Using LDPC Codes in SSD

--- Challenges and Solutions

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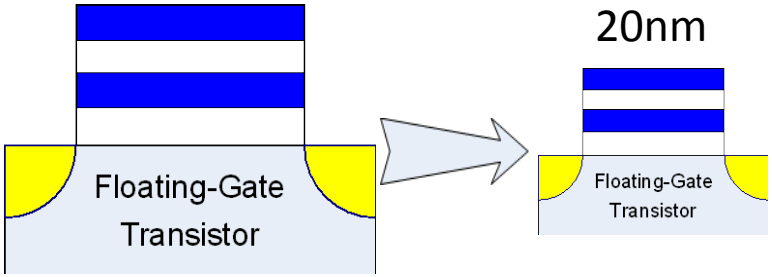
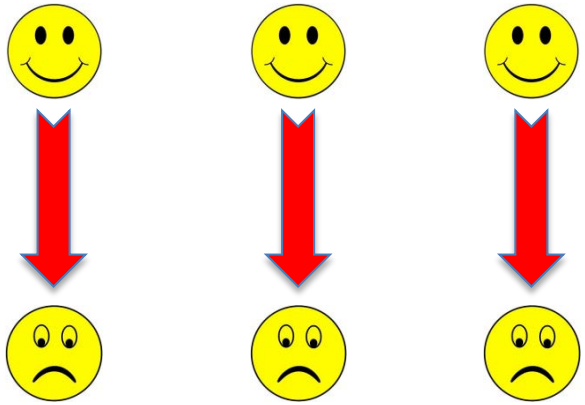
Introduction and Motivation

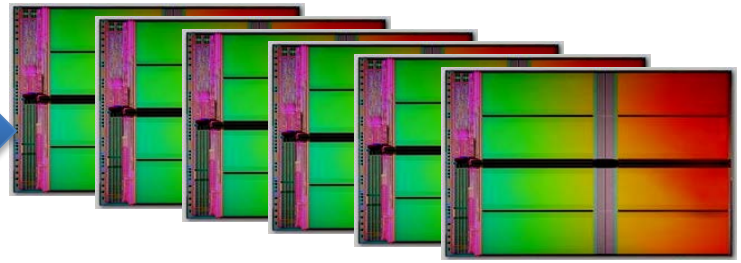
Cheaper flash



Error Rate Endurance Retention



System & Controller



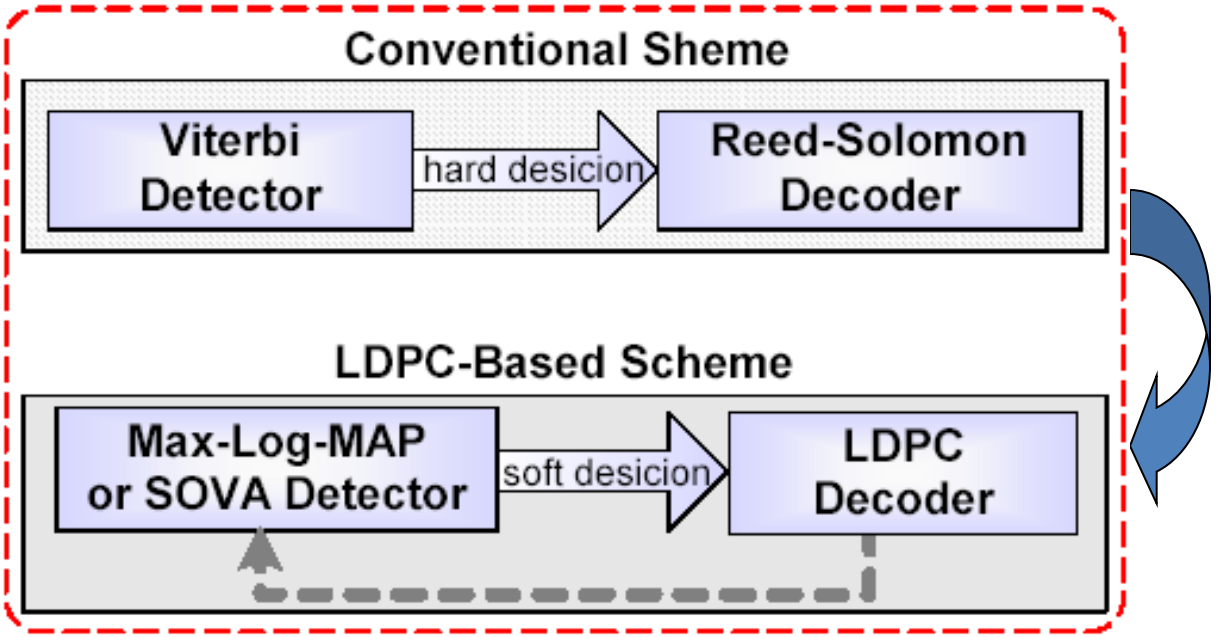
More and more powerful

Less and less reliable

Stronger Error Correction Codes

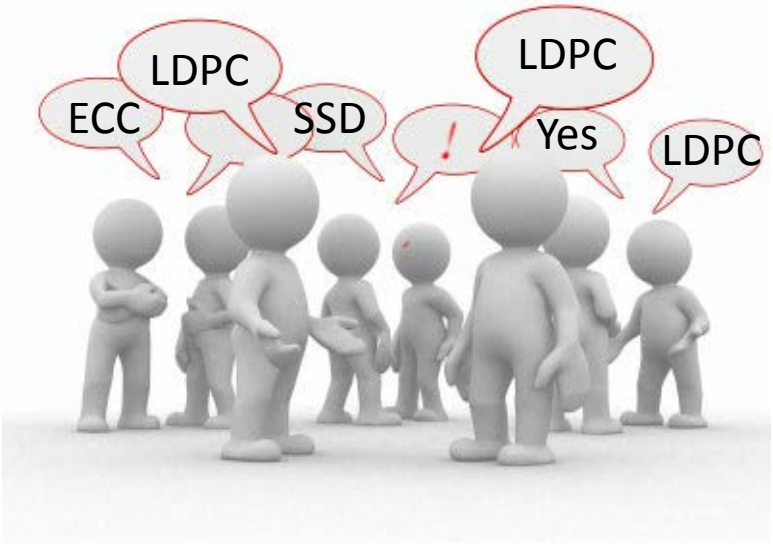
Introduction and Motivation

Hard disk drive



LDPC codes for SSD

HOT



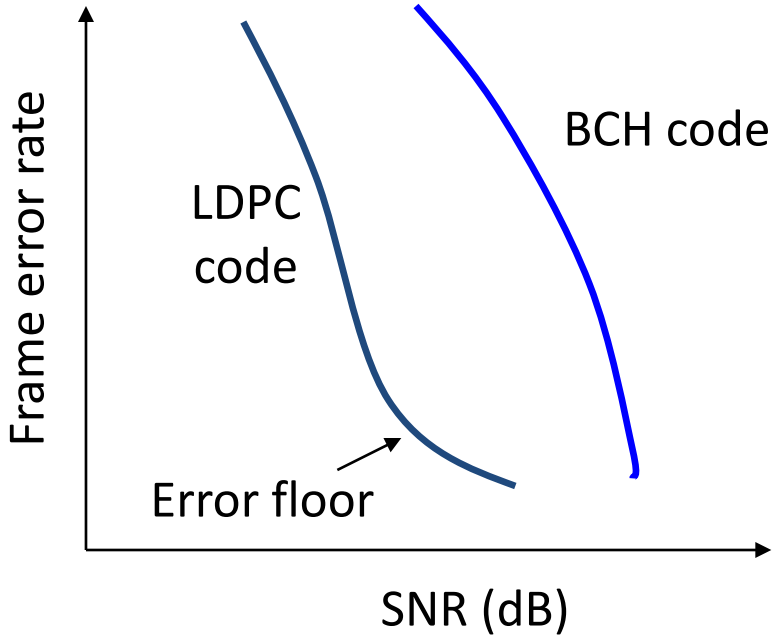
LDPC for SSDs: Challenges

? Error floor of LDPC codes

? Memory read latency overhead

? ~~Low-cost, high-speed LDPC decoder implementation~~

Error Floor of LDPC Codes



- ❑ Nature of iterative codes
- ❑ Impossible to eliminate error floor ☹
- ❑ Sufficient coding gain in practically interested frame error rate region

➨ Estimate LDPC code error floor

➨ Construct LDPC code with sufficiently low error floor

Solutions

- ✧ General-purpose Parallel Computing Facility

- ❑ **A software tool set for LDPC code error floor estimation**

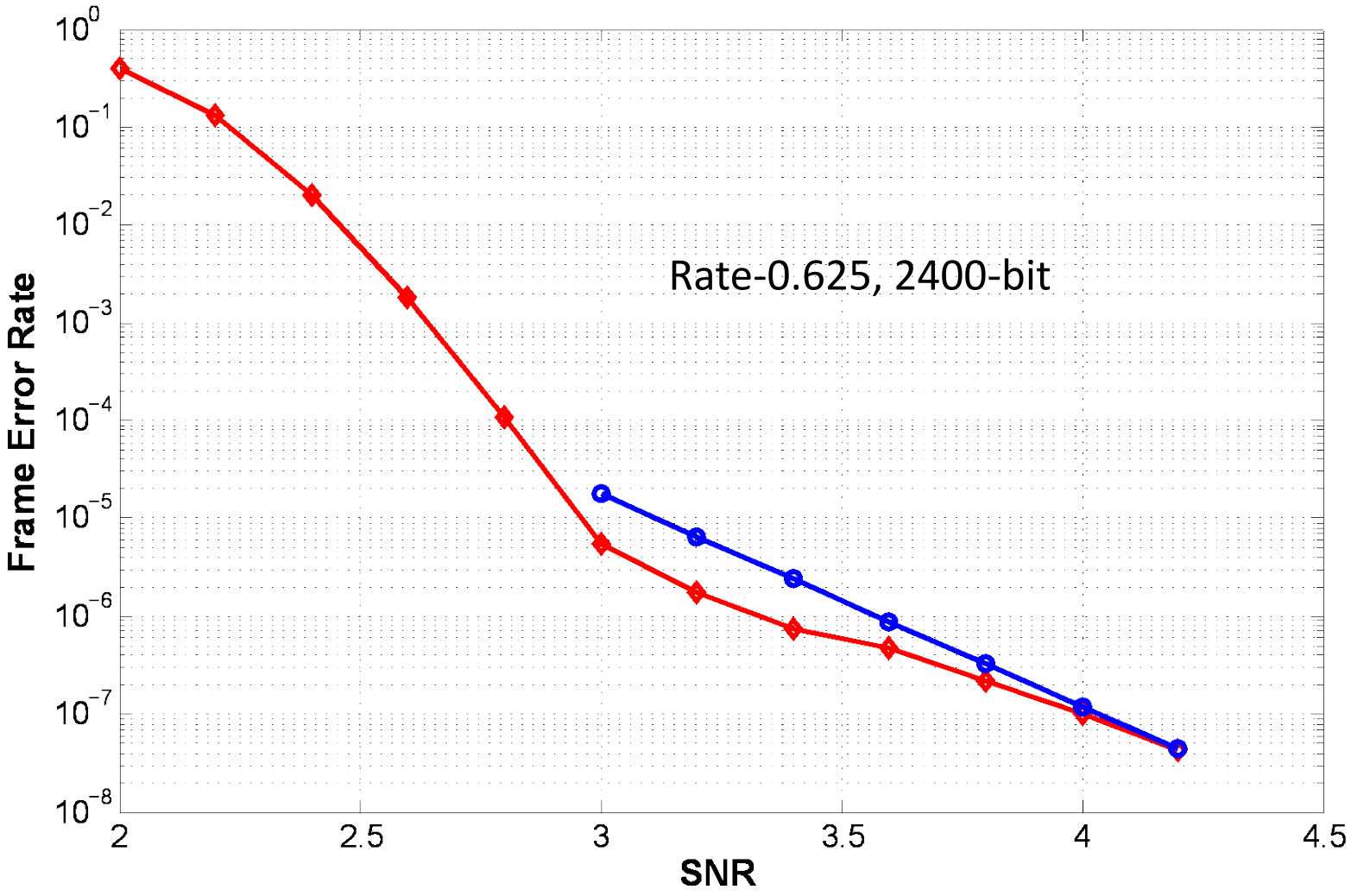
- ❑ Fully tested by running on 8192 cores in a super computer cluster

- ❑ Many algorithms/techniques to improve both accuracy and speed

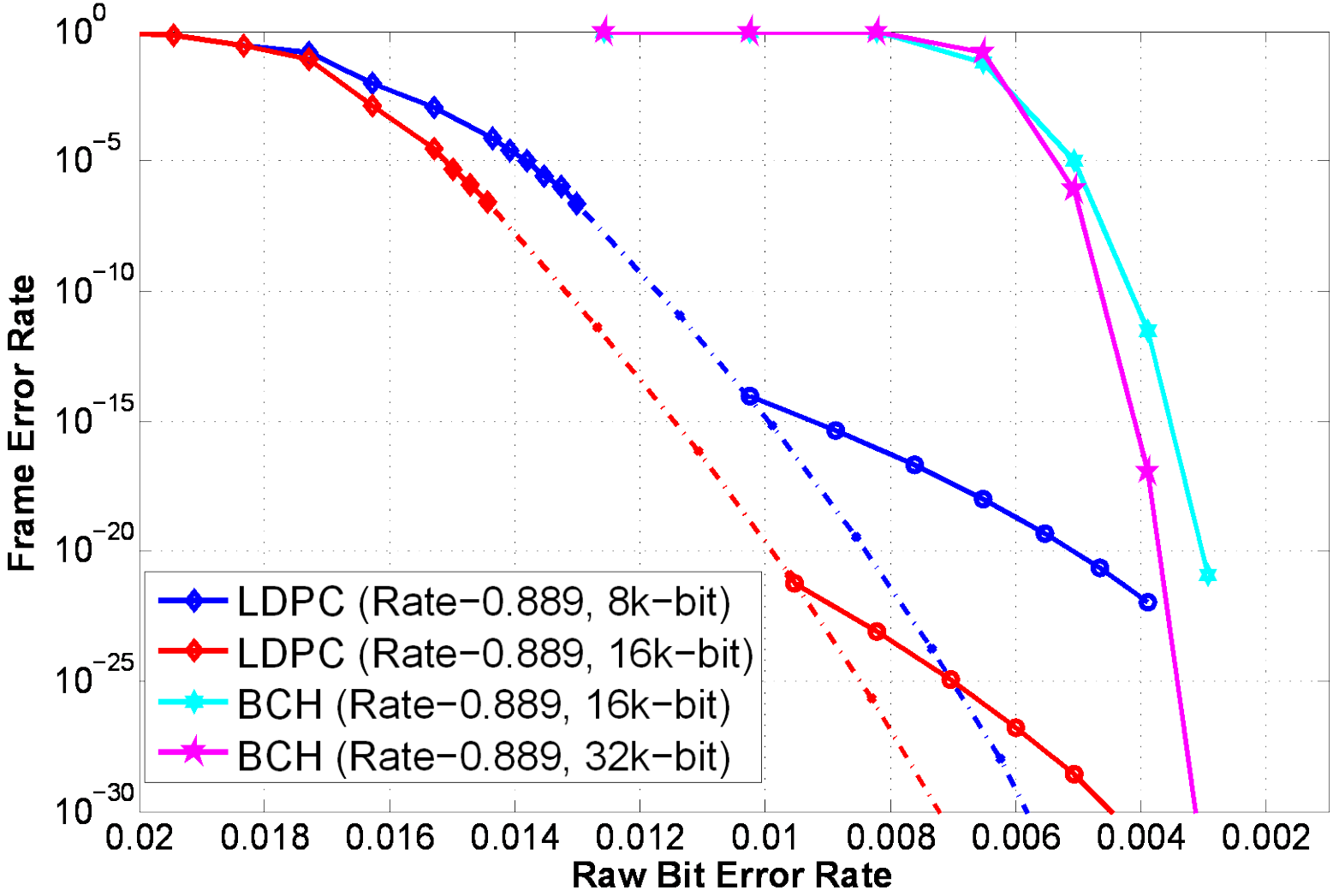
  - ➢ Estimate the error floor of a 16k-bit LDPC code in **just one day**

A tool set to construct LDPC codes with low error floor

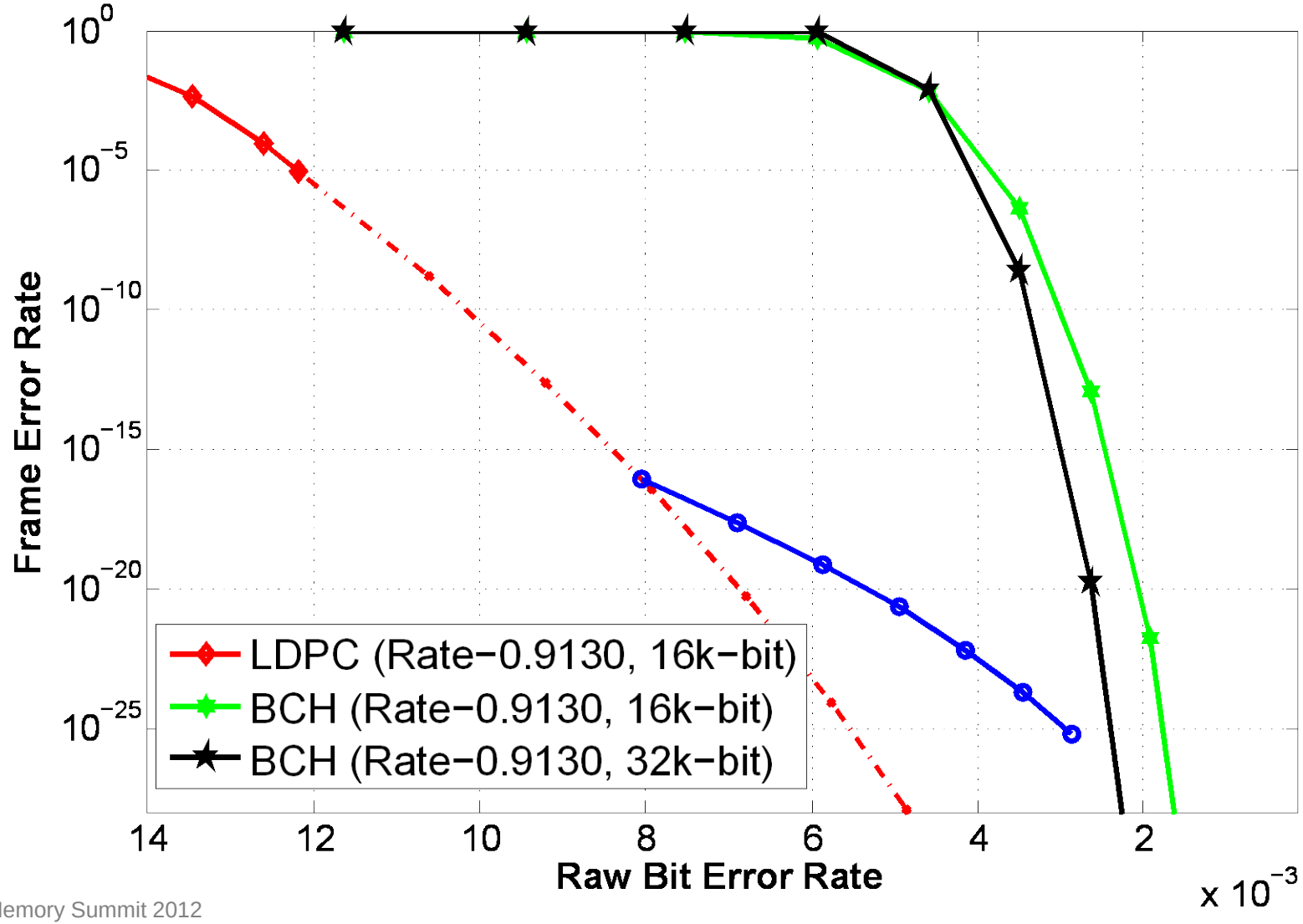
Verification



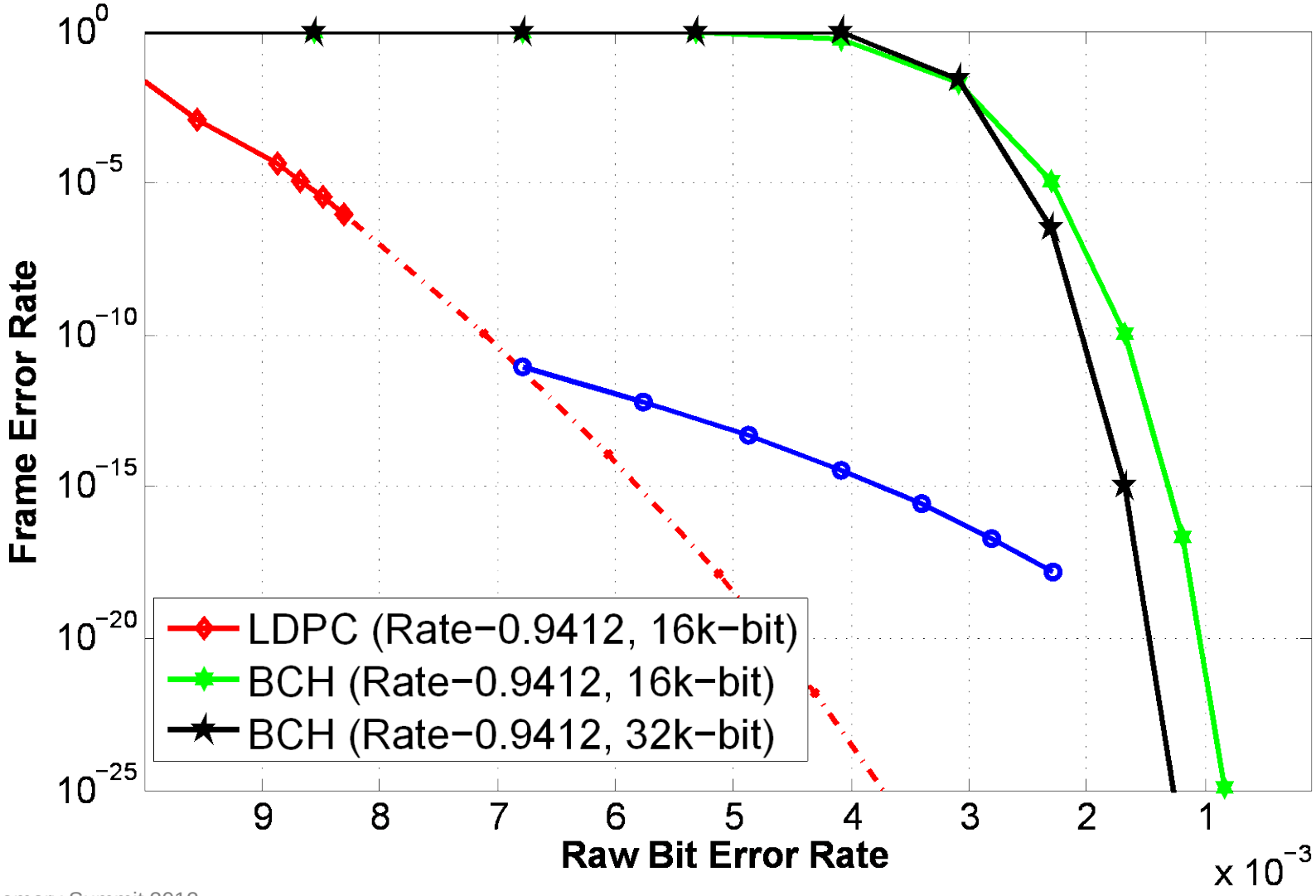
Performance of Our LDPC Codes (1)



Performance of Our LDPC Codes (2)



Performance of Our LDPC Codes (3)



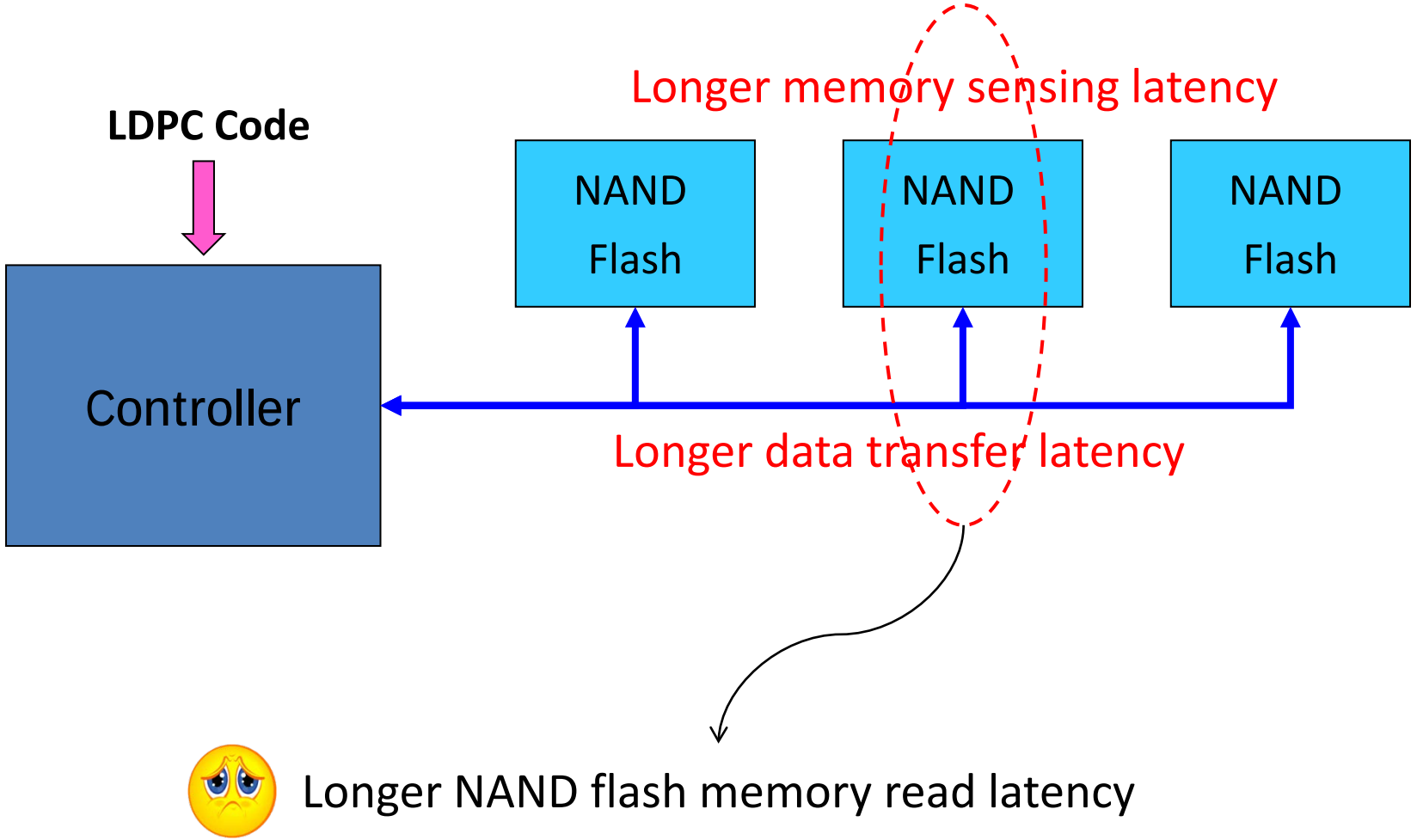
LDPC for SSDs: Challenges

Estimation of LDPC code error floor

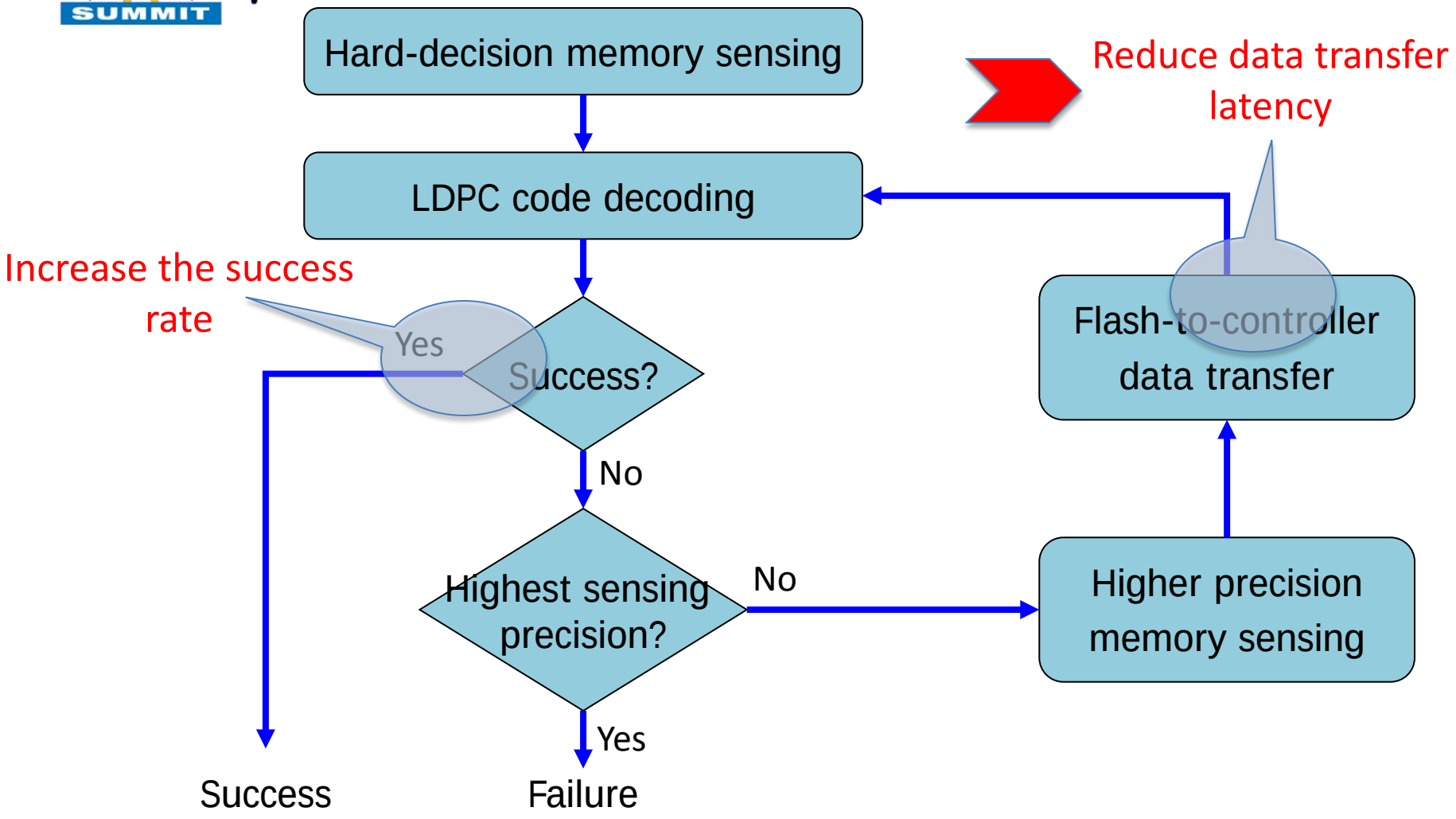
Construction of low-error-floor LDPC codes

? Memory read latency overhead

Memory Read Latency



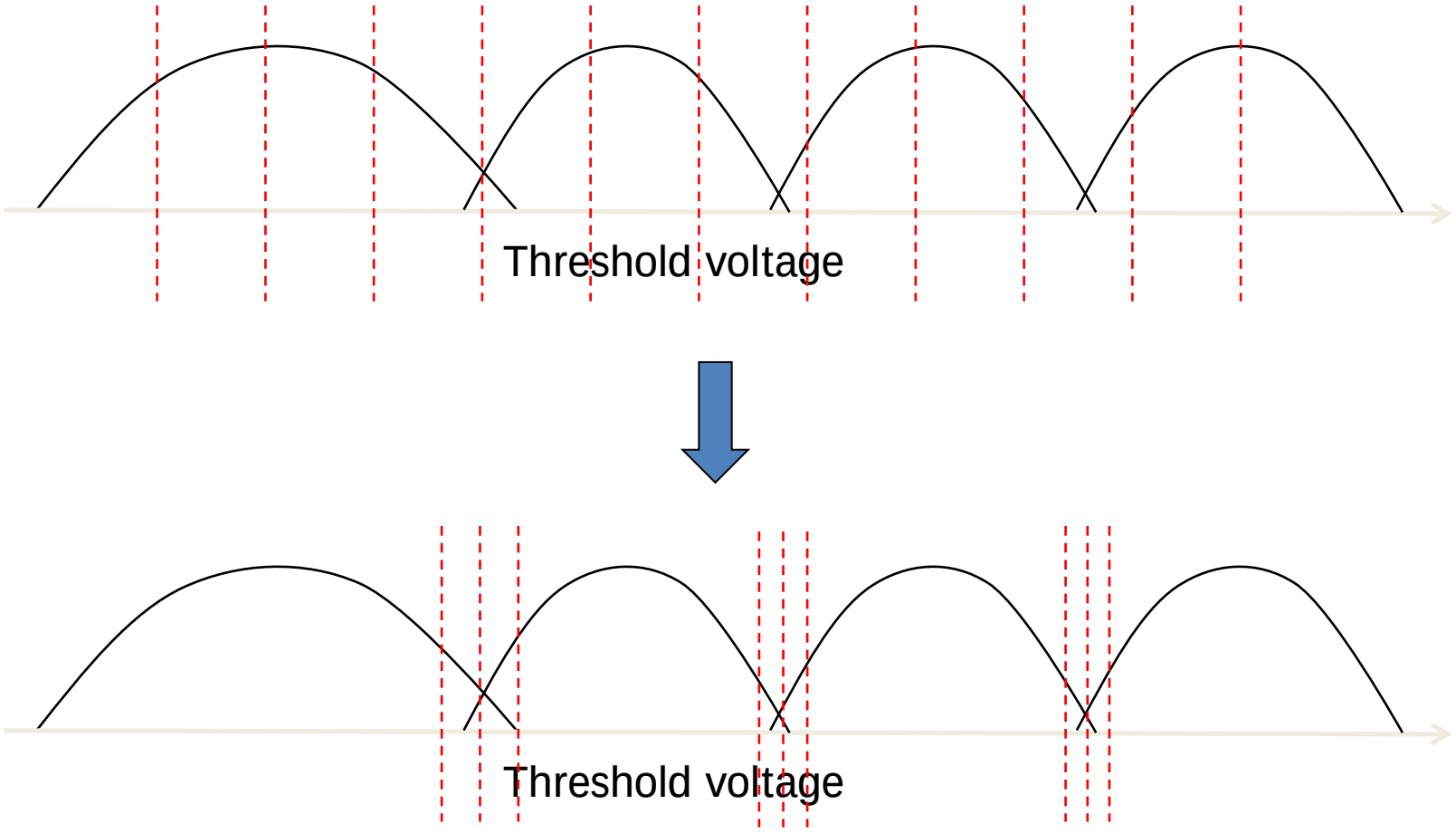
Progressive Soft-Decision Memory Sensing



A set of cross-layer design solutions

Reduce Read Latency Overhead

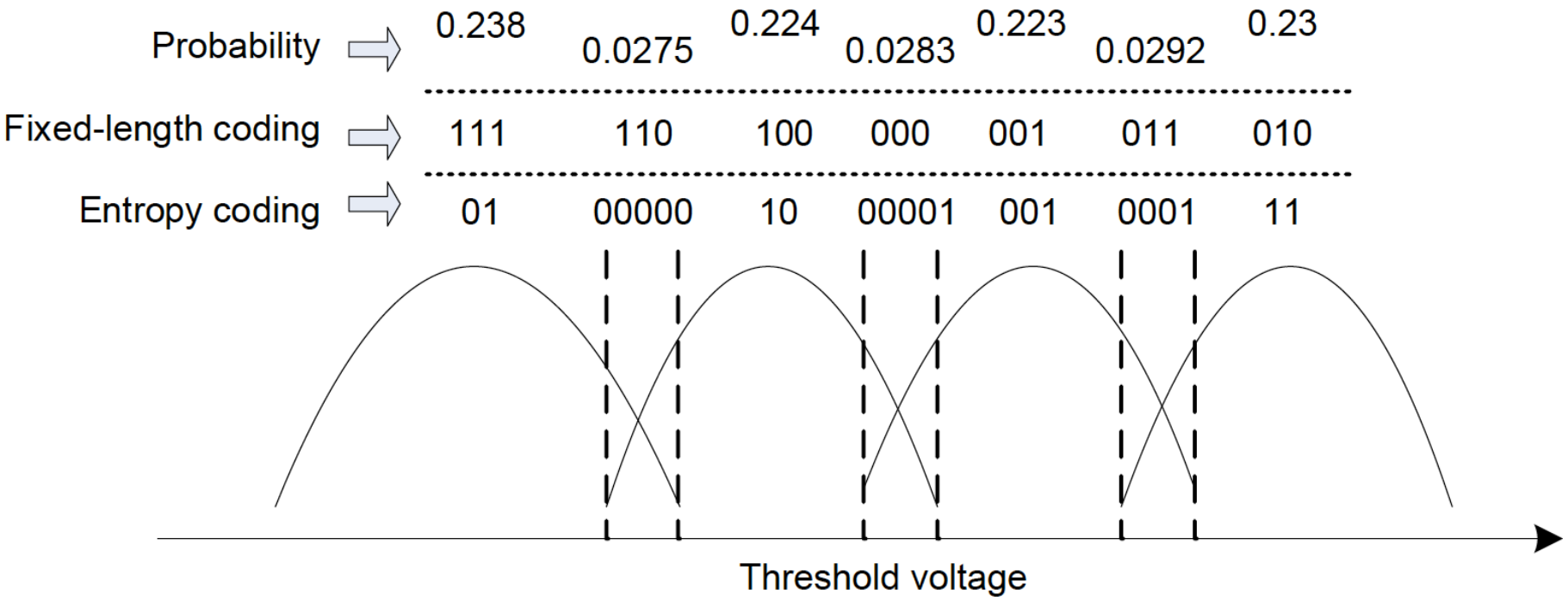
- Non-uniform quantization memory sensing



Reduce Flash-Controller Data Transfer Latency

Non-uniform quantization memory sensing

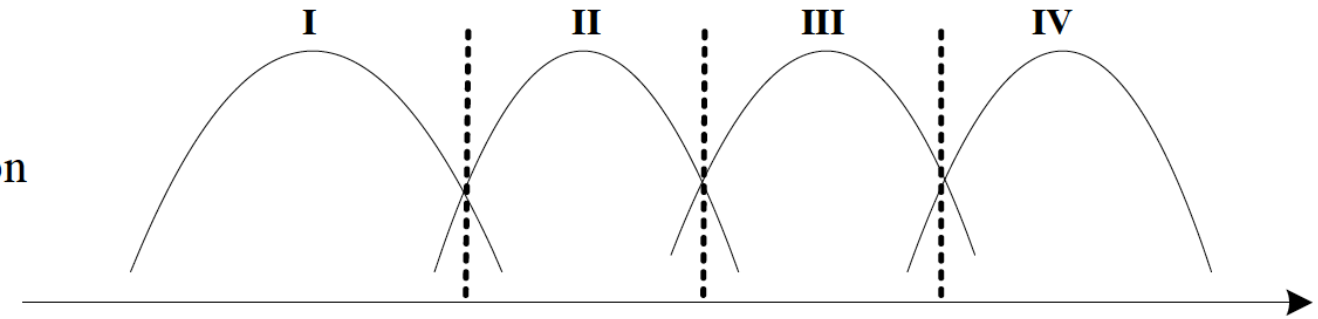
Memory cell threshold distribution



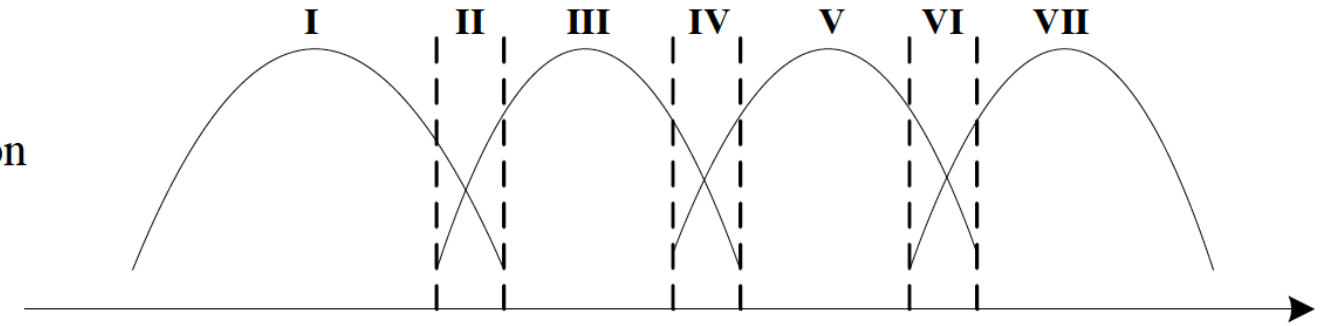
One Step Further

- Progressive soft-decision sensing

1st step: 4-level hard-decision sensing



2nd step: 7-level soft-decision sensing

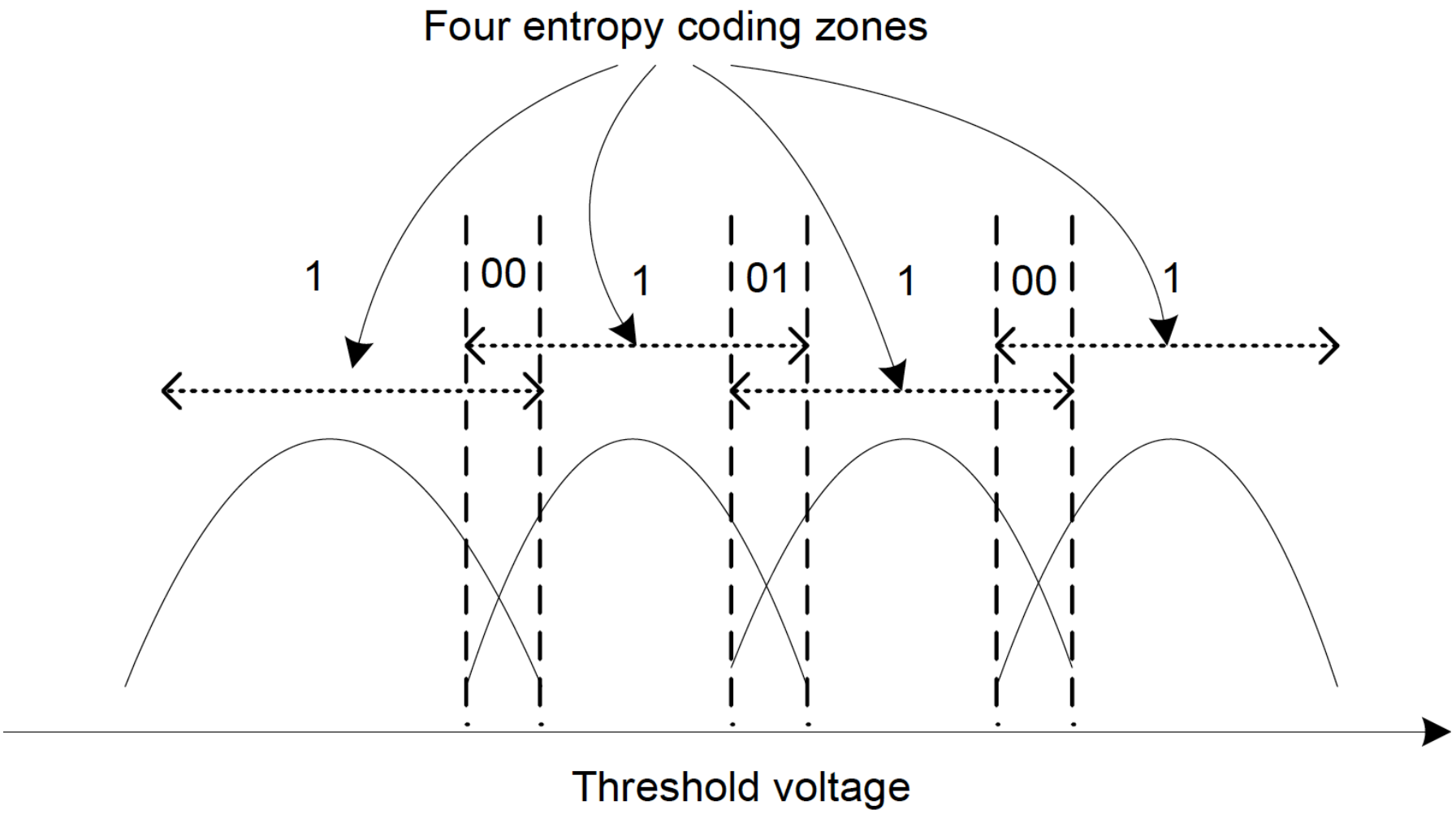


1st step sensing results

Reduce 2nd step sensing result coding overhead

Zoned Entropy Coding

Progressive soft-decision sensing ➔ zoned entropy coding



Evaluations

Probabilities and codewords of 2nd-step soft-decision sensing results.

Level index	Probability	Fixed-length coding	Entropy coding	Zoned Entropy Coding
I	0.2397	111	01	1
II	0.0255	110	00000	00
III	0.2255	100	10	1
IV	0.0263	000	00001	01
V	0.2245	001	001	1
VI	0.027	011	0001	00
VII	0.2315	010	11	1

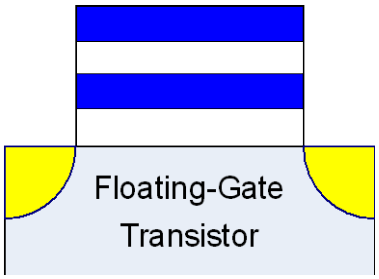
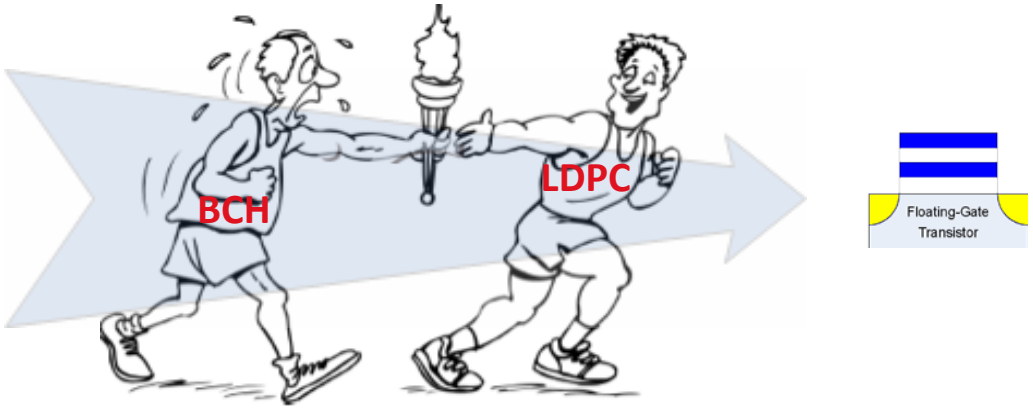
20.4% reduction of transfer latency

64.8% reduction of transfer latency

LDPC for SSDs: Challenges & Solutions

? **Error floor of LDPC codes**

- ✓ A tool set for LDPC code error floor estimation
- ✓ A tool set for low-error-floor LDPC code construction

? **Memory read latency overhead**

- ✓ A set of cross-layer design solutions to
  1. Increase decoding success rate at lower sensing precision
  2. Reduce soft-sensing data transfer latency