Exploitation of RBER Diversity across Dies to Improve ECC Performance in NAND Flash Drive

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RBER Variation across dies

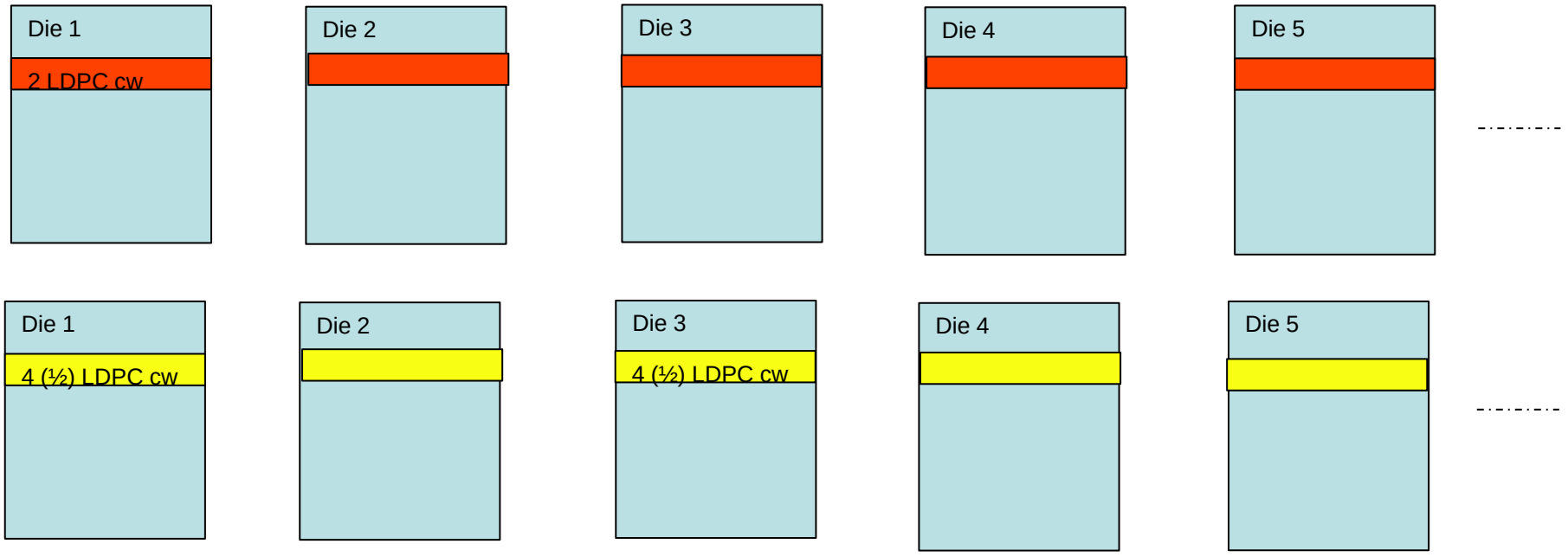
- There is a wide variation in the die to die raw bit error rate (RBER)
- There is a block to block and page to page variation in the RBER
- ECC designed for the worst page RBER- it is an overkill
- ECC designed for the average RBER is also an overkill

Leverage the RBER Diversity

- LDPC based ECC solutions
- Don’t store a full LDPC codeword in a single die
- Spread the codeword across dies
- RBER tolerance improves as number of dies split over increases
- Drawback is that the read/access time increases

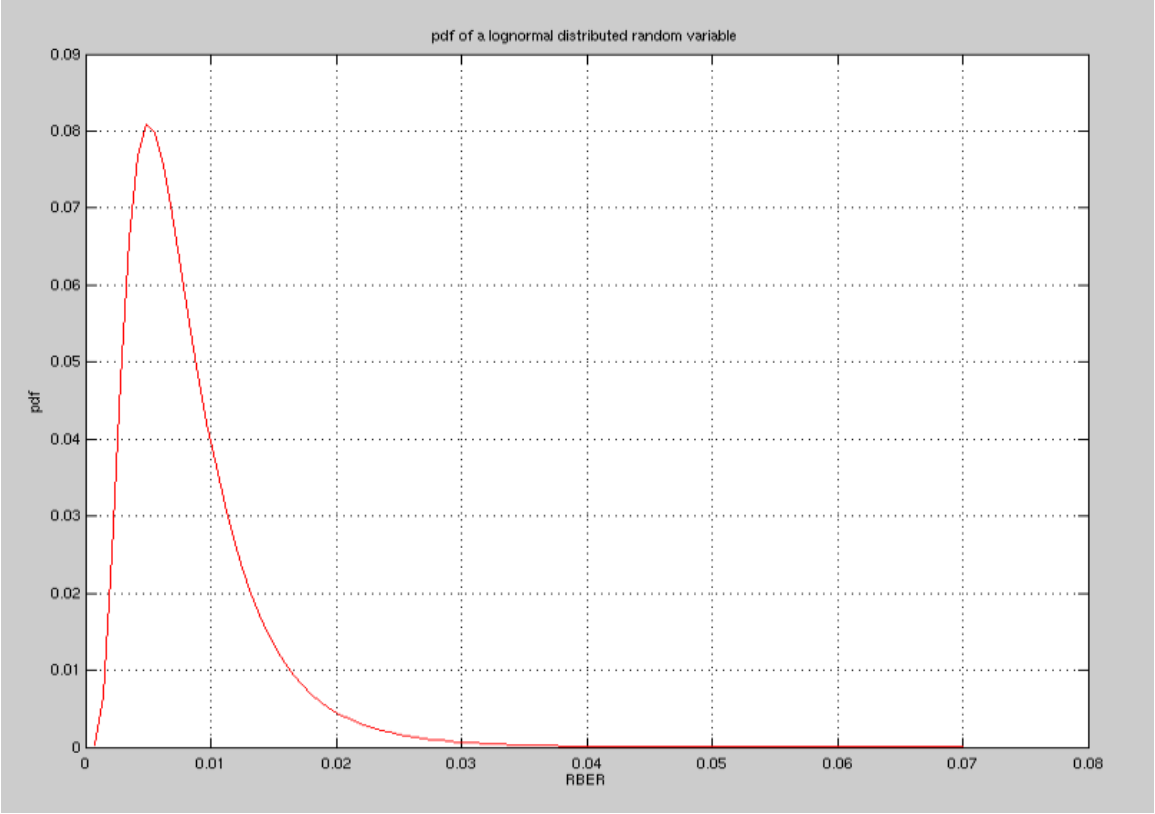
2KB LDPC Codeword Split

- 2KB LDPC codeword split across 2 dies



Modeling

- RBER across dies follows a log-normal distribution



Modeling

- Can exploit Page-to-Page and Block-to-Block variation
- Choice of dies to spread the LDPC codeword across
- Dynamic allocation as we cycle the NAND
- System rebuild option
- Effective RBER distribution is the convolution of two lognormal distributions

Spread the LDPC codeword

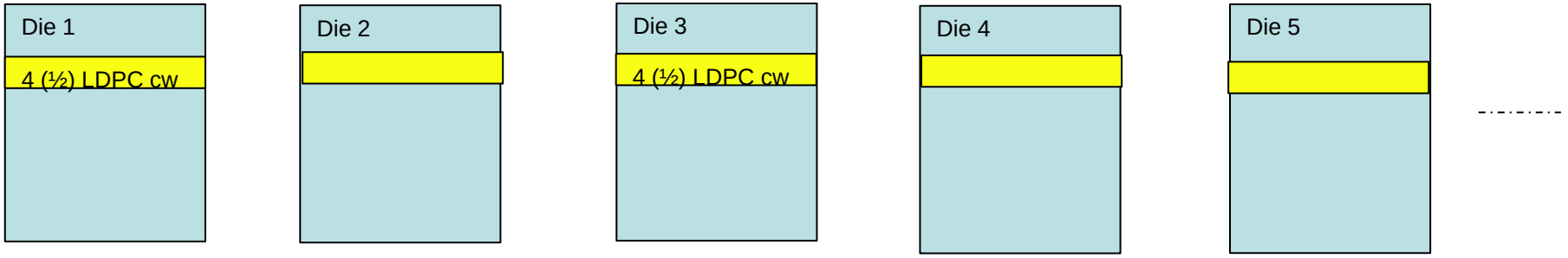
- Choice of dies to spread the LDPC codeword across
- Dynamic allocation as we cycle the NAND
- System rebuild option

Outage

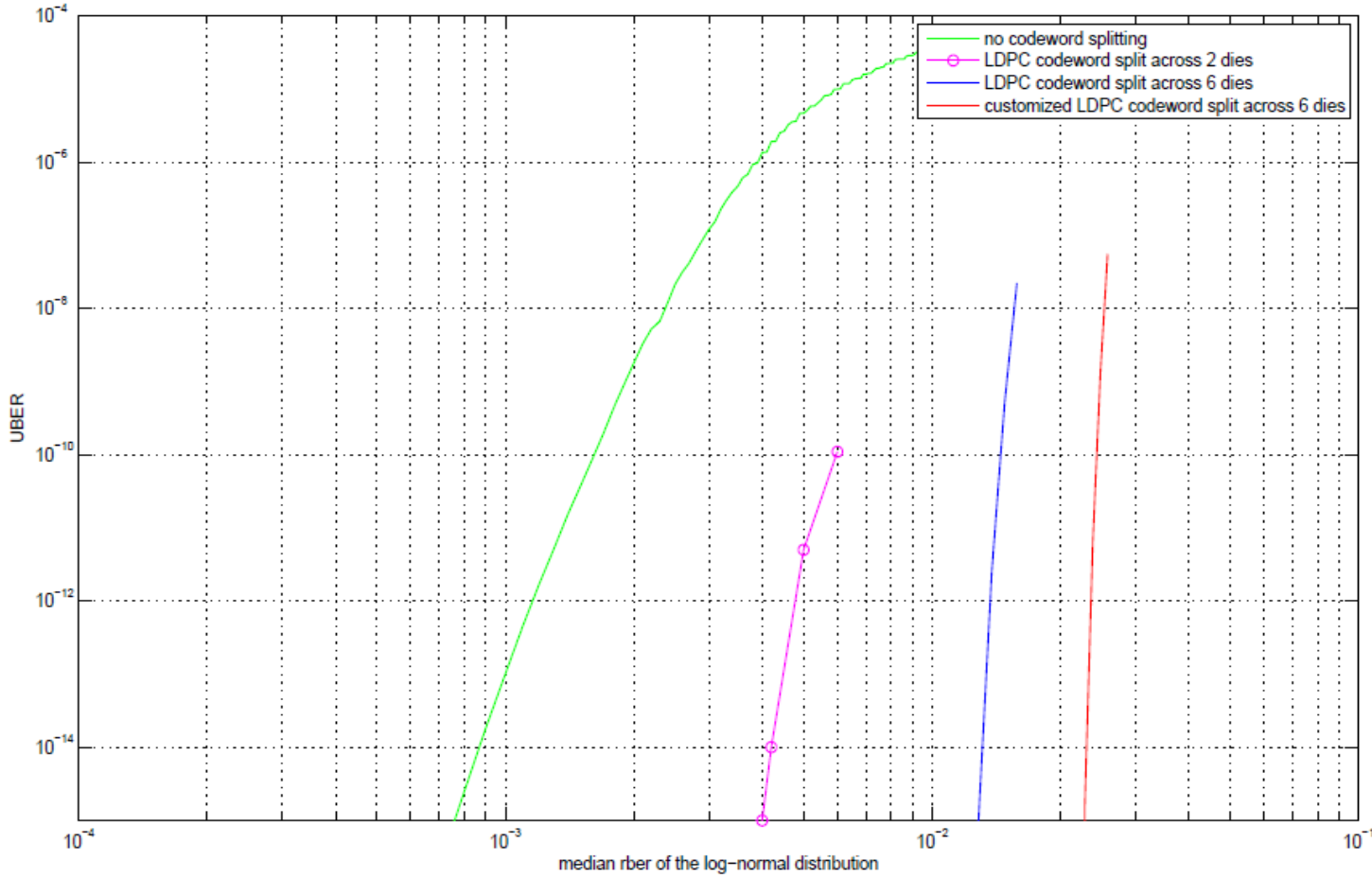
- Outage- Wireless Communications
- Instantaneous Capacity of the channel is lower than the transmission rate
- Error free transmission is not possible
- Keep this probability below system specified limits

Read and LLR assignment

- Read the two portions of the LDPC codeword
- Assign LLRs depending on the RBER of the die



RBER Gains

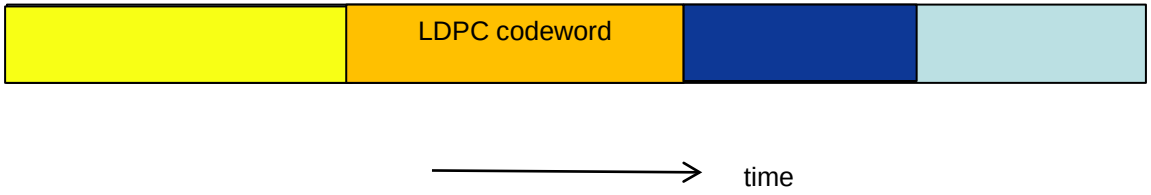

no codeword splitting
LDPC codeword split across 2 dies
LDPC codeword split across 6 dies
customized LDPC codeword split across 6 dies
UBER
median rber of the log−normal distribution

Quality of Service (QoS)

- Read completion once host access is placed
- Sequential access versus random access
- Payload is a mix of sequential and random access- Model
- Read time increase is limited and does not impair the QoS
- Not all RBER gains can be realized- QoS dictates

Similarity to block-fading Wireless Channel

- Temporal Diversity
  - Quasi-static fading channel
  - RBER of the channel varies over time for the same codeword



  - Distribution of LDPC codeword across dies is actually the same problem

LDPC Code design for block fading channels

- Customized LDPC code designs
  - AWGN Channel
  - Flash Channel
  - Quasi-static fading channels
- Diversity

LDPC Code design for block fading channels

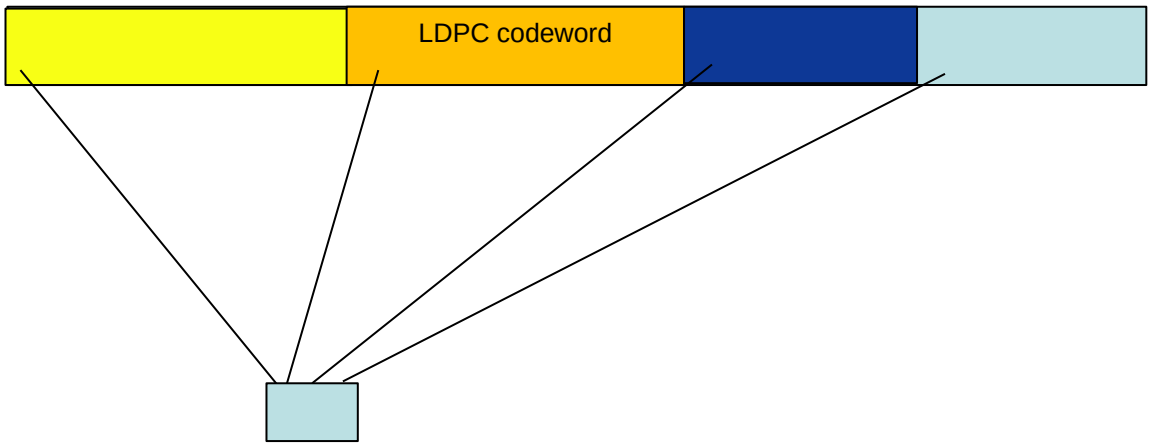
- Customized LDPC code designs
  - Root-LDPC Codes
  - Full Diversity for all information bits
  - Root connections under message passing
  - F is the number of fading blocks
  - Rate =1/F

Custom designed LDPC Codes- Comparison to BF channel

- Customized LDPC code designs
  - R=1/F not possible with F=2
  - Cannot guarantee full diversity
  - Full diversity not a must as choice of dies is a design feature
  - Wireless channels have no choice of RBER
  - Rayleigh fading channel for Wireless vs lognormal RBER distribution

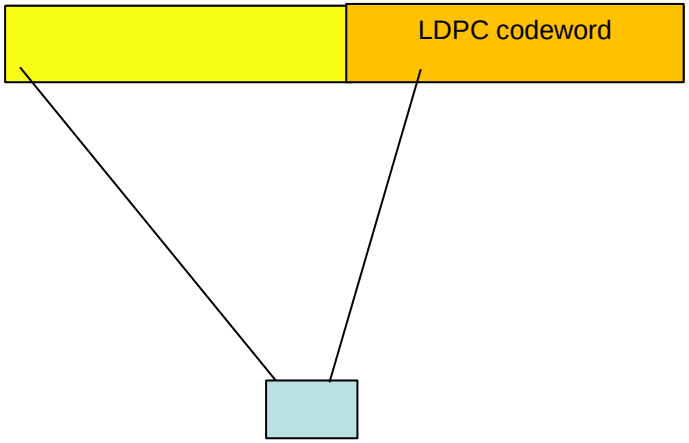
Custom designed LDPC Codes- BF channels

- Design ensures that bit node receives extrinsic information from all fading channels

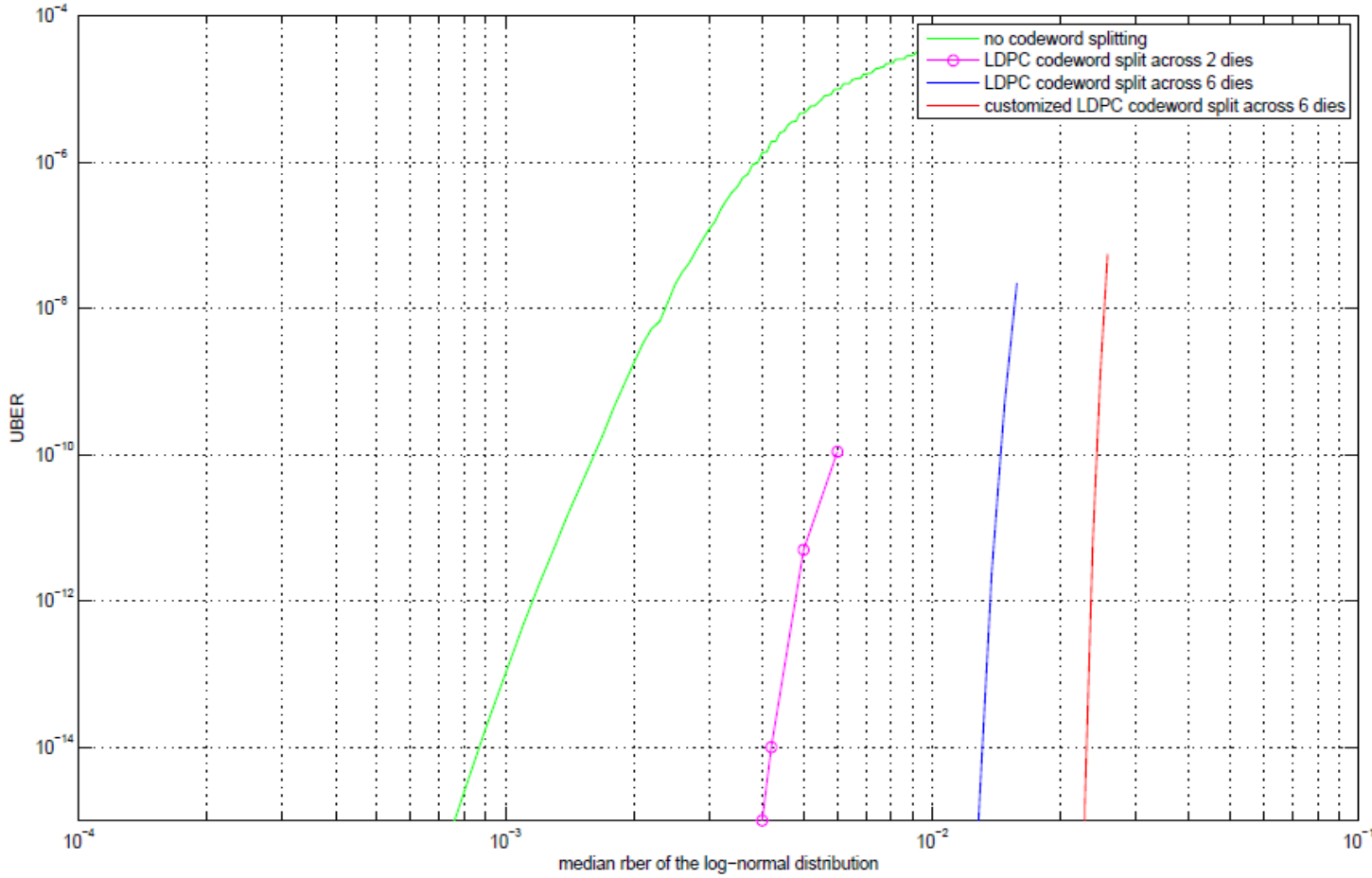


Custom designed LDPC

- Bits split into the 2 fading channel blocks
- Some parity checks localized within a single fading block
- Choice of dies
- Average across the lognormal RBER



Custom designe LDPC Gains



Summary

- Spread LDPC codeword across dies
- Impact on QoS
- RBER gains of 5x for spread across 2 dies
- Customized LDPC code design
- Comparison to Wireless Channel
- Block Fading Channels
- RBER gains of 2x for spread across 2 dies