Error Correction Coding for Passive Optical Networks

Rainer Strobel

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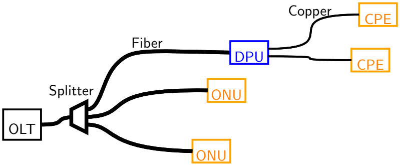
Overview

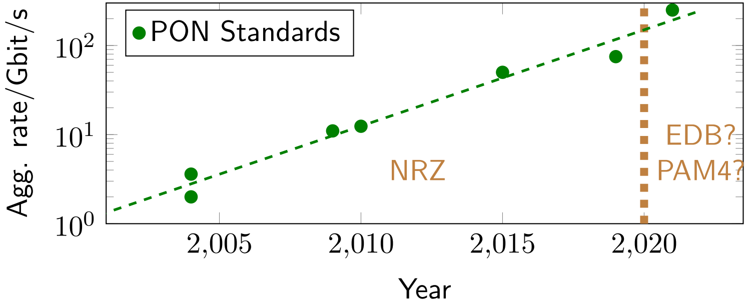
Passive Optical Networks



PON Characteristics

- Fiber access network, fiber to the home (FTTH), but also fiber to the building/distirbution point (FTTB, FTTdp)
- Point-to-multipoint (P2MP) link between optical line termination (OLT) and multiple optical network units (ONU)
- No active components between OLT and ONU
- Typical reach 20 km, typical split factor 32
- Low cost electrical/optical components

PON Innovation



Modulation

- NRZ used in standard PONs
- EDB, PAM-4 discussed for G.HSP

Multiplexing

- TDMA used in standard PONs
- TWDM used in more recent PONs

Coding

- RS code used in legacy PONs
- LDPC introduced in IEEE 802.3ca and considered for G.HSP

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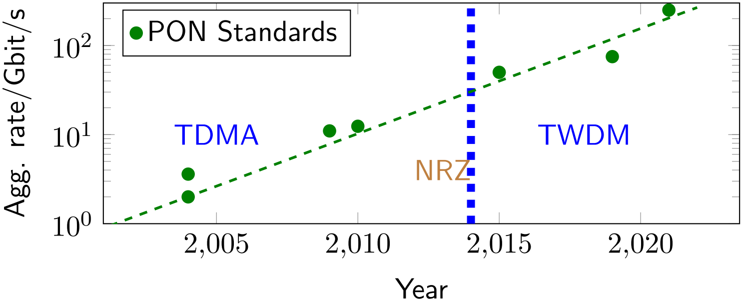

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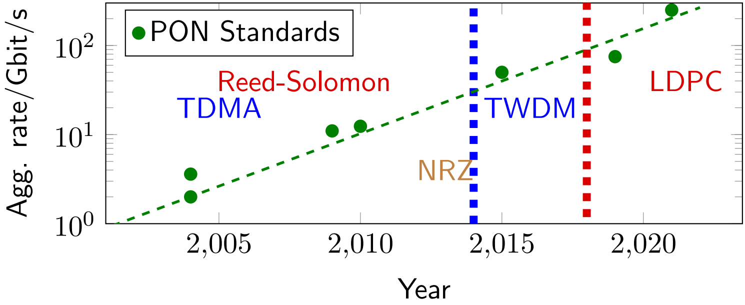

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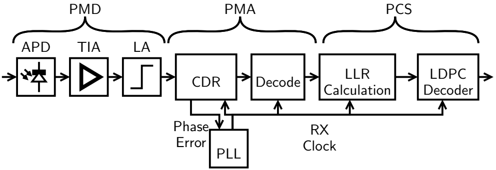
ONU Receiver Block Diagram



PON Physical Layer

PCS: Physical Coding Sublayer (LDPC, scrambling, control channel)

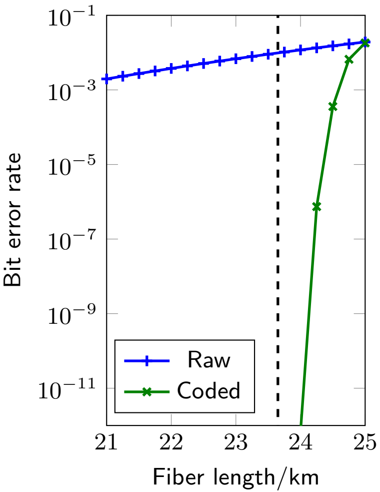
PMA: Physical Medium Attachment (digital signal recovery)

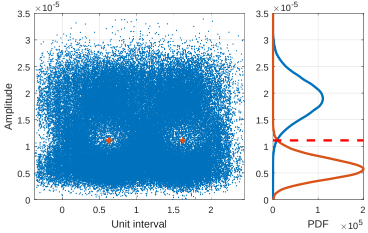
PMD: Physical Medium Dependent (optoelectronic conversion)

LDPC Requirements (25G)

- Output bit error rate $< 10^{-12}$ at 10^{-2} receive bit error rate
- Low latency $\approx 10\mu$s for wireless front-haul

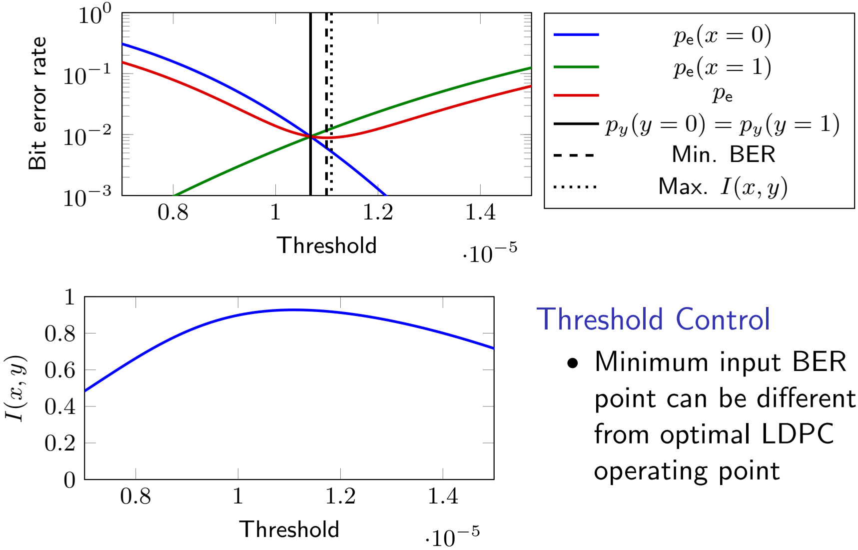
Binary Receiver Error Probabilities





- Optical channel cannot be described by a simple binary symmetric channel (BSC) or additive white Gaussian noise (AWGN) channel
- Definition of coding requirements with raw BER is not convenient

Receiver Optimization - Binary Receiver

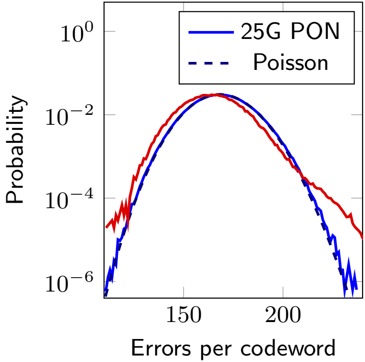


Threshold Control

- Minimum input BER point can be different from optimal LDPC operating point

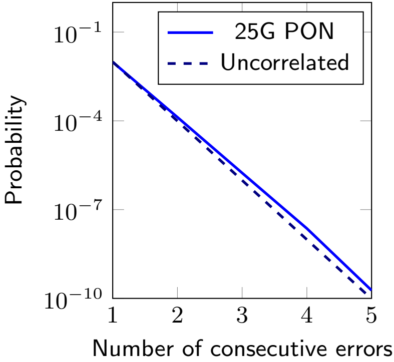
Statistical Properties

Errors per Codeword



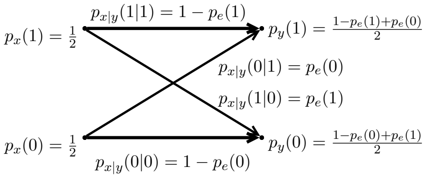
- Distribution of errors per codeword influences LDPC performance

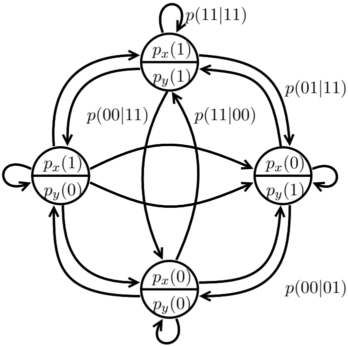
Burst Errors



- Knowledge of burst errors can be used for decoding

Binary Error Models





Memoryless Channel

$x \in \{0,1\}$: transmitted symbol;
$y \in \{0,1\}$: received symbol
$p_\mathsf{e}(0), p_\mathsf{e}(1)$: Error probability of 1 and 0 transmitted

Binary Channel with Memory

Transition matrix $\boldsymbol{T}$ and state vector $\boldsymbol{p} = [p_{xy}(0,0), p_{xy}(0,1), p_{xy}(1,0), p_{xy}(1,1)]^\mathsf{T}$ such that $\boldsymbol{p}_{t+1} = \boldsymbol{T}\boldsymbol{p}_t$.

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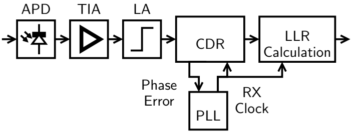
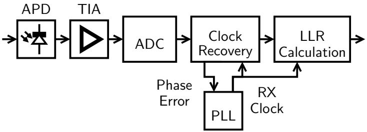
ONU Receiver Implementation





Hard Decision Receiver

- Low cost components
- Low power consumption
- Lower FEC performance

Soft Decision Receiver

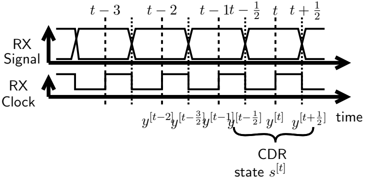
- Analog-to-digital converter required
- Higher FEC performance

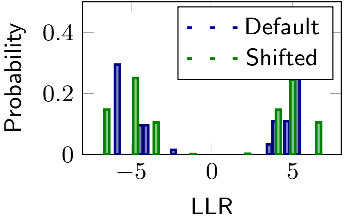
Binary Receiver/Soft Input

- Derive soft input for LDPC from CDR
- Compromise between complexity and power consumption

Receiver Optimization - Soft Information

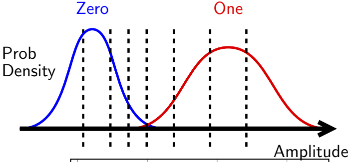
CDR State Information

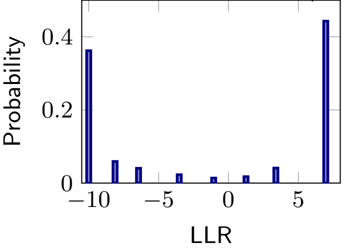




- Derive LLR from CDR states
- Optimize sample points

Analog-to-Digital Converter





- Optimize quantization intervals of ADC

Overview

Conclusion and Outlook

Conclusion

- Coding is a key component for evolving fiber access technologies
- Optimized channel coding requires
  - good understanding and modeling of the channel
  - innovative, cost-efficient transceiver designs

Outlook

- Coding in combination with improved modulation formats
- Digital signal processing and error correction coding
- Energy efficient designs for high throughput