Further Analyses about Distributed MLC for 400GbE

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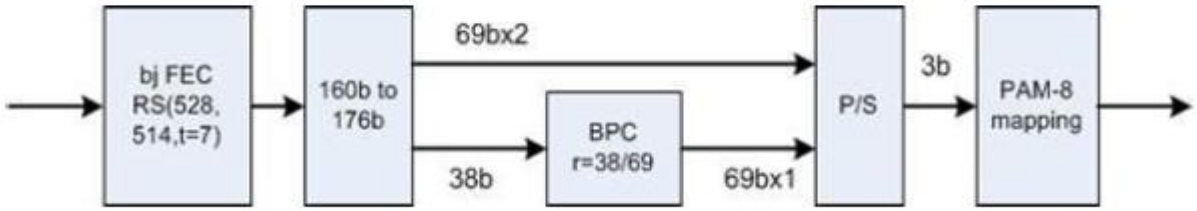
INTRODUCTION

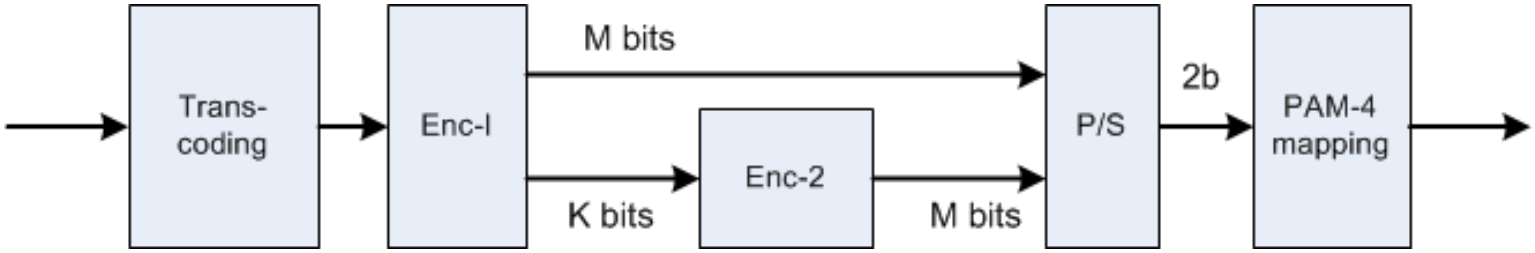
- **This presentation will provide more technical details about multi-level coding (MLC) .**
- **The analyses show the distributed-MLC structure is an interesting option compared to other existing FEC strategies. No specific FEC code is proposed or suggested for the standard.**

REVISIT MULTI-LEVEL CODING

- **A PAM8-based MLC scheme was presented on page-14 in [1] in Jan. 2013.**



- **A similar MLC scheme for communication systems based on PAM4 modulation is shown below, where P/S denotes parallel-to-serial conversion, and "Enc-1" and "Enc-2" denote encoder for Code-1 and Code-2 respectively.**



[1] C. Bergey, V. Bhatt, et al, "PAM8 Baseline Proposal", IEEE P802.3bm, task force, Jan. 2013. available from "http://www.ieee802.org/3/bm/public/jan13/bhatt_01_0113_optx.pdf"

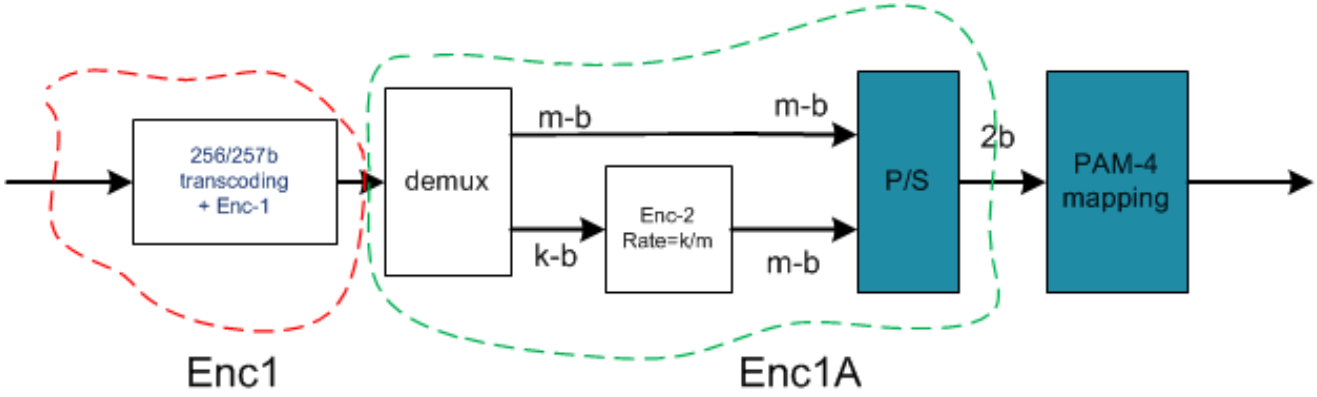
MLC (CONT'D)

- **IDEA:** use a strong FEC (e.g., Enc-2 uses 8.5dB RS code) to protect lsb, use a weak FEC (e.g., Enc-1 uses 3dB RS code) to protect msb.

- **PRINCIPLE:** Once lsb is known, only need make a decision between two options in the corresponding set (yellow colored set for lsb=0 and green set for lsb=1). Because of doubled distance between constellations, the raw BER for msb part (after lsb is known) is much lower. Thus need weak FEC to protect msb.

ANALYSES ABOUT MLC

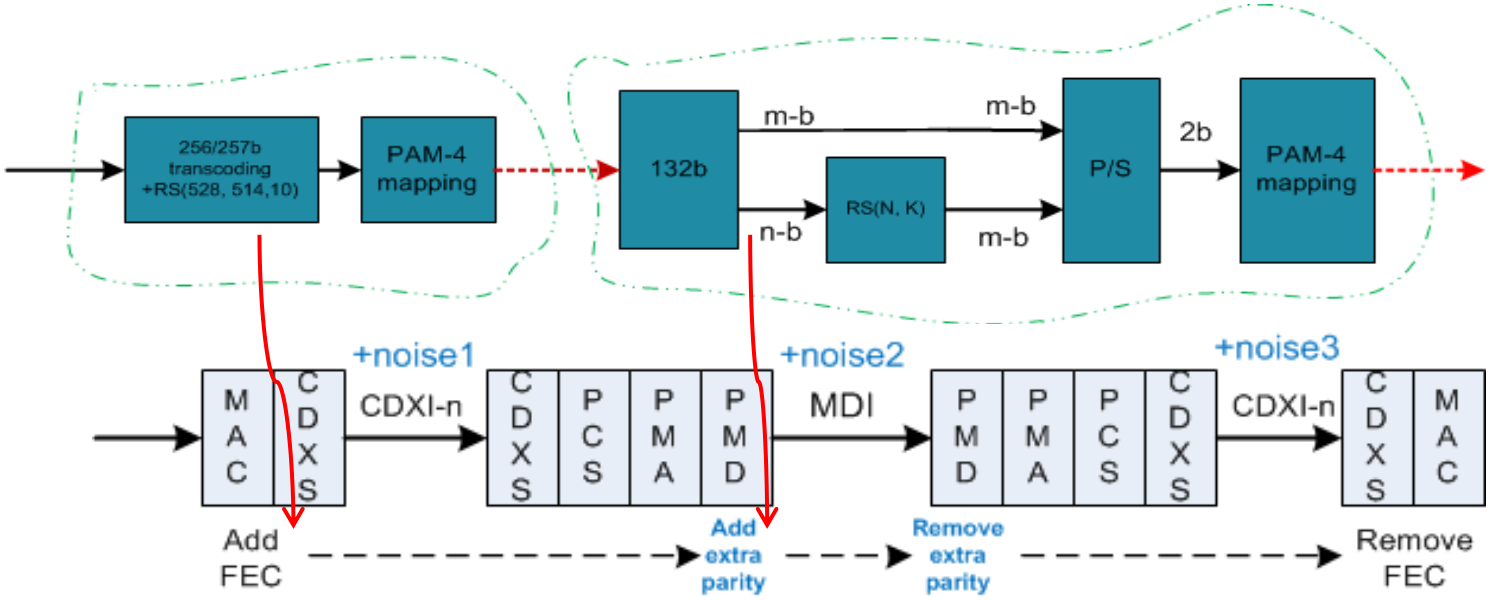
- Given a fixed overall redundancy ratio (i.e., overclocking ratio), we can allocate more redundancy to lsb to make FEC-2 a stronger one.
- Since strong FEC only runs at half data rate, the overall hardware complexity and power consumption are much reduced (e.g., 50Gbps FEC vs. 100Gbps FEC).
- The drawback is the slightly increased decoding latency due to serial processing of lsb decoding followed by msb decoding.



DISTRIBUTED MLC

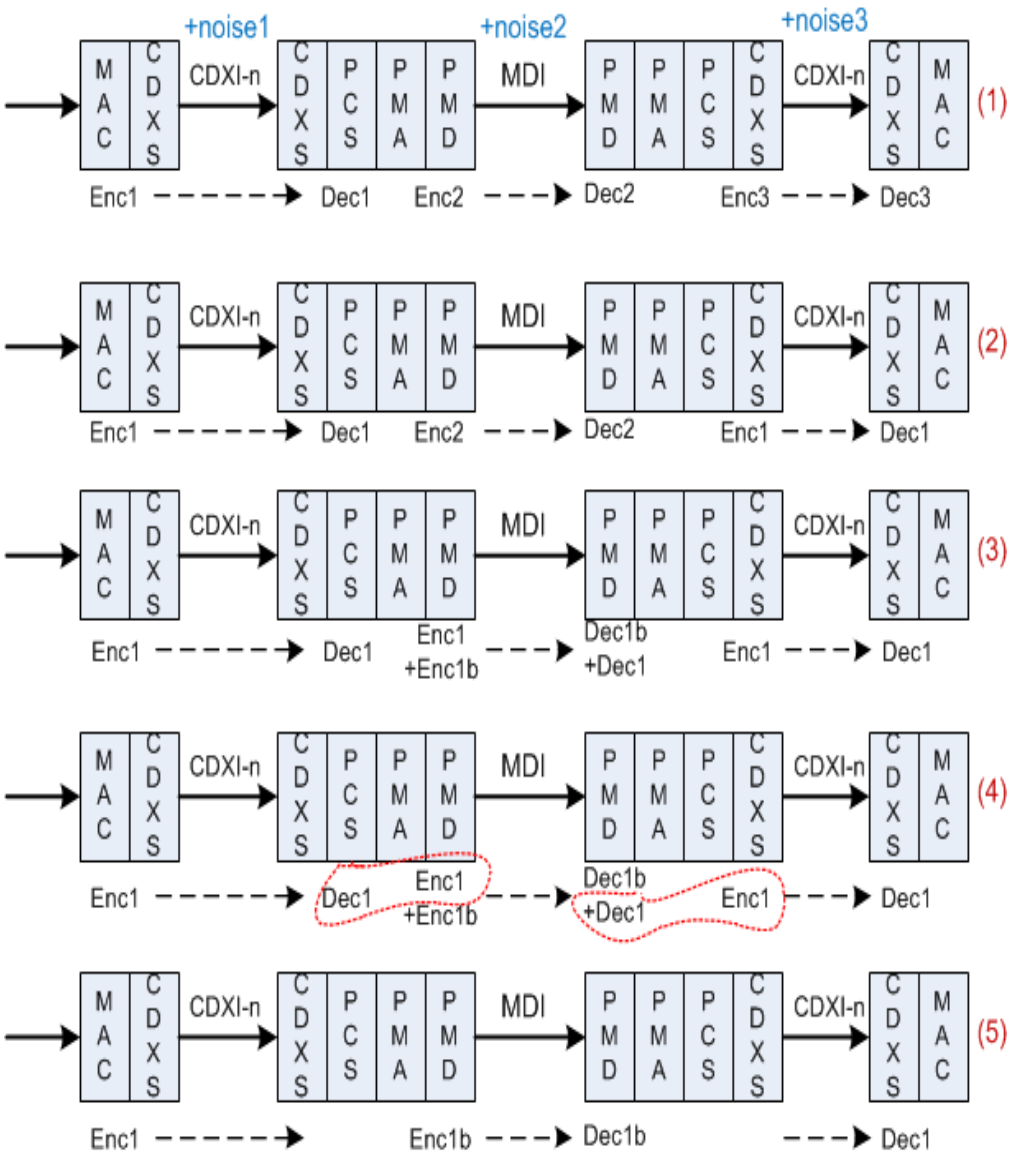
- With distributed MLC (dis-MLC) [2], the MLC encoding process is separately done in 2 different locations for multi-segment communications.

- Code-1 can select KR4 FEC or any other light FEC.
- Code-2 uses a strong FEC. It can also be an umbrella code consisting of *mother code* and *daughter code*.
- Example-1: Code-1 uses KR4 FEC, m=69, n=63
  Code-2 uses RS(552, 504, t=24, m=10). OC =4.5%



[2] http://www.ieee802.org/3/bs/public/adhoc/logic/oct21_14/wangz_01_1014_logic.pdf

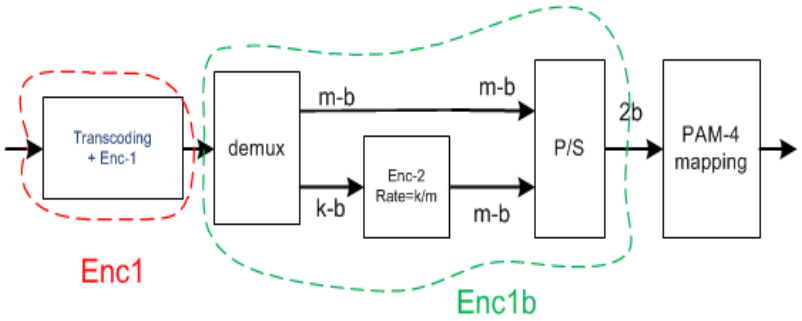
DIS-MLC IS A SIMPLIFIED SEGMENT-2-SEGMENT SCHEME



1) Typical *segment-to-segment* FEC structure

(2) Simplification: make code1=code3 making it symmetrical

(3) A special case of (2): use MLC for code2. Select outer code=code1, the 2nd portion of MLC is denoted as Enc1b.

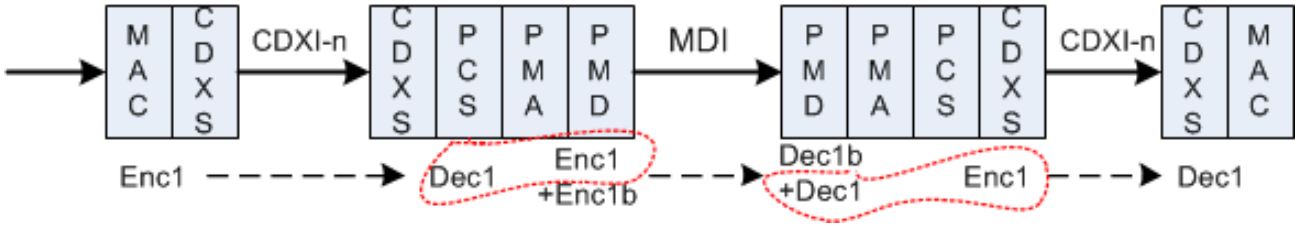


(4) Merge “Dec-1 and Enc-1” operations at module side. This is equivalent to correcting all errors without removing parity data

(5) One more step simplification based on (4): cancel “Dec1+Enc1” operation at module. This creates a distributed MLC scheme.

ANALYSES ABOUT DIS-MLC

- Key features:
  - Much reduced overall latency and overall power consumption
  - Reduce load for both switch and module due to distributed decoding.
  - Users can still have option of inserting "Dec1+Enc1" operation as shown below without changing standard spec. In this case, it goes back to segment-2-segment case. In practice, users can monitor input BER to decide the necessity to enable the "Clean Up" operation.
  - However, if we define a Seg-2-Seg scheme, then the long latency and large power consumption are forced.



- "Enc1b" is a part of MLC, It is not an independent FEC. Thus it differs from encapsulated case.
- Noise1+noise3 will be handled by code-1 while noise2 will be mainly handled by code-2.

ANALYSES (CONT'D)

- In case of error propagation, msb are much less affected than lsb. For instance, sliced msb values will be correct as long as the total induced noises are smaller than dmin (min distance between 2 constellations in PAM-N systems). For lsb, it will cause errors if the induced error is larger than dmin/2.

- To support multi-PMDs, options include
  - let Code-2 use umbrella code to provide tradeoffs between coding gain, power, and latency while ensuring same clocking rate all the time
    - mother code: longer code, higher gain with longer latency
    - daughter code: shorter code , lower gain with lower latency
  - bypass 2nd part of MLC encoding for good channels. Not preferred due to non-constant PLL ratio.

FEC CANDIDATE CODE WITH 8+DB CG

- **Use MLC-based umbrella coding (MLC-UC):**
  - Ex-2: Code-1 uses RS(528, 514, t=7), OC=9%
    - Inner daughter code: RS(144, 120, t=12) (optional)
    - Inner mother code: RS(288, 240, t=24).
    - CG ~ 8.5dB (mother code mode)
    - Power: < 3.5X KR4-FEC

- Compared to 5-segment connections with segment-2-segment FEC scheme using BCH1 for PMD:
  - Seg-2-seg case:: HW: ~ 1X5+10X1= 15X bj FEC
    Latency: ~ 50nsX4+100ns =300ns
    Power: 10~12X bj FEC
  - Dis-MLC case: : HW: ~ 1X+4X = 5X bj FEC
    Latency: ~50ns + 100ns = 150ns
    Power: ~ 3.5X bj FEC

- In brief, either latency, hardware, or power can be reduced by more than half with **dis-MLC scheme** in the worst case.

SUMMARY

- MLC schemes used for communication systems based on PAM-N or QAM-M modulations are well-known and mature.
- Using MLC to achieve high coding gain for FEC is both power and hardware efficient.
- The distributed MLC (dis-MLC) scheme has been shown to be a simplified version of Segment-to-Segment FEC strategy under certain conditions. It has good advantages in terms of power, latency, and hardware complexity in real implementation.