?

- An RS(255,223) is used in 10G EPON and has a 10^{-3} to 10^{-12} correcting ability
- To meet power budgets in 100G PON it might be required to use a higher gain FEC.
- By using a higher gain FEC with bit error correcting ability from 10^{-2} to 10^{-12} about 2 dB improvement in optical power budget can be obtained

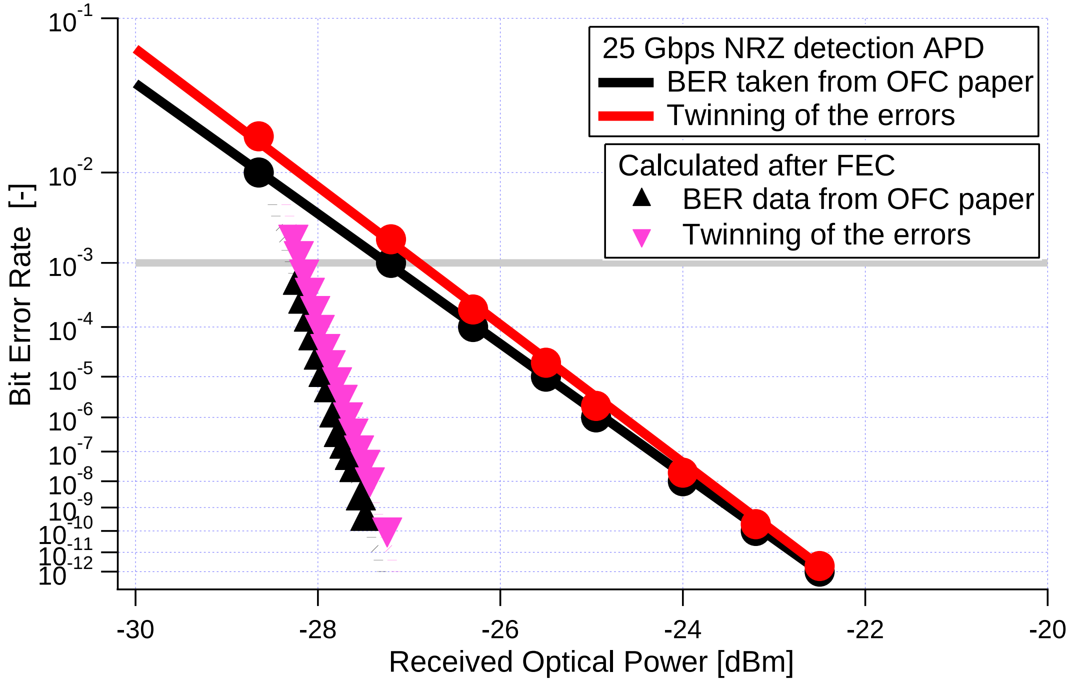
However, the implementation complexity and overhead has to be taken into account when going to a higher gain FEC code

Some thoughts on high gain FECs in 100G PON

- Only hard decision FECs are considered for lowest cost
- Low complexity is required to ensure low cost decoder implementation at the ONU.
- FEC codes for upstream and downstream have different requirements. Best results will be achieved when optimized individually.
- For upstream burst-error correcting FEC codes will be most desirable
- Short (and adjustable) FEC codeword length for upstream, which length is acceptable?
- Sub-rating is assumed to optimize optical power budget therefore the overhead should probably be limited to 13-20%.

NRZ detection with and without pre-coding for 25G based APD receiver

review from V. Houtsma, et al., “Unified Evolution-Ready 25/50/100 Gbps-EPON Architecture Proposal”, houtsma_3ca_1_0516.pdf



- About a 2-dB improvement in optical power budget can be obtained by going to high gain FEC with 10^{-2} error correcting capability
- Black and red curve show BER of NRZ detected signal without and with pre-coding (roughly doubling of the errors)
- At10^{-2}, the power penalty due to doubling of the errors is about 0.6 dB **before** FEC compared to 0.3 dB at10^{-3}

Measurements taken from SiFotonics OFC paper of a 25G SiGe APD receiver.

M. Huang et al. ,"Breakthrough of 25Gb/s Germanium on Silicon Avalanche Photodiode" OFC 2016, Tu2D.2.pdf

Target requirements for high gain FEC in 25G PON

- Post FEC needs to be 10^{-12}
- 1-2 dB improvement in optical power budget desirable
- Similar OH as 10G EPON, which is 13% (limit to about 20%)
- Latency on the order of 10 μs or less
- Fits in a FPGA/has ‘reasonable’ complexity for ONU.
- Mitigates pre-coding twin errors for NRZ detection

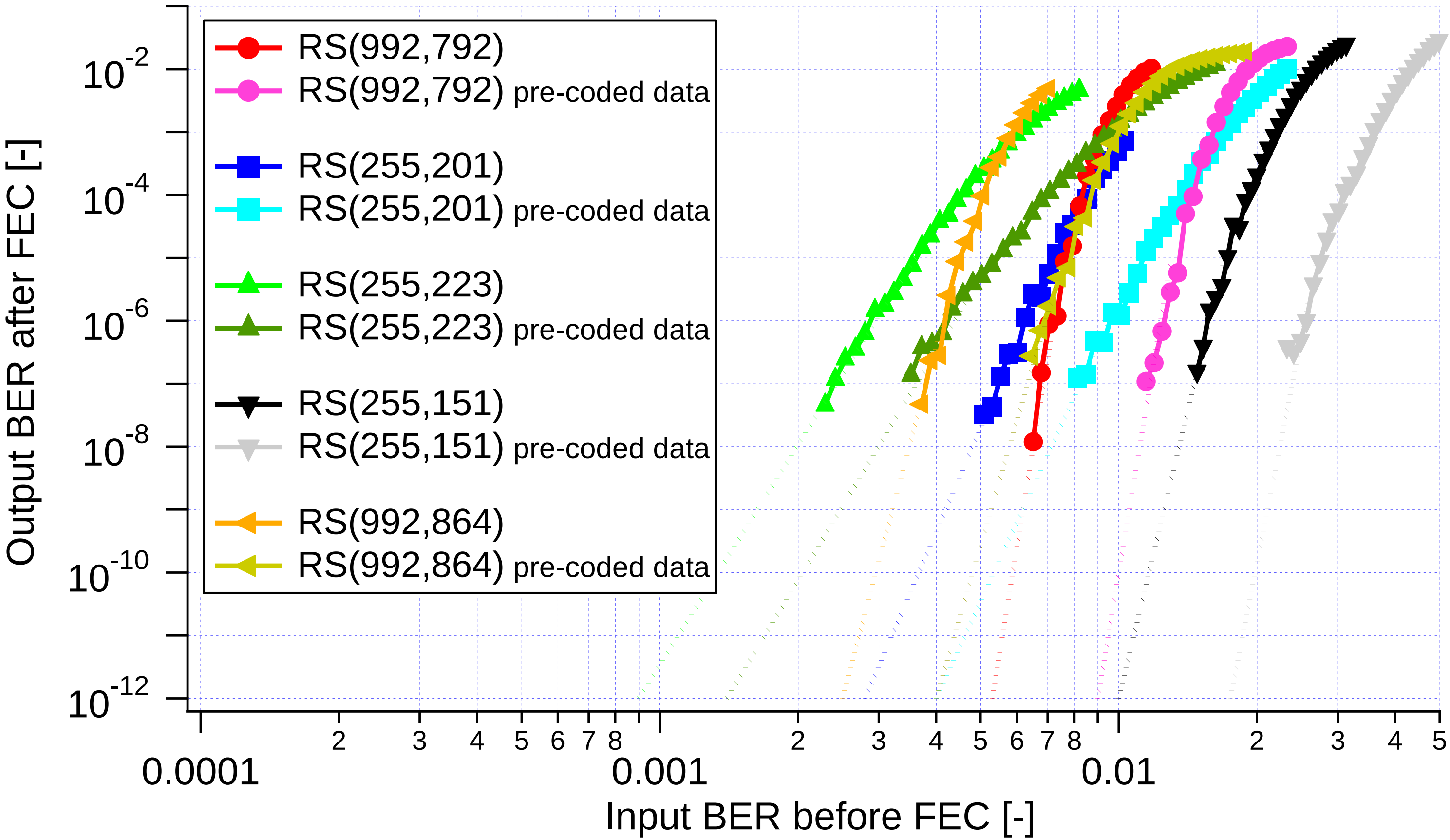
Comparison of Some High-Gain FEC Codes

FEC code	OH (%)	BER for 10^{-12} (NO PRECODING)	BER for 10^{-12} (PRECODING)	Complexity	Optical Power improvement (approximate) (dB)	Optical power penalty for NRZ using pre-coding BEFORE → AFTER FEC (dB)
RS(255,223) 10G EPON	13	1e-3	1.4e-3	+++	0	0.3 → 0.1
RS(992,864)	13	2.5e-3	4e-3	+	0.5	0.4→ 0.15
LDPC(1908,1697)[1]	11	8e-3	tbd	--	1.5	0.5→ tbd
BCH (480,434,5) × (472,435,4)[2]	20	1.1e-2	tbd	-	2.0	0.6→ tbd
RS(255,201)	20	2.9e-3	4e-3	++	0.5	0.4 → 0.15
RS(992,792)	20	5.2e-3	9e-3	+	1.0	0.6 → 0.05
RS(255,151)	41	1e-2	1.8e-2	++	2.0	0.6 → ~ 0

[1] www.ieee802.org/3/av/public/2007_05/3av_0705_daido_1.pdf

[2] T. Minghui, et al., "28-Gb/s/λ TDM-PON with Narrow Filter Compensation and Enhanced FEC Supporting 31.5 dB Link Loss Budget after 20-km Downstream Transmission in the C-band," in OFC2016), paper Th1I.4.

Impact of FEC on BER for pre-coded and non pre-coded NRZ detection



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Conclusions

- It is not trivial to find a FEC code satisfying PON requirements with a 10^{-2} input BER. An input BER of $5 \cdot 10^{-3}$ might be more realistic
- Input BER of $5 \cdot 10^{-3}$ results in 1.0 & 1.5 dB optical power budget improvement for 25G NRZ & EDB respectively.
- Reed Solomon codes are a good fit, because they are easy to implement. Also they are naturally very robust against twin errors and burst errors in general.
- RS(992,792) could be good candidate with 20% OH and $5 \cdot 10^{-3}$ error correcting capability to 10^{-12} with a very small after-FEC penalty for NRZ using pre-coding of 0.05 dB
- Advanced FECs like concatenated RS+BCH and staircase codes were not considered since they have quite large conjectured FEC block lengths. If this is acceptable, it might be an option for the downstream, however latency as well as error flooring should be investigated.

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