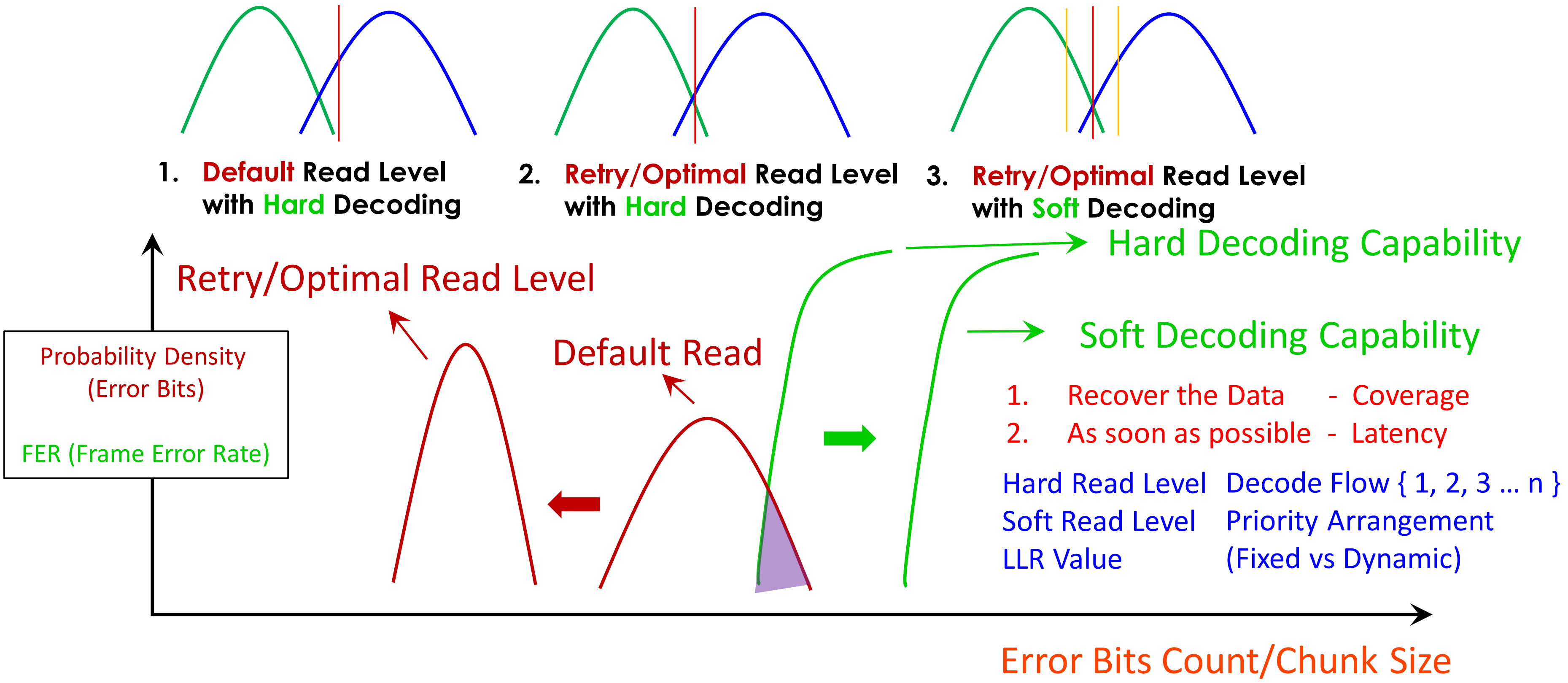
Novel Error Recovery Architecture Based on Machine Learning

Cloud Zeng

LITEON/Storage/NVM Lab

Error Recovery Flow

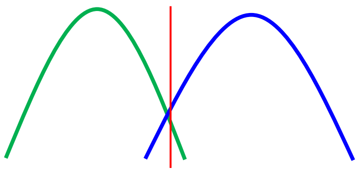


Error Recovery Scheme with ML

Category	Item	Description	Remark
P/E	Cycle	0, 1000, …~	
	Temperature	(Random)	
	Dwell	(Random)	
Test Item	Data Retention	0, 1, … ~ (Days)	Room/High Temperature
	Read Disturb	0, 1000, … ~	High Temperature
	Cross-Temperature	HT/LT Write – LT/HT Read	

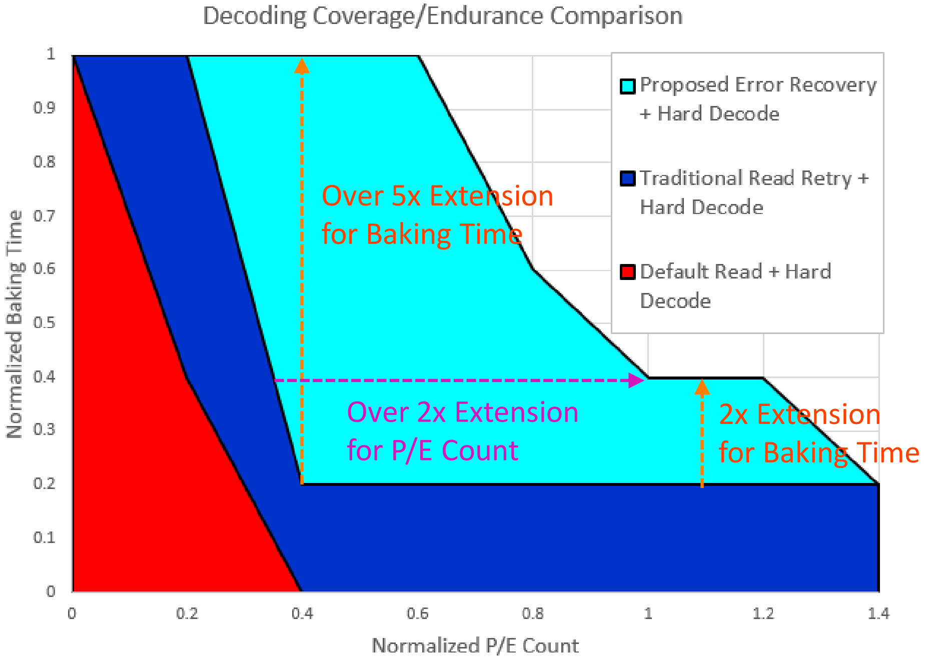
- An Error Recovery Scheme is developed by Machine Learning
- This Scheme can be applied to variant operation condition (**combination of {PE, DR, RD, Temperature, Cross-Temperature}**)
- This Scheme can extend the endurance and reduce the latency

Endurance with Hard Decoding



Optimal Read Level
with Hard Decoding

Hard/Soft Read Level, LLR
Prediction Model



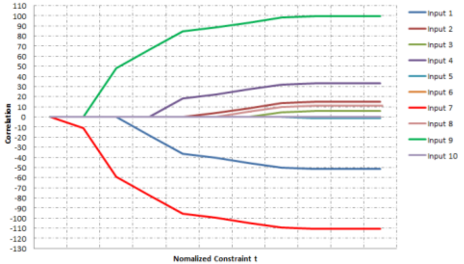
- Our Error Recovery Scheme use ML to find Optimal Parameters for variant operation conditions (**combination of {PE, DR, RD, Temperature}**)
- 5x Extension for Baking Time & 2x Extension for P/E Count

Prediction Model - Optimal Read Level

Example: Data Collection

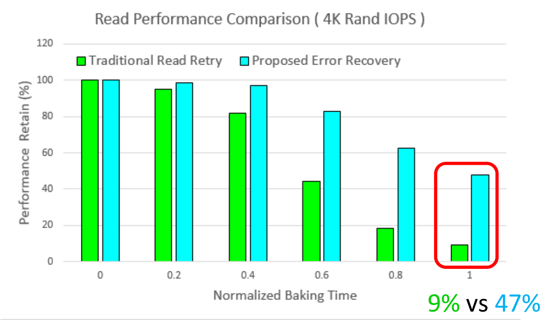
	Input Para 1	Input Para 2	Input Para 3	Input Para 4	Input Para 5	Input Para 6	Optimal HD Read Level
Data 1	1100	589	1794	6322	1000	1000	6
Data 2	932	908	1503	7849	500	500	-5
…	…						
Data N	990	842	1894	5692	300	400	3

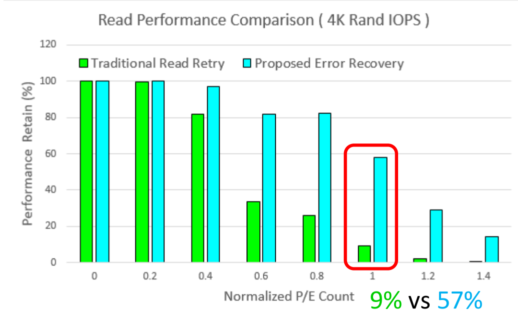
Feature Selection

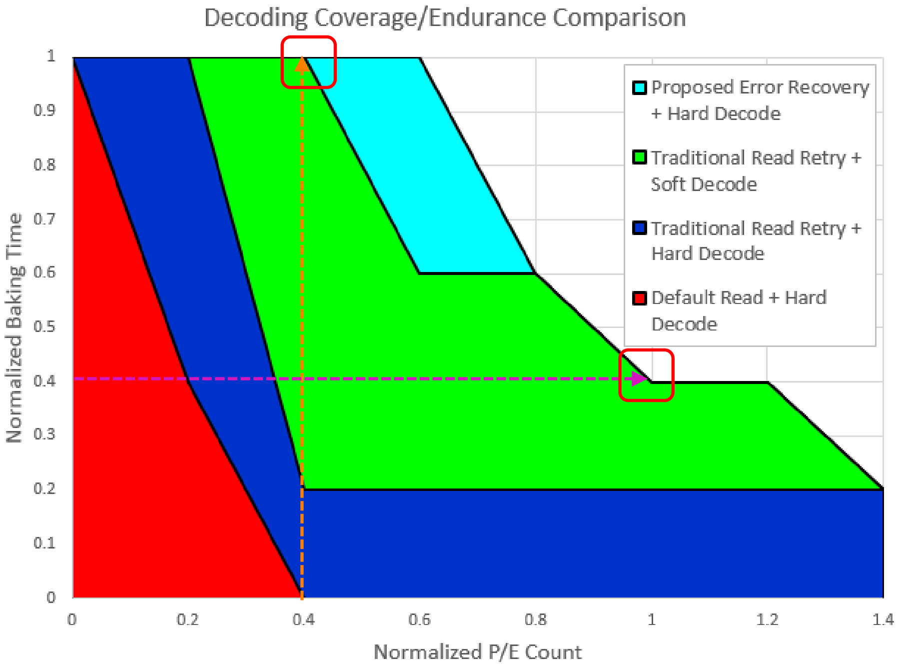


- **What's the Optimal HD Read Level after n Days/Weeks?**
- **Input Parameters:**
  - P/E Cycle, Retention Time, Read Count, Temperature, Dwell … Program/Erase Time, Histogram ….
- **Regression Problem:**
  - Ordinary Least Square(OLS) Regression
  - Ridge Regression (Hoerl and Kennard, 1970)
  - Other Regression Analysis can be used to solve this problem

Throughput/IOPS Comparison

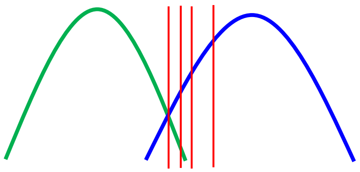


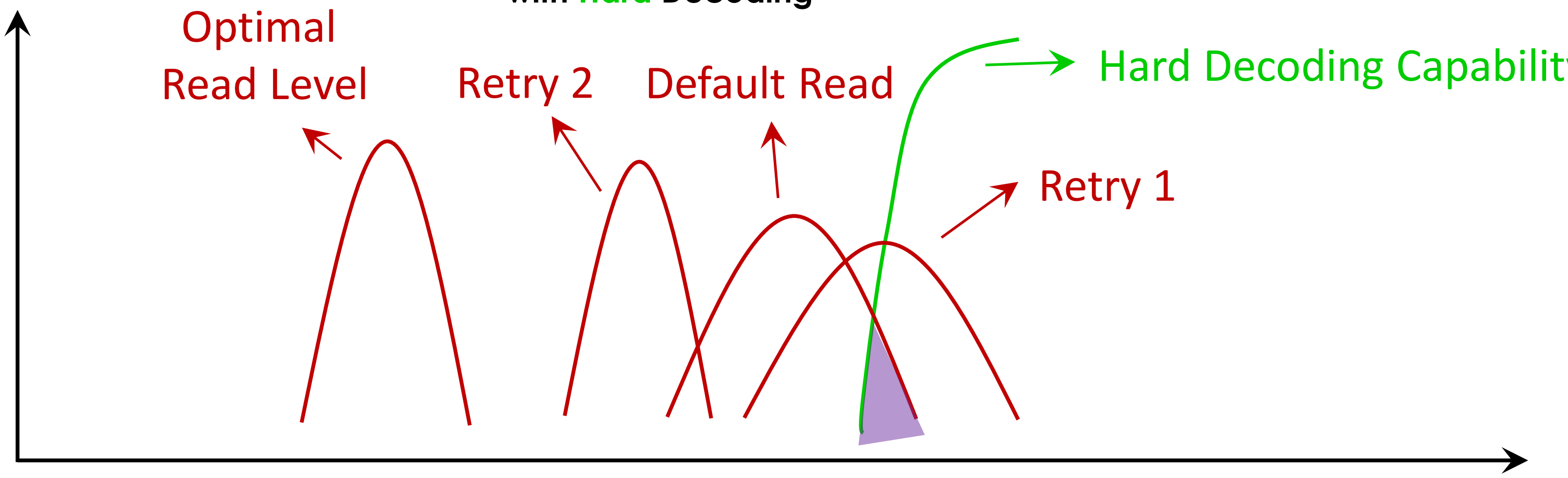




- Proposed Error Recovery Scheme always has less read latency compared with Traditional Error Recovery Scheme

Optimized Read Retry Sequence



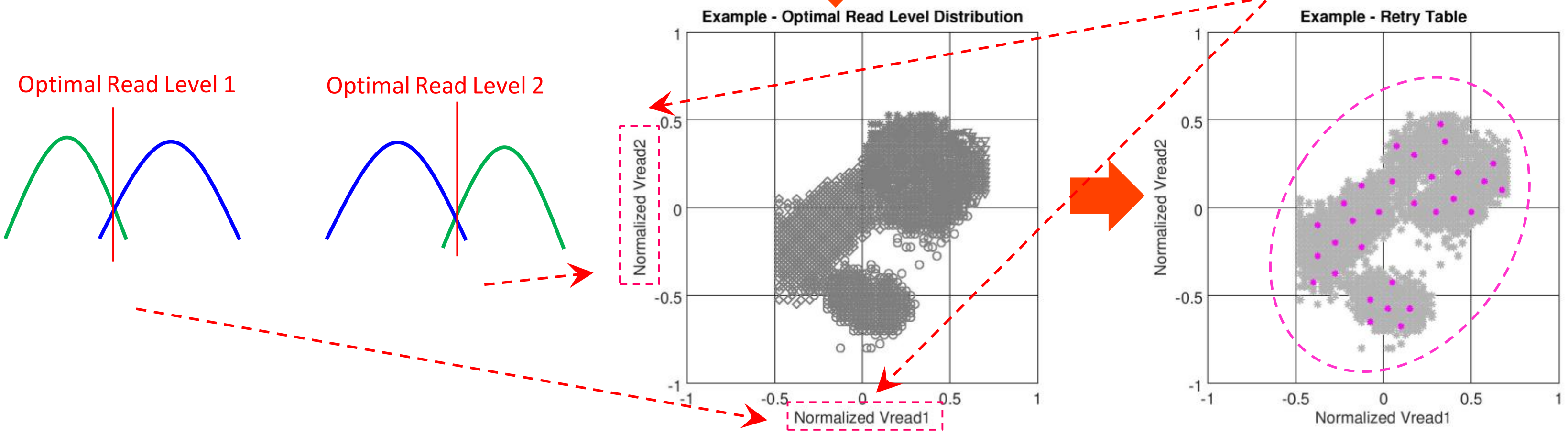


Read Retry Table – Clustering

Billions of ECC Chunks Info were collected over dice under different failure mode

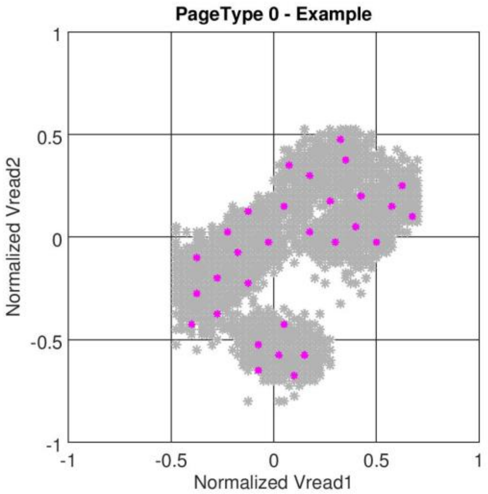
ECC Chunks Info

Die	Plane	BLK	WL	PageType	P/E Count	Baking Time	Optimal Read LV1	Optimal Read LV2
2	0	100	64	0	3000	24	+10	-6
2	1	101	78	0	4000	24	+7	+9
3	1	120	31	0	4000	36	+3	-12
…								

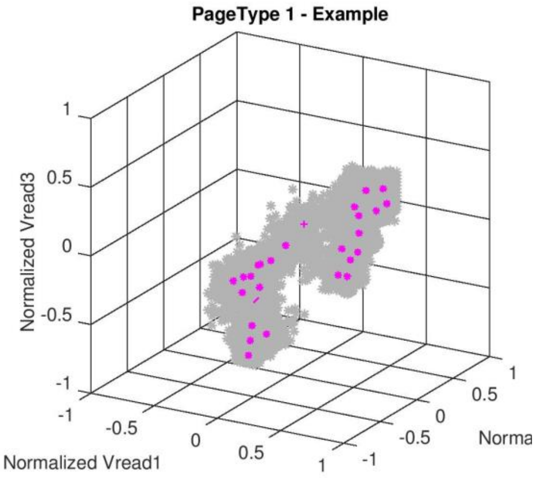


Read Retry Table – Coverage

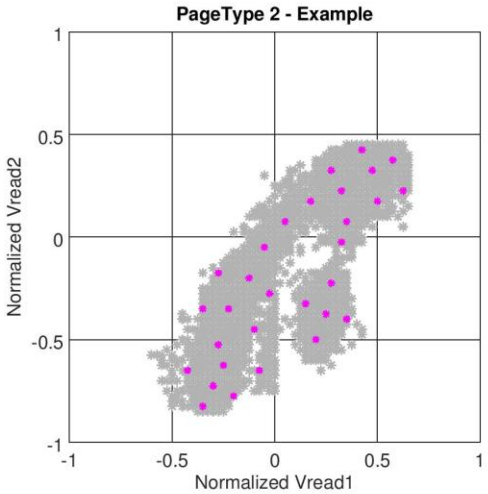
How many Retry Tables are required to cover the following case ?



60 sets → 100%
19 sets → 90%



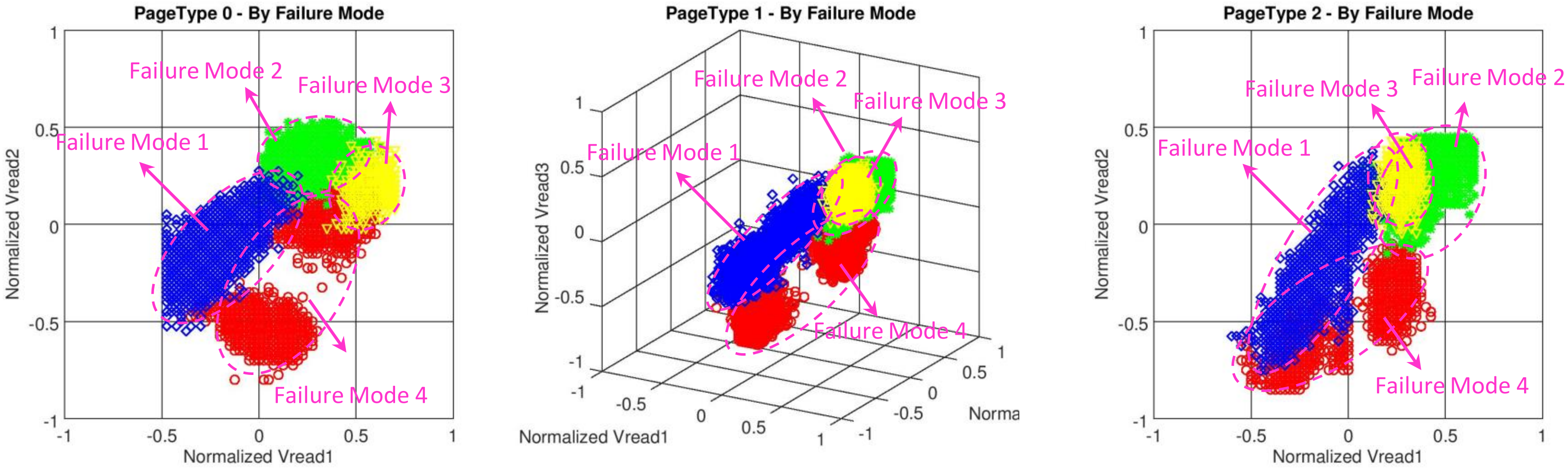
173 sets → 100%
40 sets → 90%



57 sets → 100%
17 sets → 90%

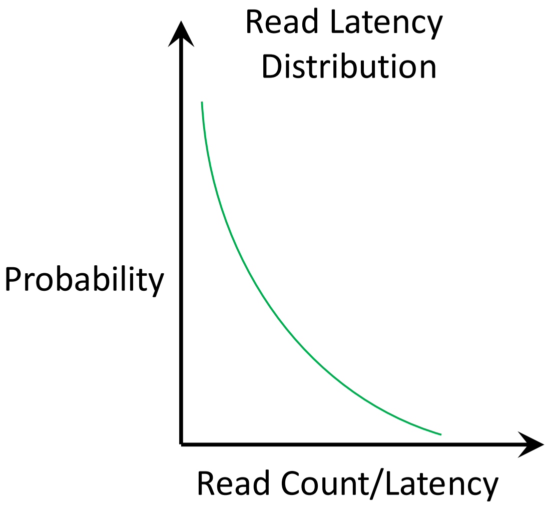
Reduced Retry Table – Coverage

Find some indexes to reduce retry tables without Coverage Loss

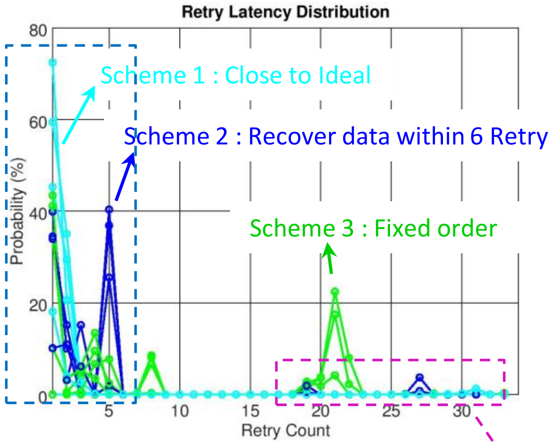


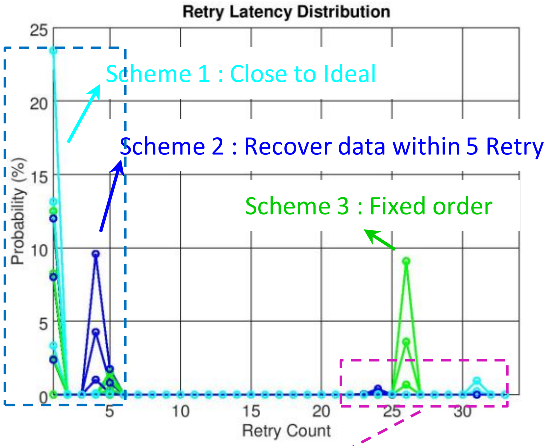
Reduced Retry Table – Latency

Change Default Read Level and the Priority of Retry Table dynamically



Ideal : monotonically decreasing

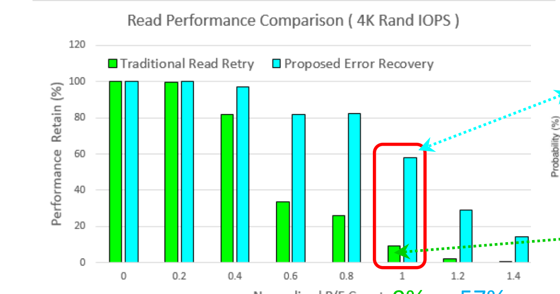


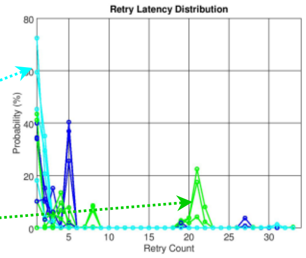


1. Proposed Error Recovery Scheme with extra overhead
2. Proposed Error Recovery Scheme without overhead
3. Traditional Retry Table (Fixed Order)

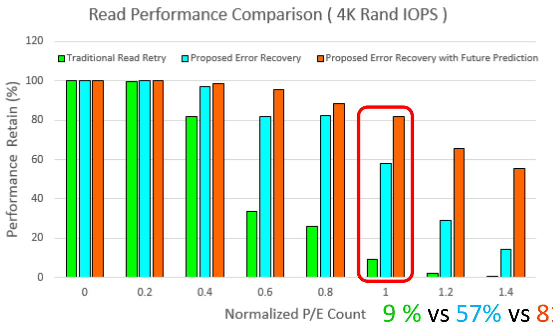
Last line of defense → Prediction Model : Optimal Read Level/LLR

Throughput with Future Status Prediction

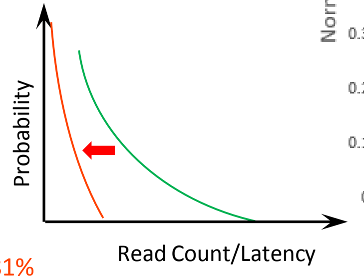


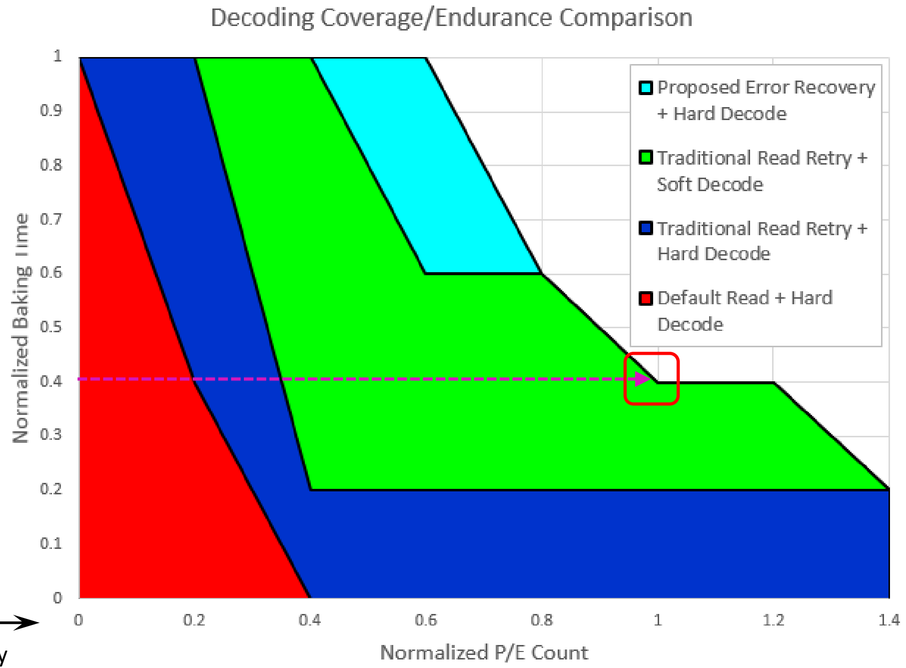


9% vs 57%



9 % vs 57% vs 81%





- Read Performance Drop can be further reduced with Future Status Prediction

Difficulty For Future Status Prediction

Prediction Flow Triggered

↓

Select Block/Page $Block_{sel}$/$Page_{sel}$

↓

Collect/Save Required Parameters

↓

Apply Future Status Prediction Model Ex. Retry/Fail Rate, Optimal Read Level .. after 1 week

P1 : Trigger Condition/Frequency ?

P2 : Which block/page(s) should be selected ?

P3 : Important/Required Parameters ?

P 1~3 : Machine Learning

P4 : Operation Condition in 1 week !!!

P5 : Power-Off !!!

P 4~5 : Dynamically Adjusted Prediction Model

Summary

- **Current NAND Flash Endurance can be Greatly Extended**
  - Optimal Parameters : Retry/Optimal Read Level, LLR
  - Powerful Recovery Flow : Soft Decode, Future Status Prediction..
  - The key point is … QoS (Quality of Service)
- **Error Recovery Scheme based on Machine Learning**
  - Optimized Read Retry Sequence
  - Optimal Read Level, LLR Estimation/Prediction Model
  - Future Status Prediction Model
- **New Error Recovery Architecture**
  - Adjust Error Recovery Flow based on failure mode/operation condition
  - Dynamically Adjusted Estimation/Prediction Model

THAT YOU!

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