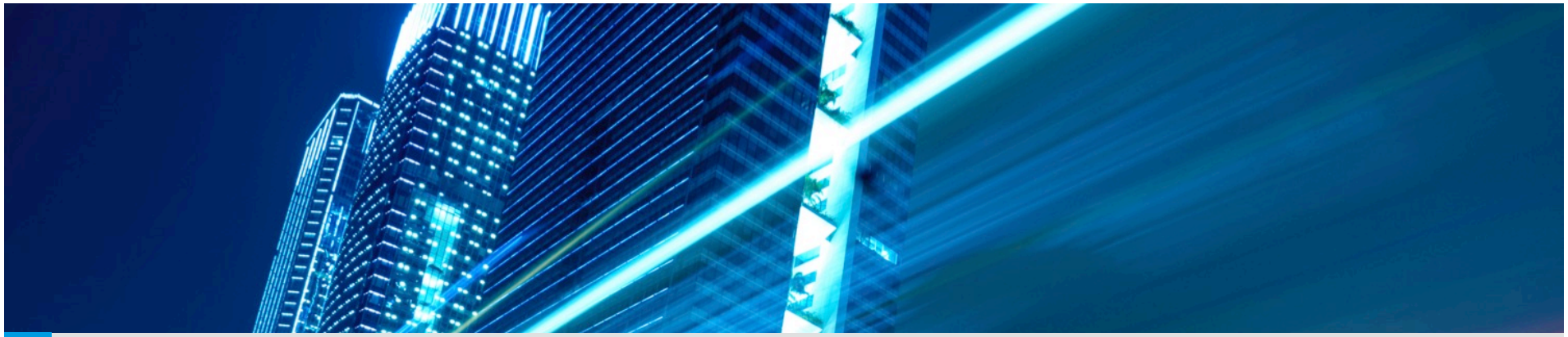


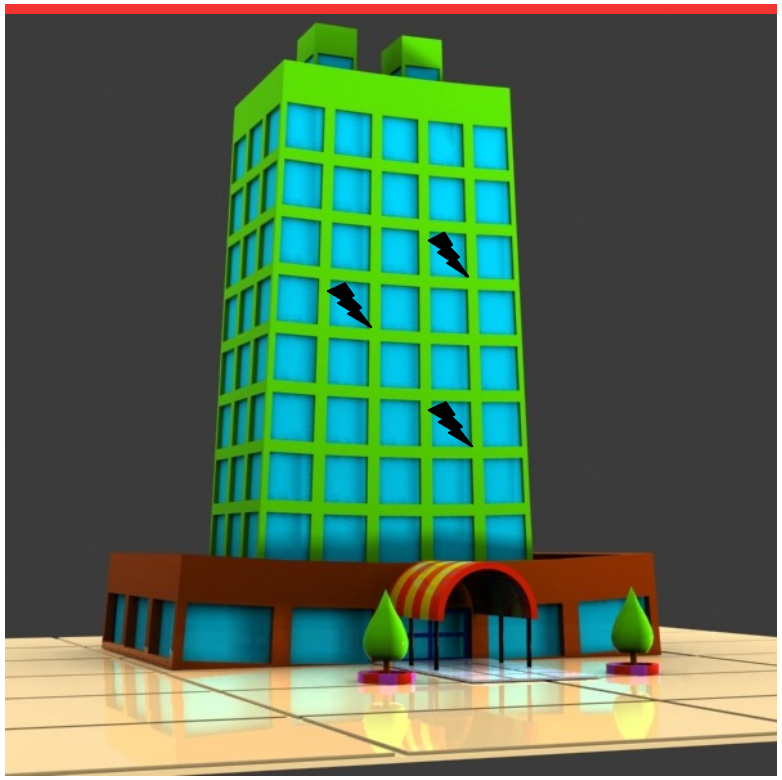
Employing ECCs via Overprovisioning to Improve Flash Reliability:

A New, Cost Efficient Approach

Stella Achtenberg, Eran Sharon, Idan Alrod
Advanced Memory Solutions,

3-8-2016

NAND Memory

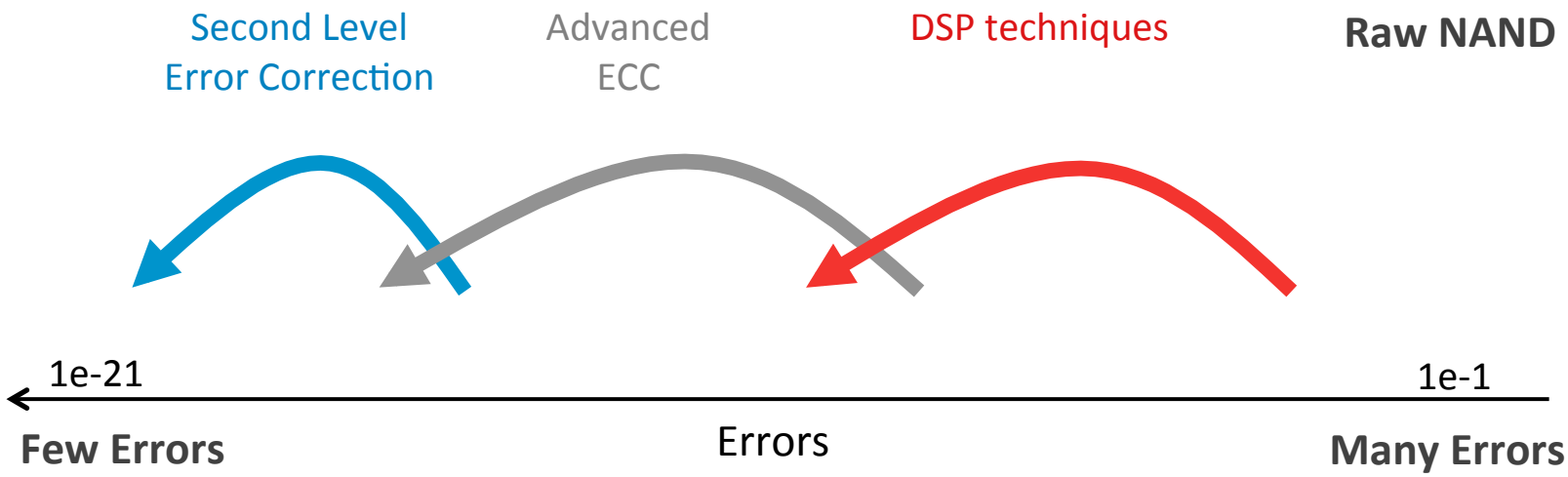


Mobile

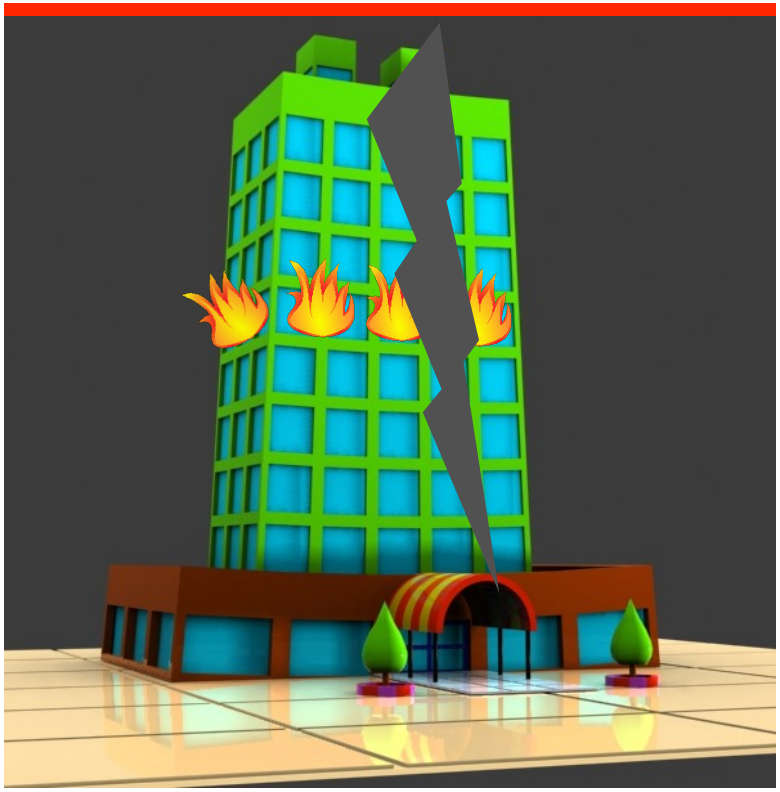
Client SSD

Enterprise SSD

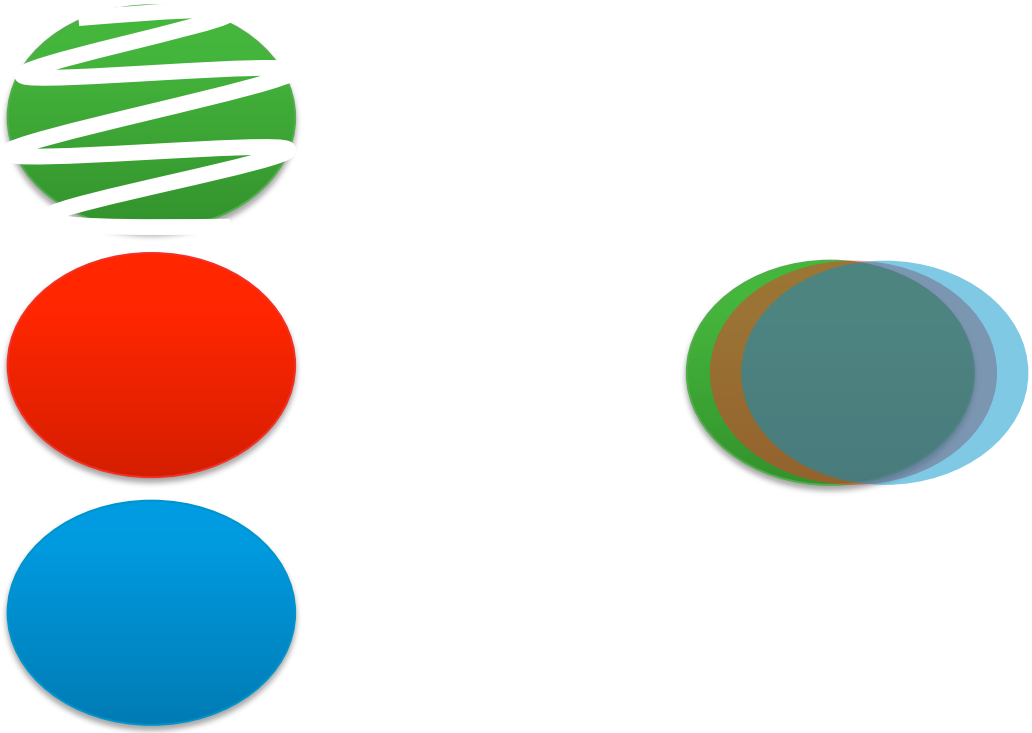
Handling Random Errors



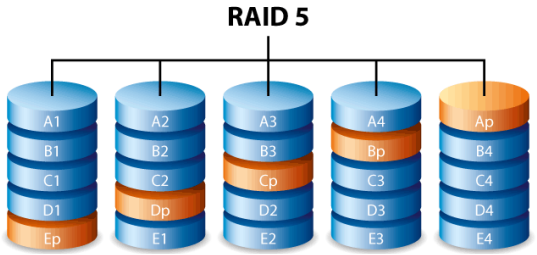
NAND Memory

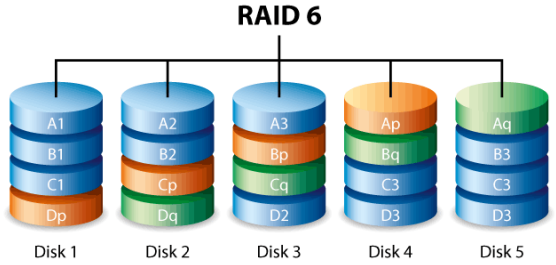


RAID Example



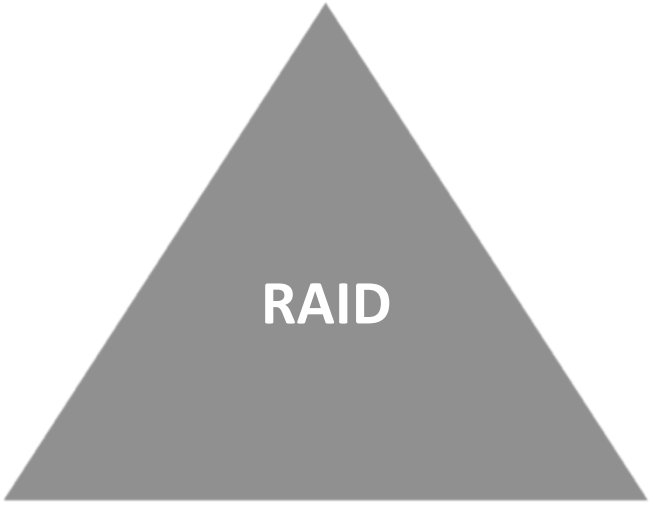
Handling Physical Defects

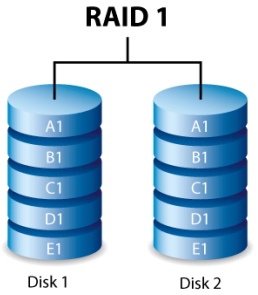


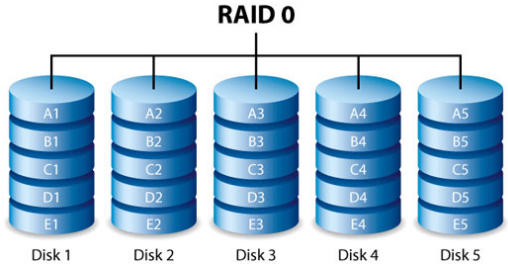


Reliability

Overprovisioning







Performance

Storage Reliability Requirements

- A metric for occurrence of data errors per bits read:

$$UBER = number\ of\ data\ errors / number\ of\ bits\ rea$$

- Extremely Low UBER requirements < 10^{-18}

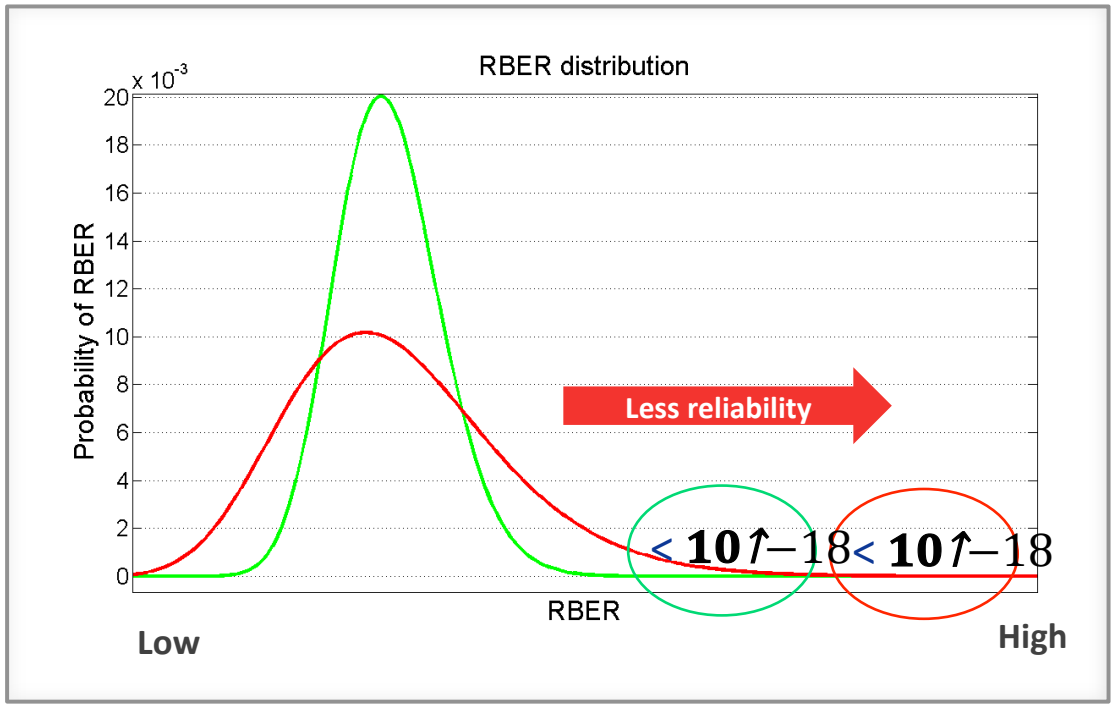
- DPPM = Defective Parts per Million

Client SSD

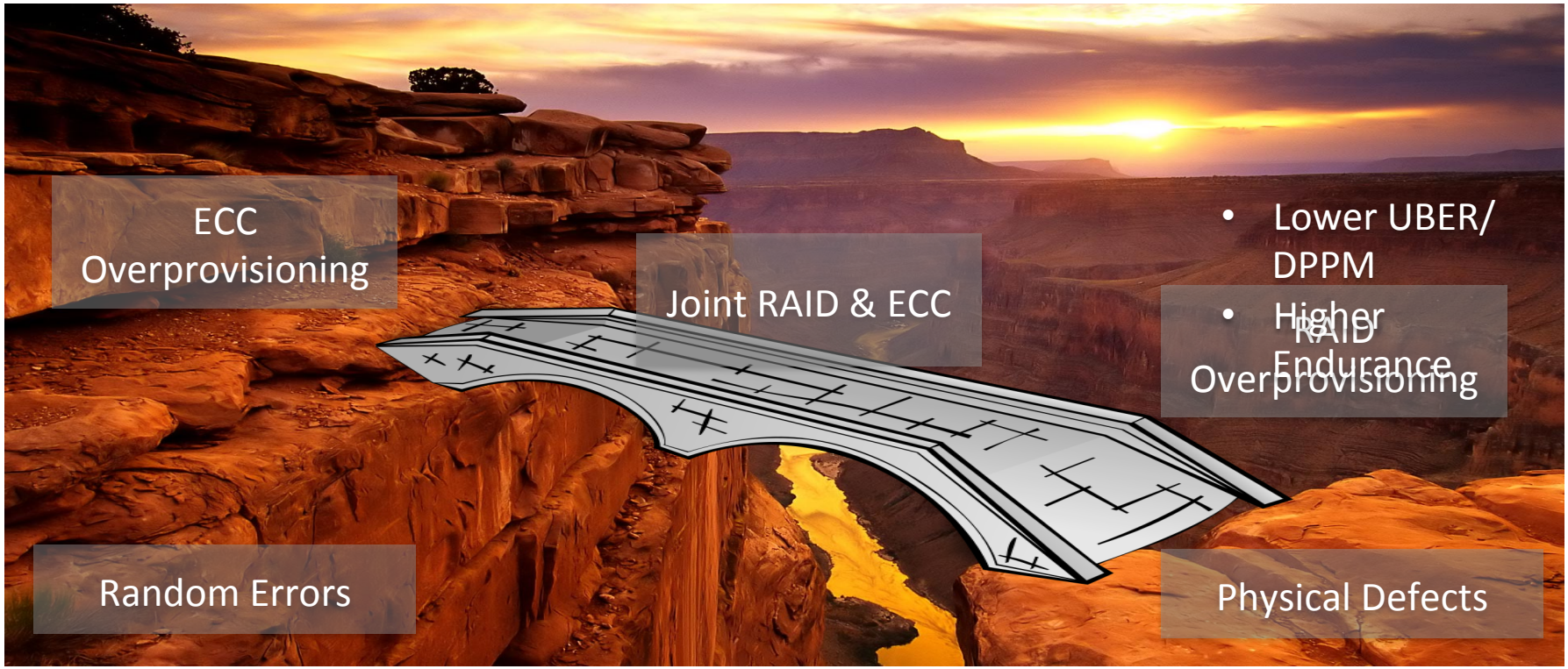
Enterprise SSD

Problem statement

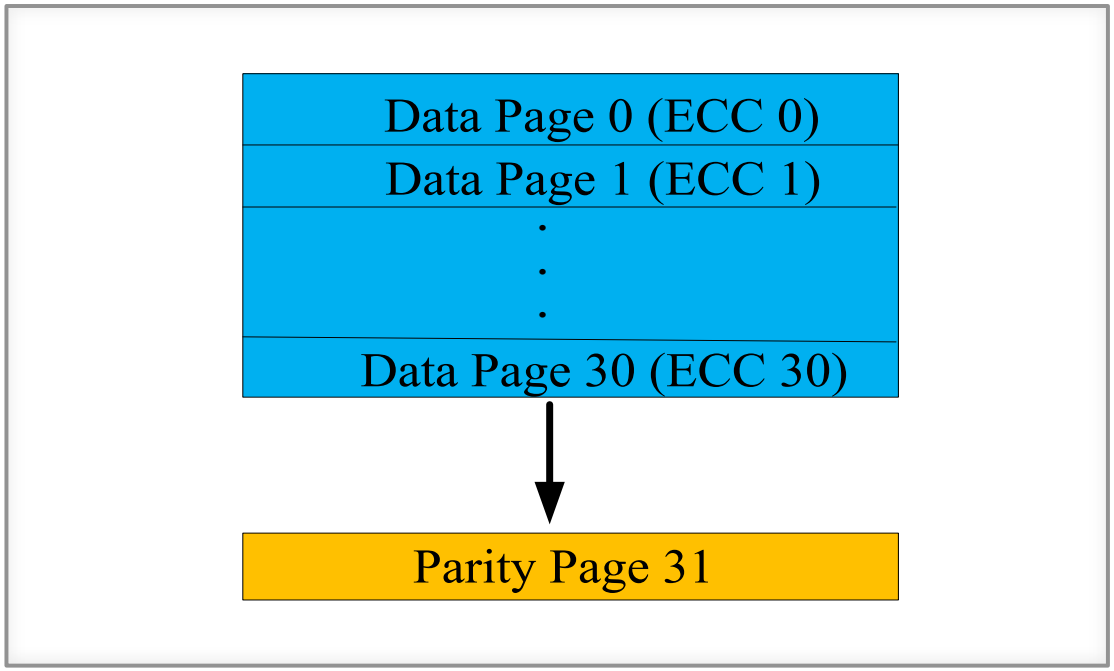
3-Dimensional stacking and process scaling increase RBER variability



Overprovisioning potential

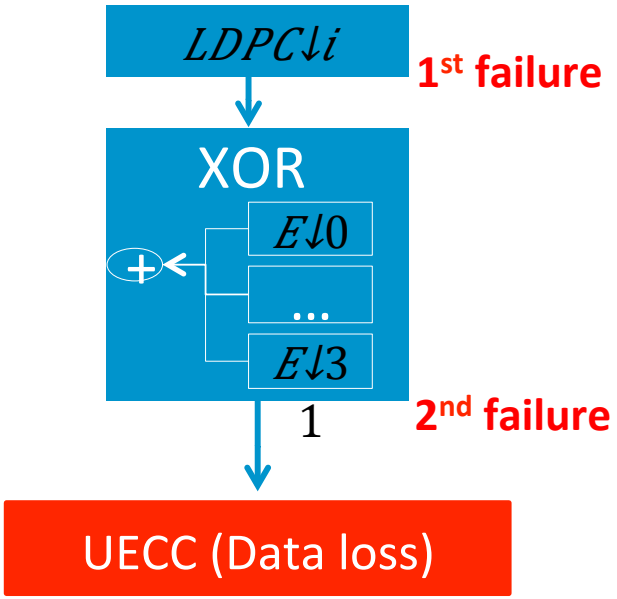


Case study: 32 Die XOR RAID



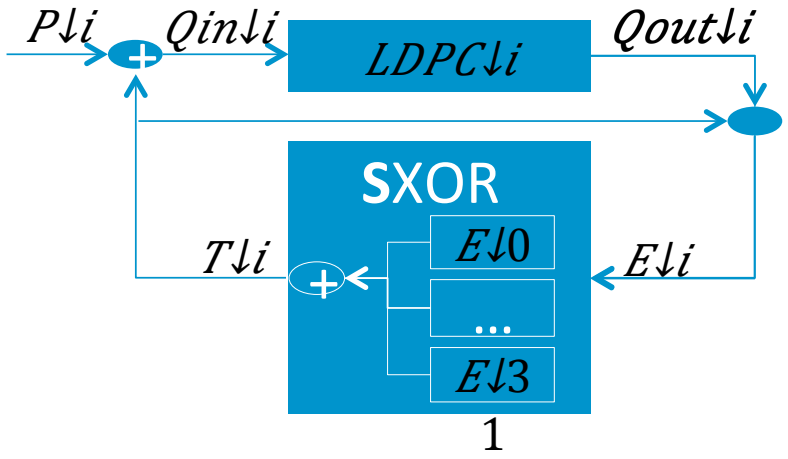
Current solution

- Decode using soft information
- In case of failure, decode the entire RAID stripe
  - Single error ➔ Recovery
  - More than single error ➔ UECC



New methodology

- Optimal information exchange between RAID & LDPC
  - Extrinsic "soft" LDPC output → into the RAID
  - Updated "soft" RAID output → back to the LDPC
  - Iterate until convergence or timeout



$$T_i = \varphi^{-1}\left(\sum_{j \setminus i} \varphi(E_j)\right),$$
$$\varphi(x) = \{\operatorname{sign}(x), -\log\tanh x/2\}$$

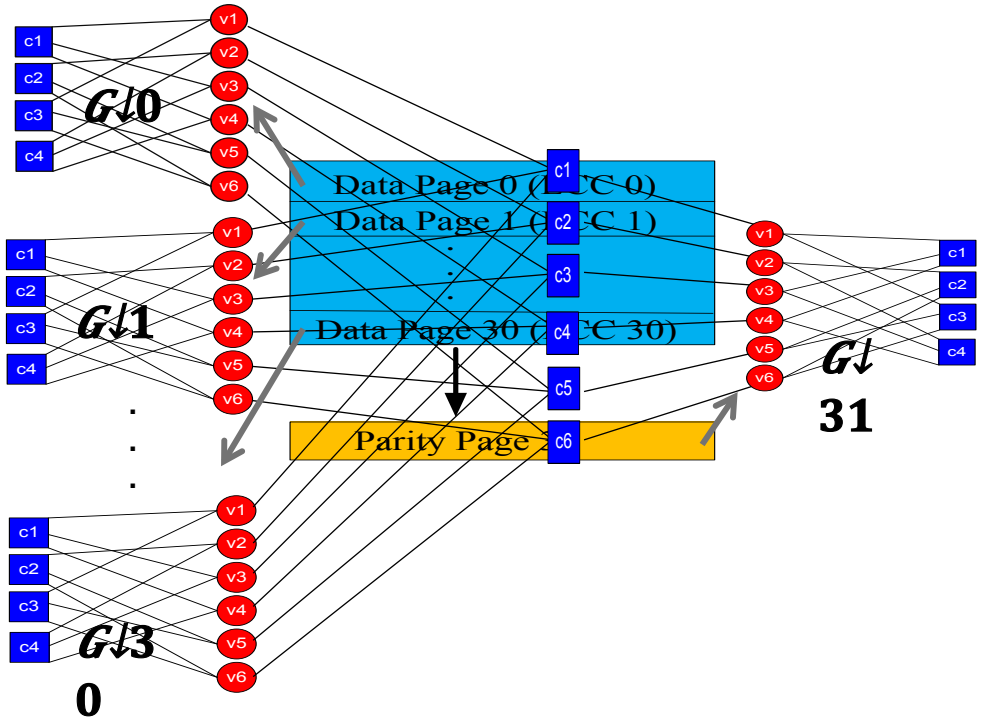
Previous Work

"Error Correction Using Multiple Data Sources" –
US patent application by Sharon et al (2014, SanDisk)

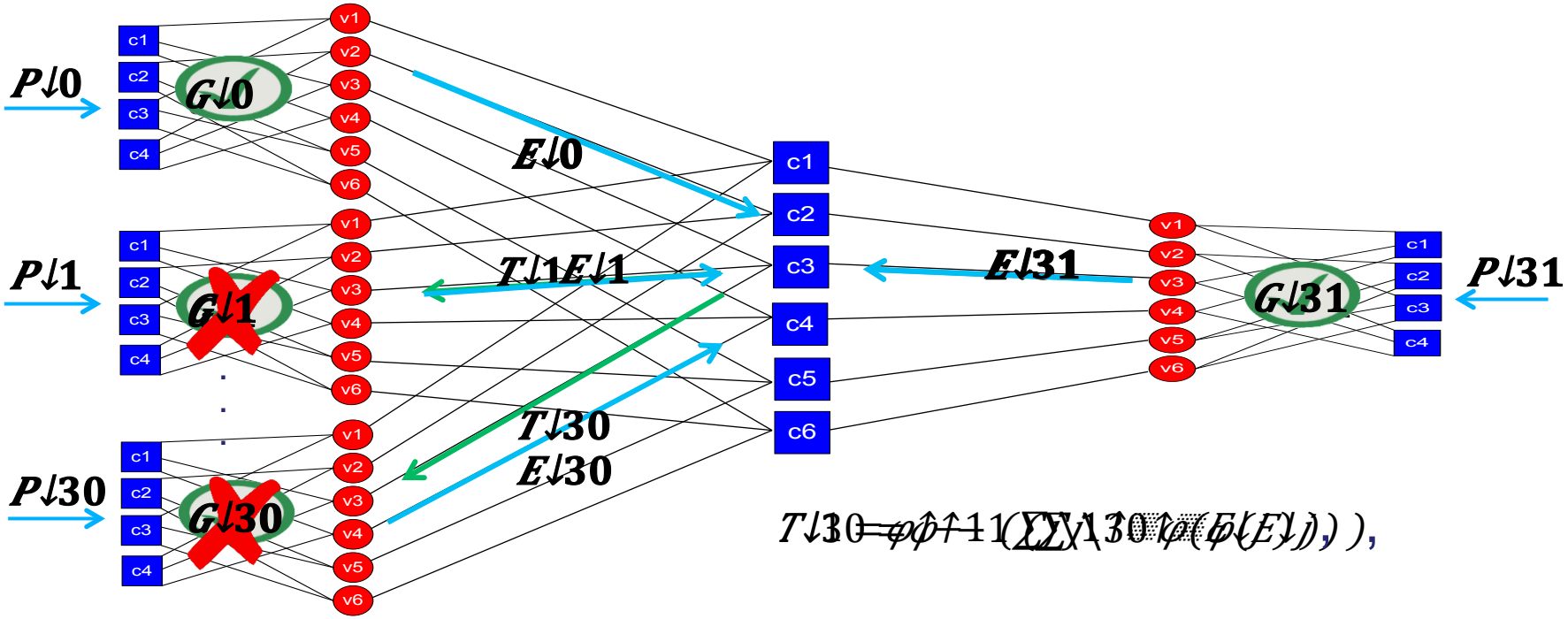
"Soft Decision Decoding of RAID Stripe for Higher Endurance of Flash Memory Based Solid State Drives" –
Ravi Motwani and Chong Ong (2015, Intel)

Graph Representation

- XOR RAID
- LDPC codewords
- XOR page is a codeword
- Effectively a long code with joint ECC and RAID overprovisioning



Recovery flow



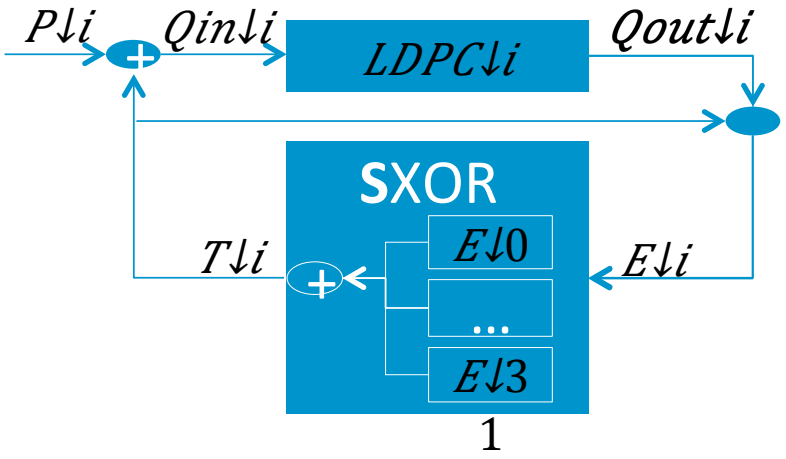
Pros and Cons

Pros:

- Enhanced correction capability

Cons:

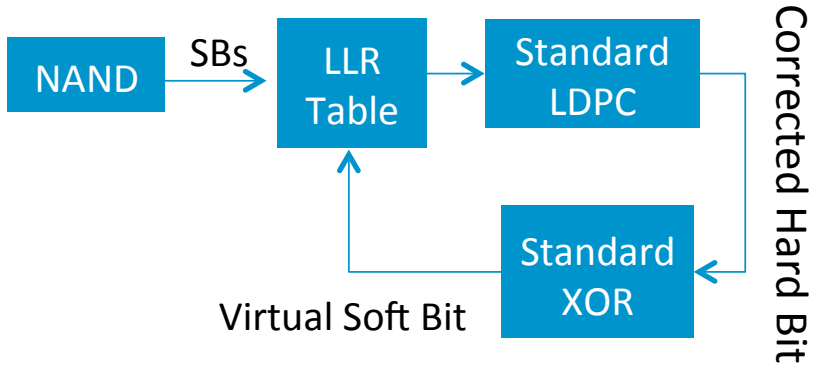
- High cost and complexity
  - RAM (Storing $E\downarrow 0$,...,$E\downarrow 31$)
  - Soft XOR instead of XOR
  - Latency



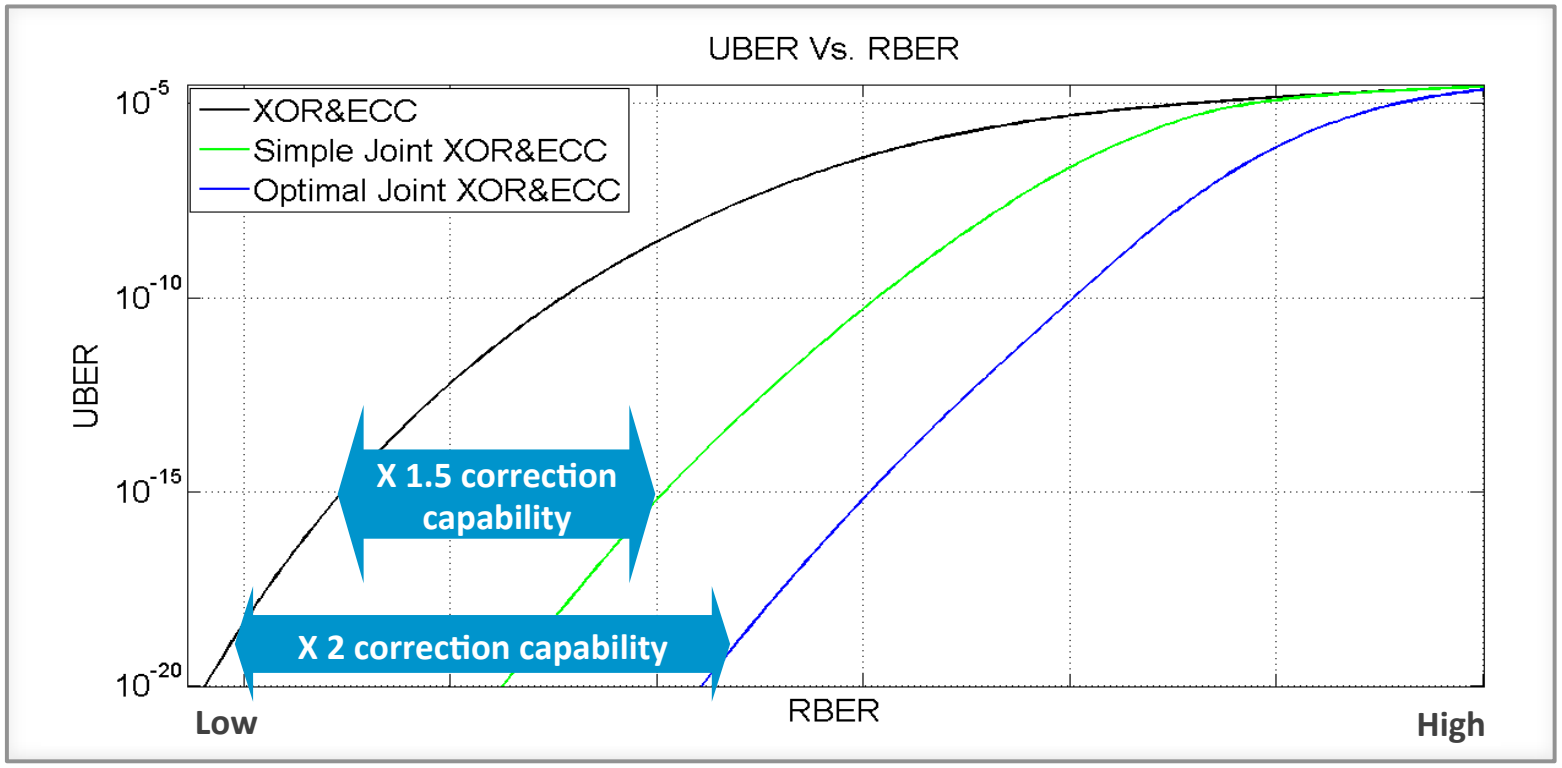
$$T\downarrow i = \varphi\uparrow -1\ (\sum j \backslash i\uparrow \blacksquare \varphi(E\downarrow j)),$$
$$\varphi(x) = \{\text{sign}(x), -\log\tanh x/2\ \}$$

Simple joint RAID & ECC

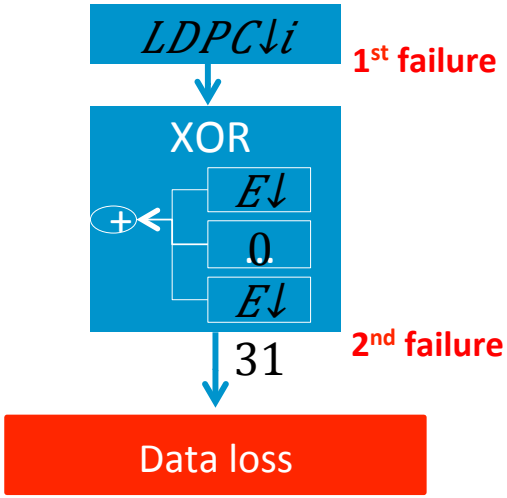
- Simple variant using standard hardware:
  - XOR page as “Virtual” Soft Bit page
  - Dedicated LLR table emulates LLR summation



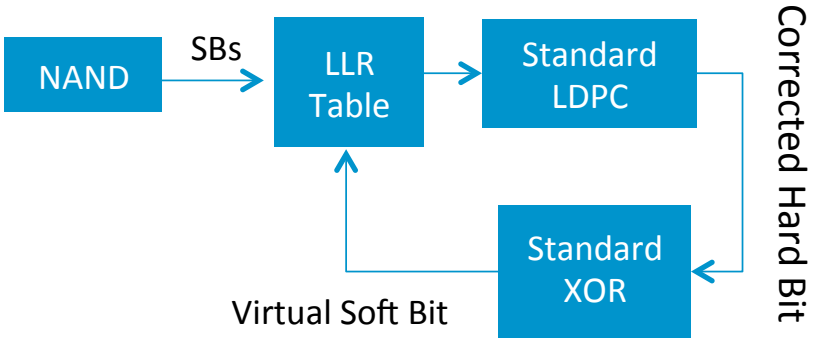
UBER improvement



Existing versus New

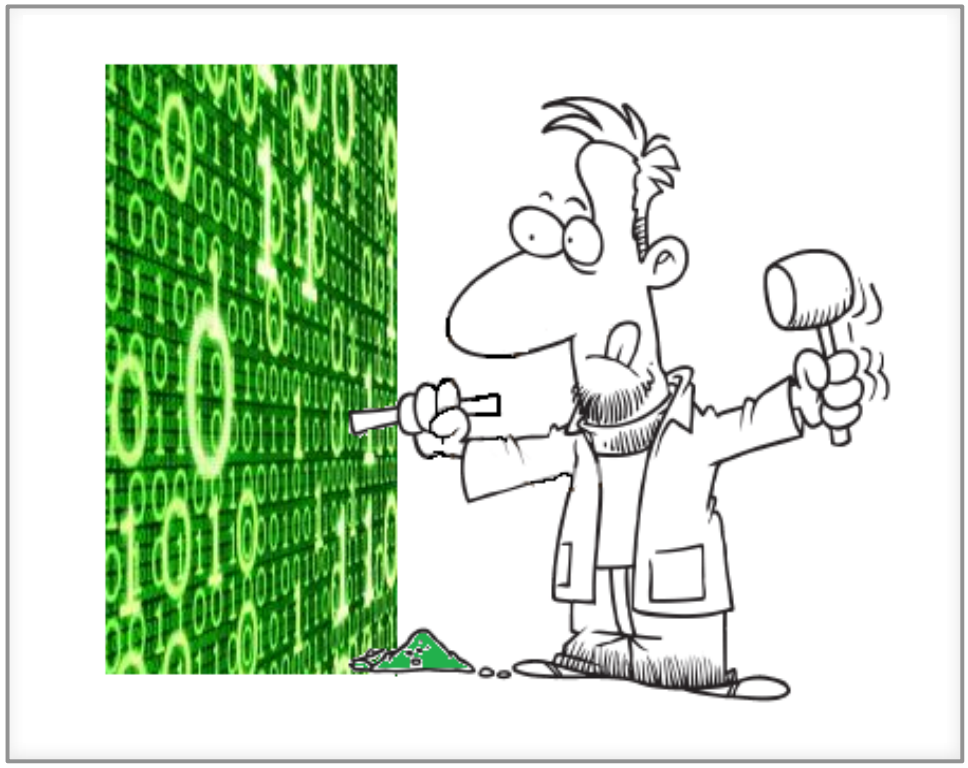


- Independent LDPC & RAID
- Single failure recovery



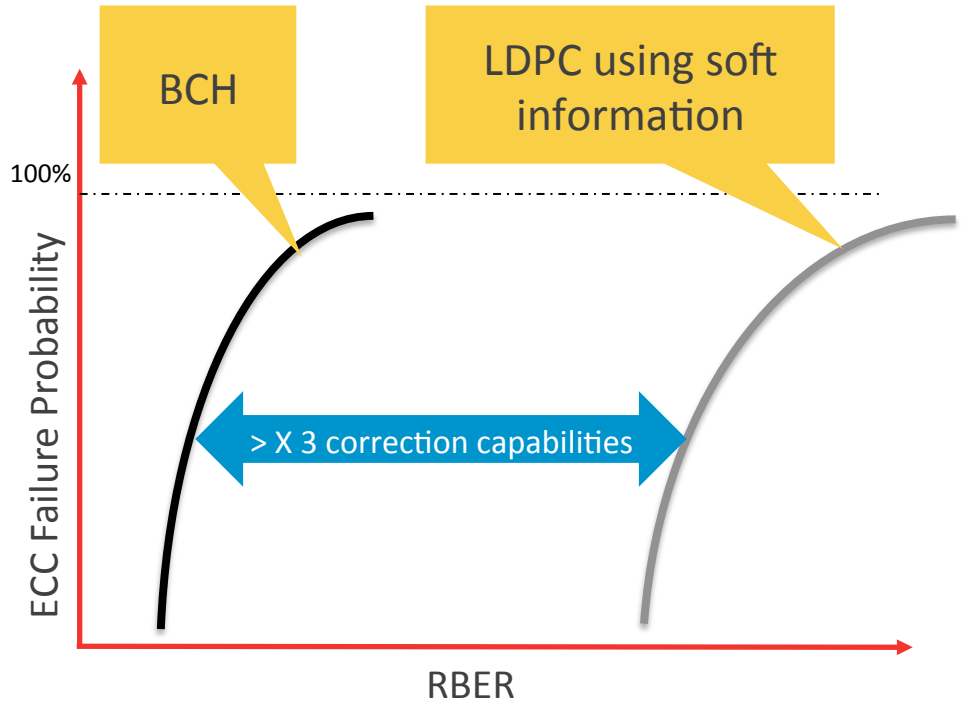
- Joint LDPC & RAID
- Standard HW
- Correcting up to 32 failures
- Substantially reduces UBER

Joint Hard Decoder and RAID



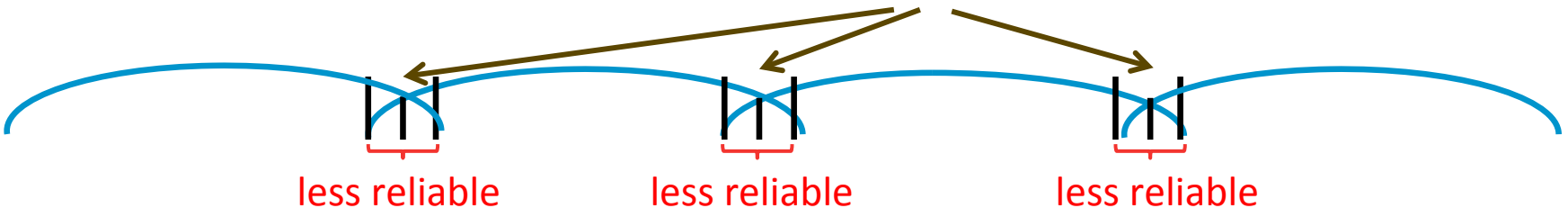
BCH (Bose, Chaudhuri, Hocquenghem)

- Simple hardware
- Constant latency
- Can not use soft information
- Lower correction capability



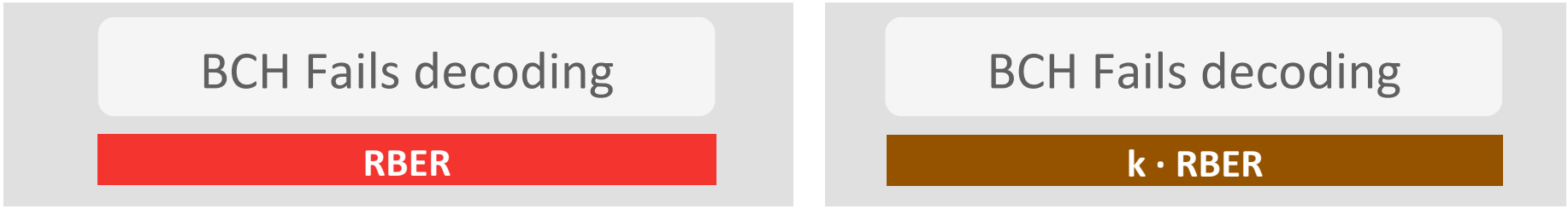
Generating Soft Information

- Soft-Bit read (+/-Δ around the read thresholds):



- Soft-Bit divides the cells population into two categories:
  - Population of reliable cells, exhibiting low BER
  - Population of unreliable cells, exhibiting high BER

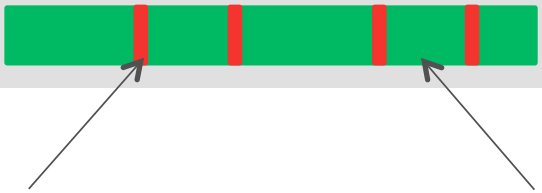
Joint Hard Decoding and RAID



Joint Hard Decoding and RAID

Codeword read from Flash

RBER = $\alpha \cdot p_{high} + (1-\alpha) \cdot p_{low}$



High RBER (p_{high})

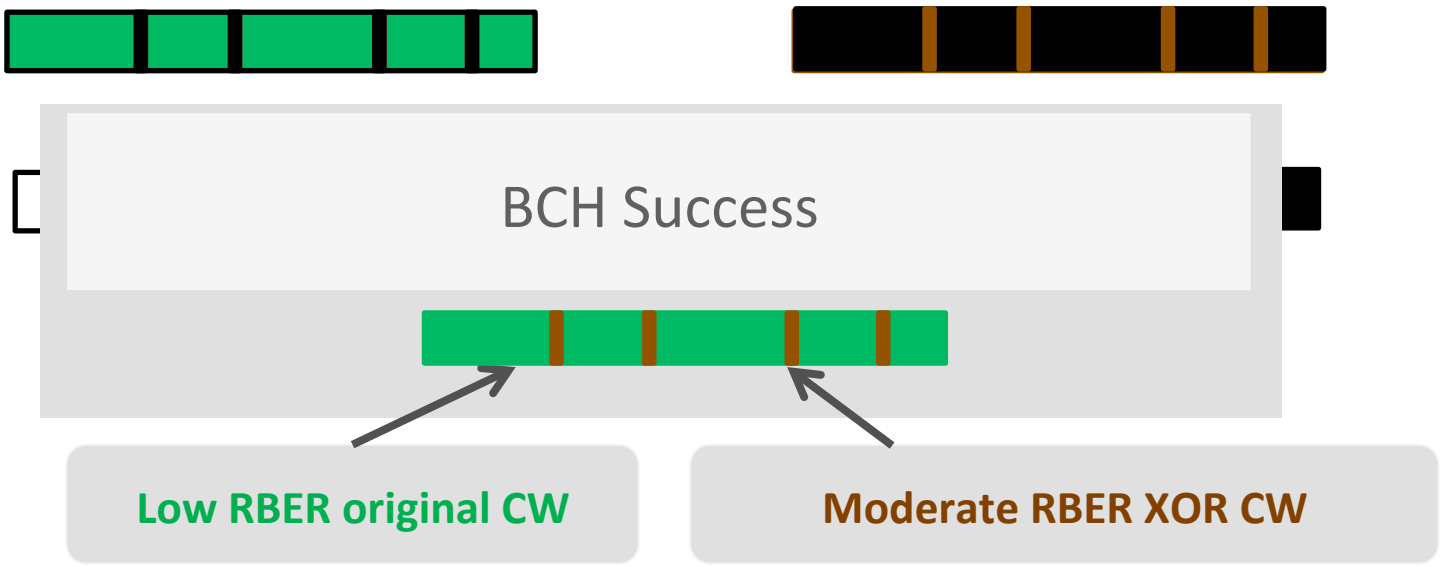
Low RBER (p_{low})

BCH Fails decoding

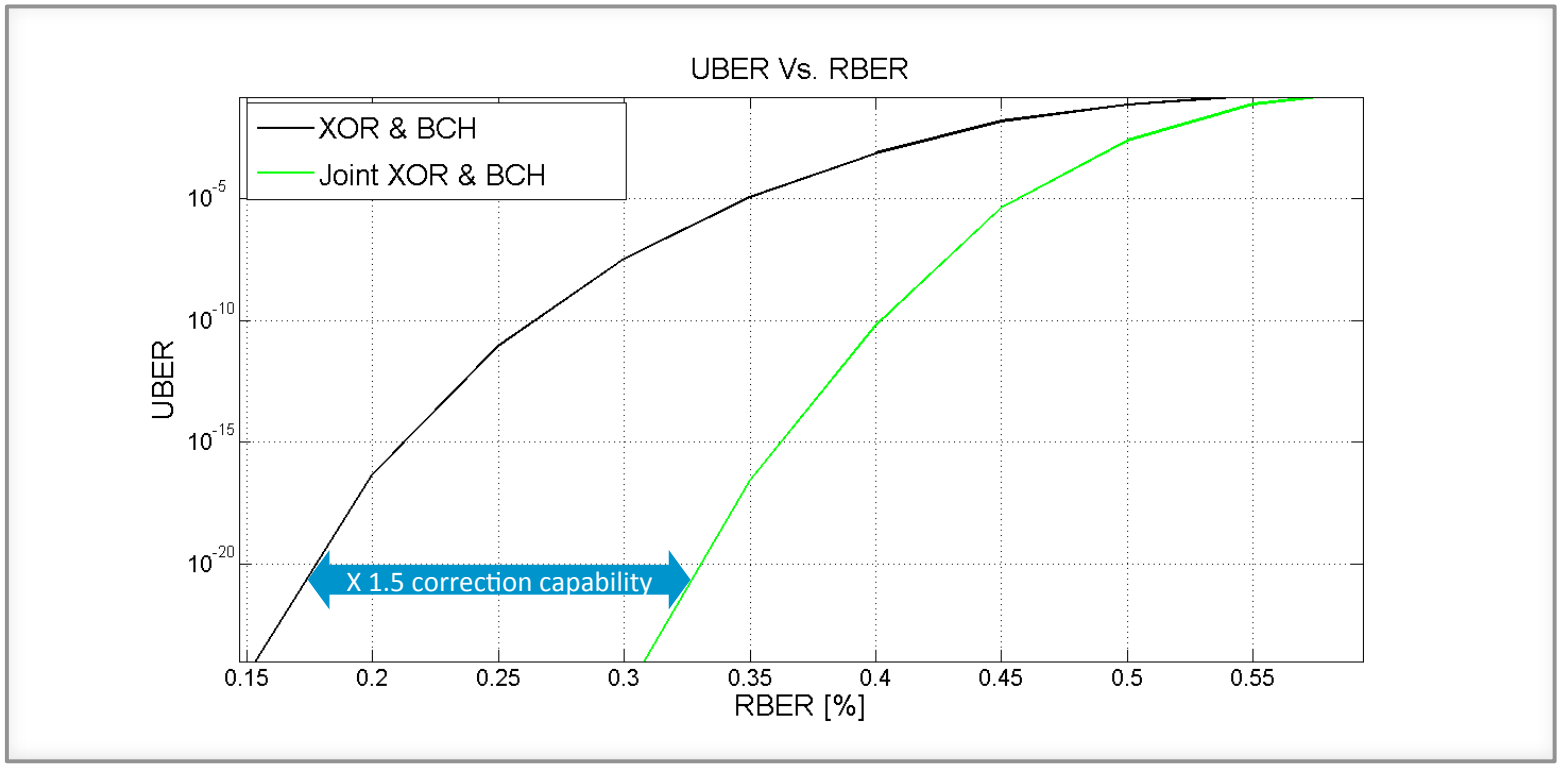
k · RBER

Read SB indicating unreliable cells

Joint Hard Decoding and RAID



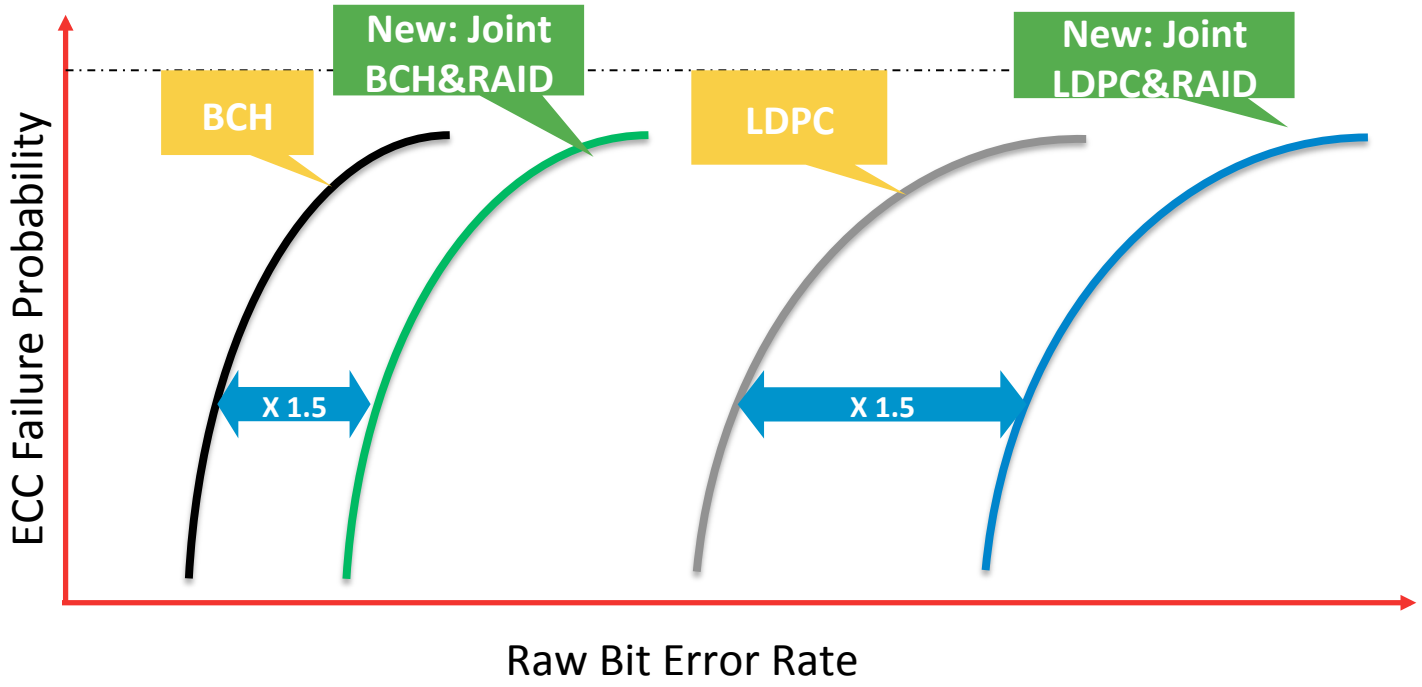
UBER improvement



Summary

- Storage systems require very high reliability
- 3-Dimensional stacking and process scaling increase RBER variability, compromising reliability
- Joint RAID & ECC enhance reliability without adding cost:
  - Soft Decoder – Low complexity joint RAID & LDPC
  - Hard Decoder – Joint RAID & BCH

Summary


New: Joint BCH&RAID
BCH
LDPC
New: Joint LDPC&RAID
X 1.5
X 1.5
ECC Failure Probability
Raw Bit Error Rate