

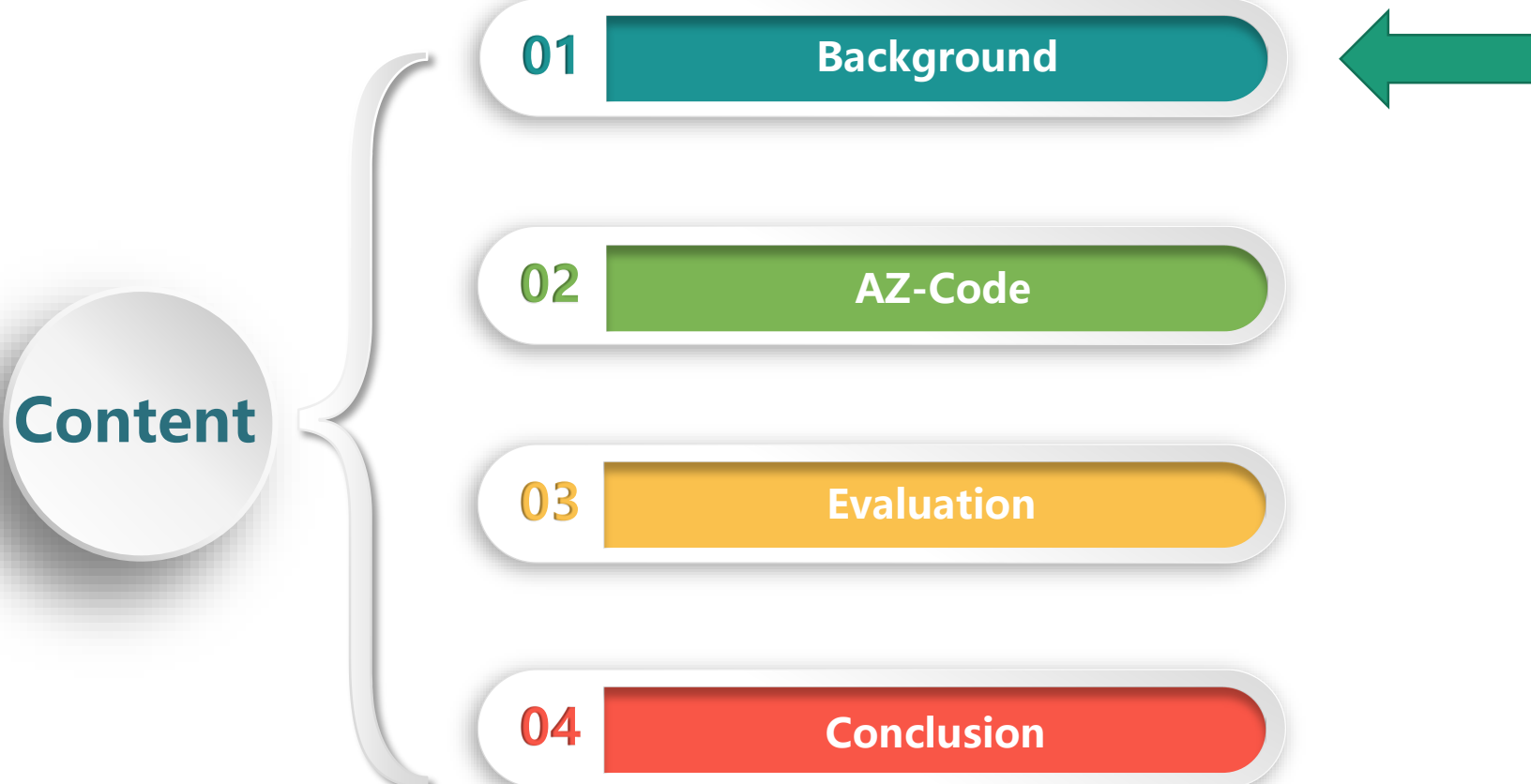
The 35th International Conference on Massive Storage Systems and Technology (MSST 2019)

AZ-Code: An Efficient Availability Zone Level Erasure Code to Provide High Fault Tolerance in Cloud Storage Systems

Xin Xie, **Chentao Wu**, Junqing Gu, Han
Qiu, Jie Li, Minyi Guo, Xubin He,
Yuanyuan Dong, and Yafei Zhao



Content



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graph LR; Content((Content)) --- 01[01 Background]; Content --- 02[02 AZ-Code]; Content --- 03[03 Evaluation]; Content --- 04[04 Conclusion]; Arrow[Green Arrow] --> 01;
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Background

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AZ-Code

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Evaluation

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Conclusion

Background

- Availability Zones

- A common method to store data in cloud storage system

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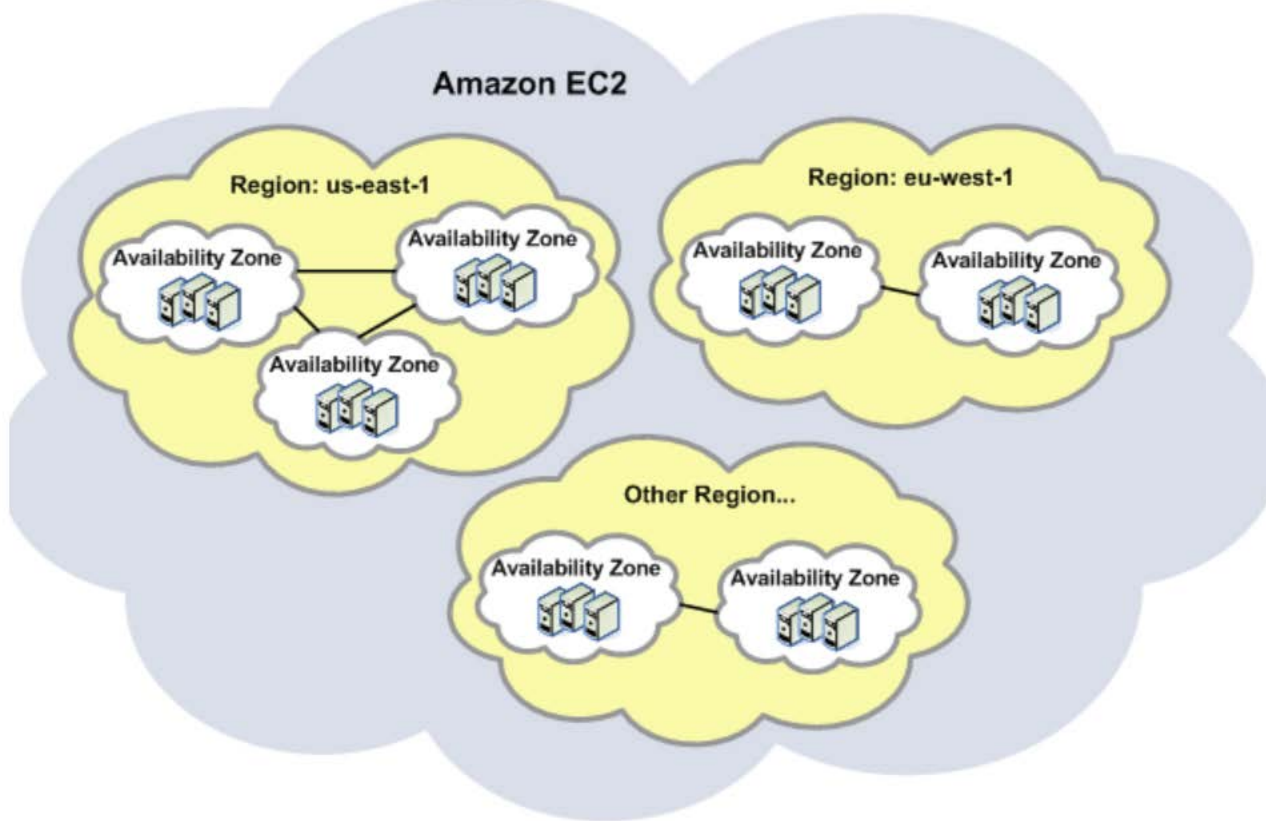
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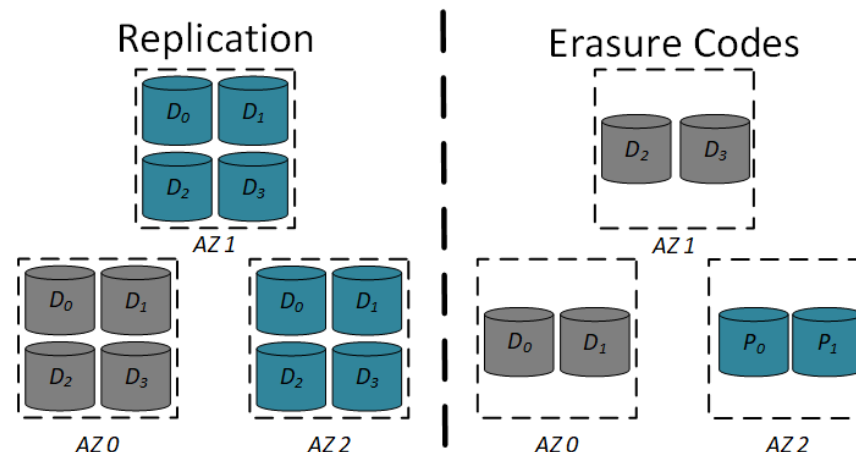
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<https://amazonaws-china.com/cn/>

Erasure Codes

- Traditional replication strategies
 - High reliability & High storage cost
- Erasure Codes (EC)
 - High reliability & Low storage cost
 - 2 types:
 - XOR-based erasure codes (e.g. EVENODD [TC'95], STAR code [FAST'05], TIP-Code[DSN'2015])
 - RS-based erasure codes (e.g. RS code, LRC[ATC'2012][ISIT'15])

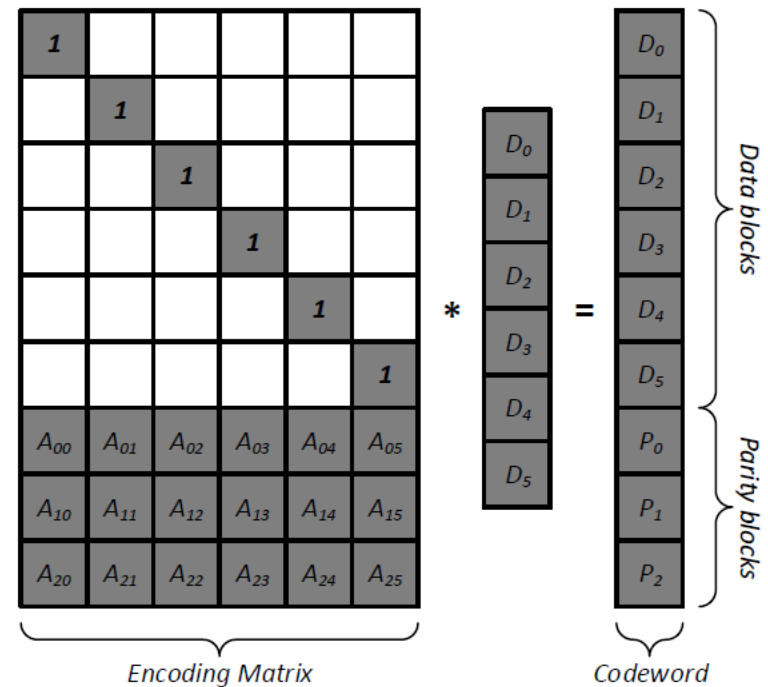


Requirements of Erasure Codes in Multiple AZs

- Requirements of Erasure Codes in Multiple AZs :
 - **High Reliability**
 - tolerate concurrent AZ level failures (e.g., lost a whole AZ)
 - **High Storage Efficiency**
 - make the storage efficiency as high as possible in AZ environments
 - **Low Recovery Cost**
 - Low computation cost
 - Low network bandwidth requirement
 - Small number of I/Os
 - **High Scalability**
 - provide fast scaling processes when scale up or scale out

Classic Erasure Codes in Cloud Storage Systems : RS Code

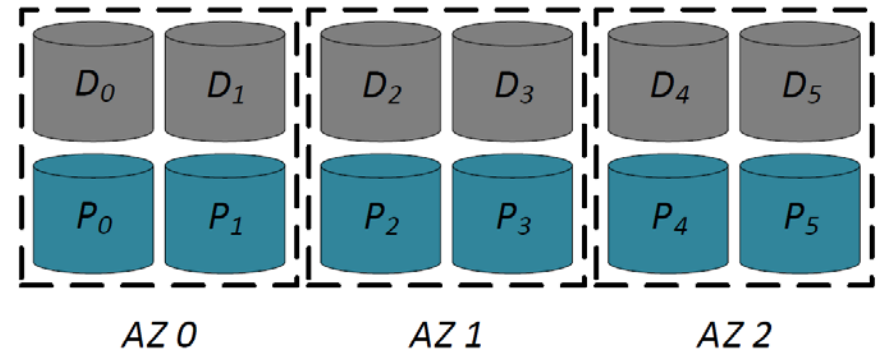
- Reed Solomon Code [Irving S. Reed Gustave Solomon 1960], usually represented as RS(k,r)
 - k: the number of data blocks.
 - r: the number of parity blocks.
 - n: the total number of blocks ($n=k+r$).
- All operations of RS code are based on Galois Field



The encoding process of RS(6,4)

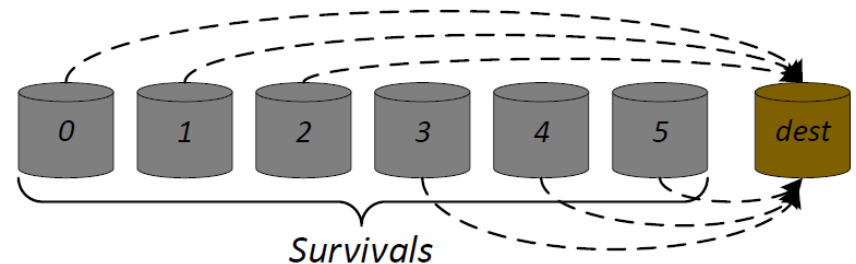
RS Code in Multiple AZs

- RS Code can be applied in multiple AZs
 - All nodes are evenly distributed among all AZs.



RS(6,6) in 3 AZ

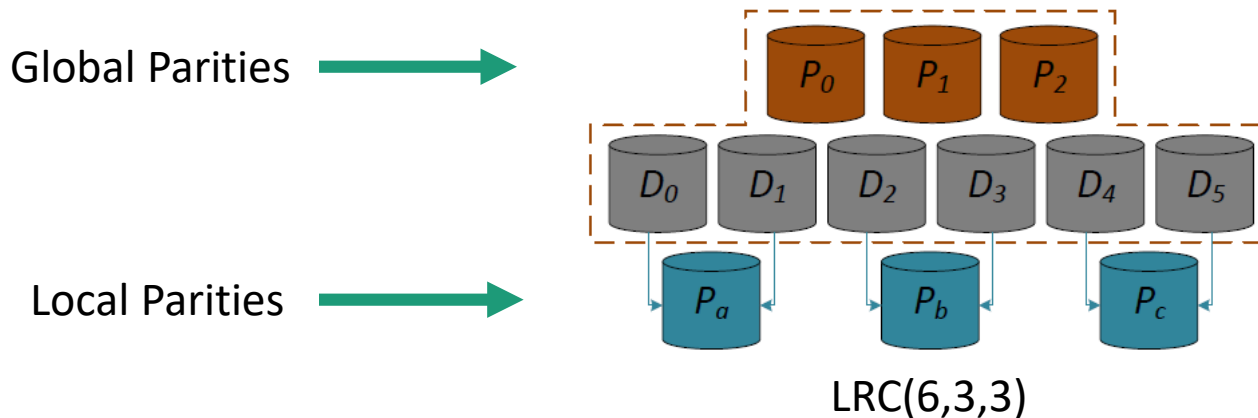
- Recovery process need many data nodes -----
high recovery cost



The decoding proess of RS(6,6)
(one failure node)

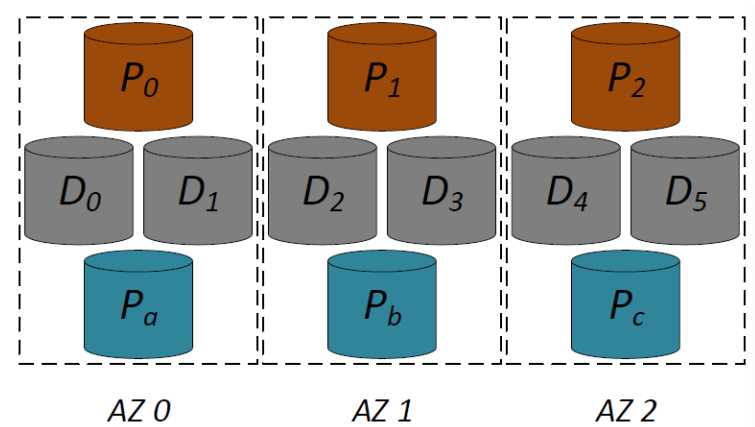
Classic Erasure Codes in Cloud Storage Systems :LRC [ATC'2012][ISIT'15]

- $LRC(k, z, r)$
 - k : the number of data blocks.
 - z : the number of groups.
 - r : the number of parity blocks.
 - Applied in Windows Azure Storage and Facebook cloud
- Main idea: Use local parities, but **increase storage cost**



LRC in Multiple AZs

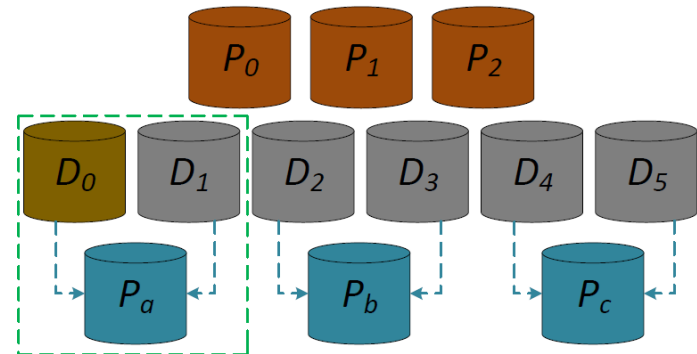
- LRC can be applied in multiple AZs
 - All nodes are evenly distributed among all AZs.



LRC(6,3,3) in 3AZ

- Recovery process need local data nodes -----

lower recovery cost



The decoding process of LRC(6,3,3) (one failure node)

Existing Erasure Codes in Cloud Storage Systems : Other Methods

- XOR-based Codes
 - Low computational complexity
 - Scalability issue
 - E.g. STAR [FAST'05], TIP-Code [DSN'15], GRID codes [ACM TOS'09], etc.
- MSR Code: one special case of regenerating code with the property of Maximum Distance Separable (MDS) codes
 - Low recovery cost
 - Very high computational complexity

Summary on Existing Erasure Codes in Multiple AZs

	Reliability	Scalability	Storage Efficiency	Recovery Cost	Computational Complexity
RS Code					
LRC Code					
MSR Code					
GRID Code					
AZ-Code					

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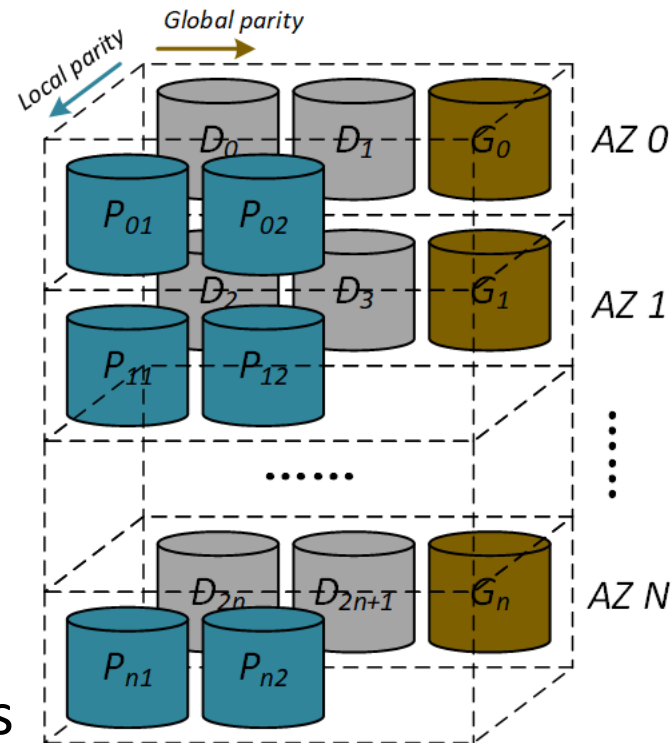
Evaluation

04

Conclusion

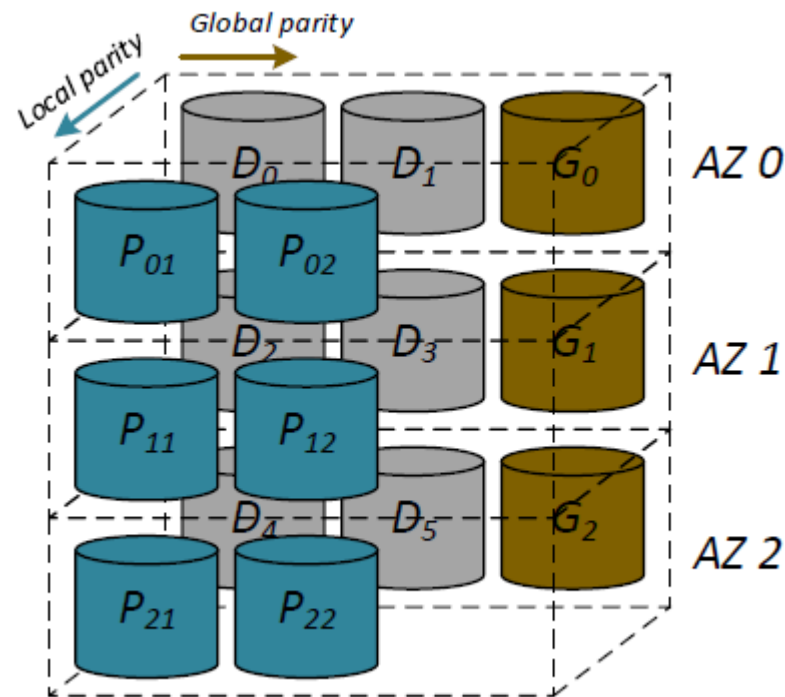
AZ-Code Overview

- Our idea: Combination of LRC and MSR codes
 - Local Parity: MSR codes → Fast Recovery and high performance on decoding process
 - Global parity: RS code → low cost and high fault tolerance
- AZ-Code: $AZ(k, z, p, g)$
 - k : the number of data blocks
 - z : the number of AZs
 - p : the number of local parity blocks
 - g : the number of global parity blocks



A 3AZ Example of AZ-Code

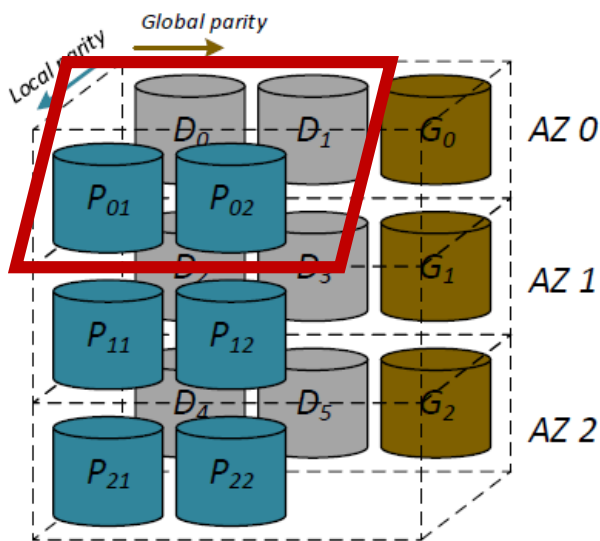
- AZ-Code:
 - $k = 6, z=3, p=2, g = 3$
- Local Parities:
 - MSR(4,2,4)
- Global Parities:
 - RS(6,3)
- We use this configuration as an example in our paper.



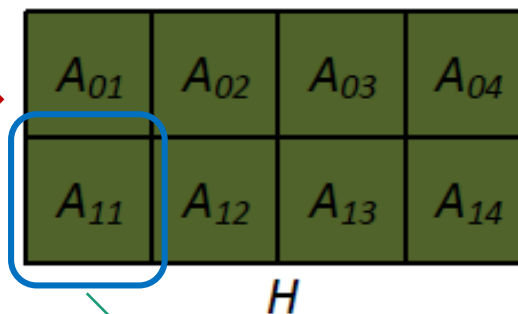
AZ(6,3,2,3) in 3AZ

Construction of AZ-Code: Local Parity

- Configuration: $n = 4, k = 2, r = 2, s = m = 2, l = 4$.
 - H: encoding matrix with the size of $(r \times l) \times (n \times l)$.
 Any $r \times r$ submatrix reversible
 - A_{ij} : $l \times l$ submatrix.
- Single node recovery cost of MSR :



$$\delta = \frac{n}{n-k}$$



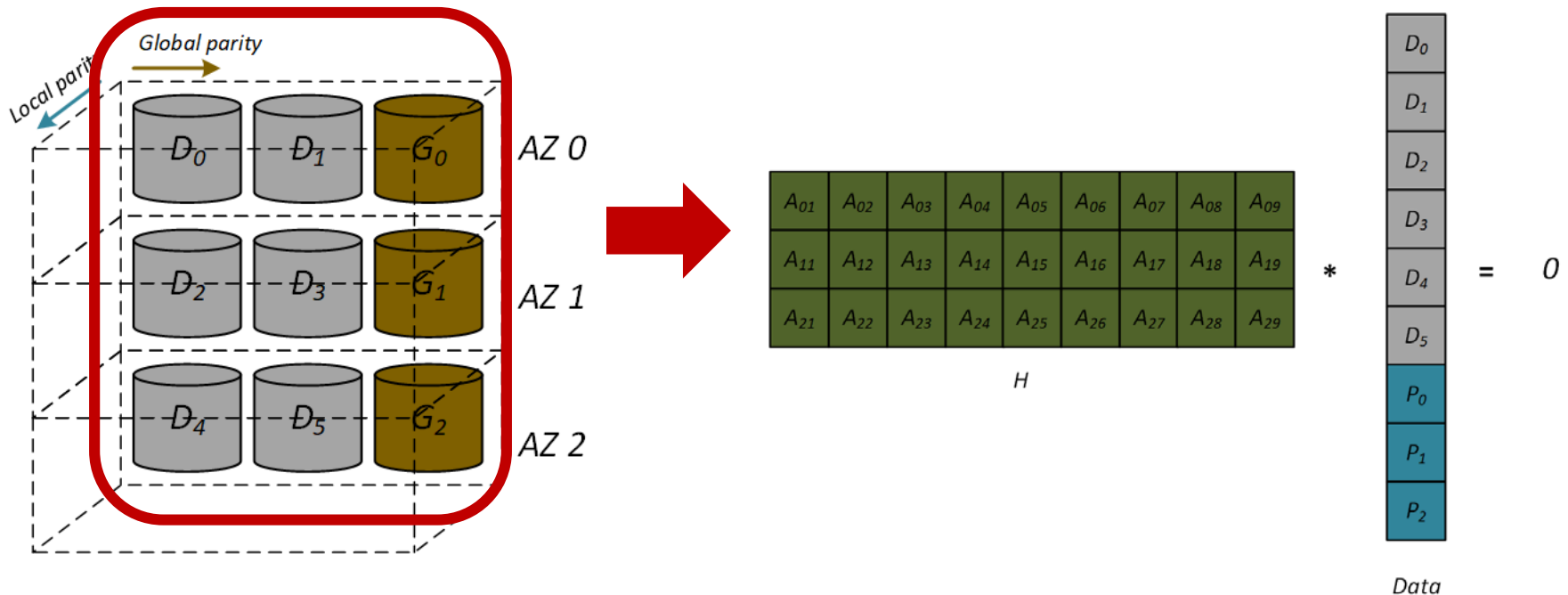
submatrix ($l \times l$)

$$\begin{matrix} D_0 \\ D_1 \\ P_0 \\ P_1 \end{matrix} * = 0$$

Data

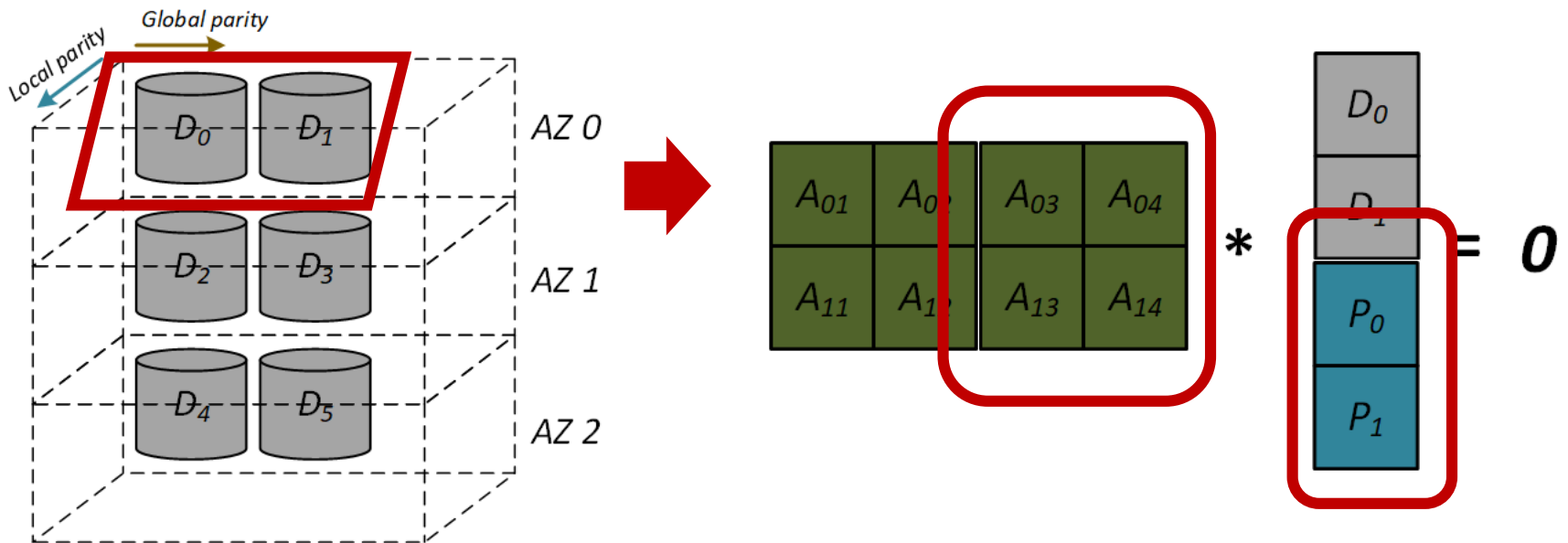
Construction of AZ-Code: Global Parity

- RS Code (PCM method): $n = 9, k = 6, r = 3$
 - H: encoding matrix with the size of $r * n$.
Any $r * r$ submatrix reversible
 - A_{ij} : a number on Galois Field.



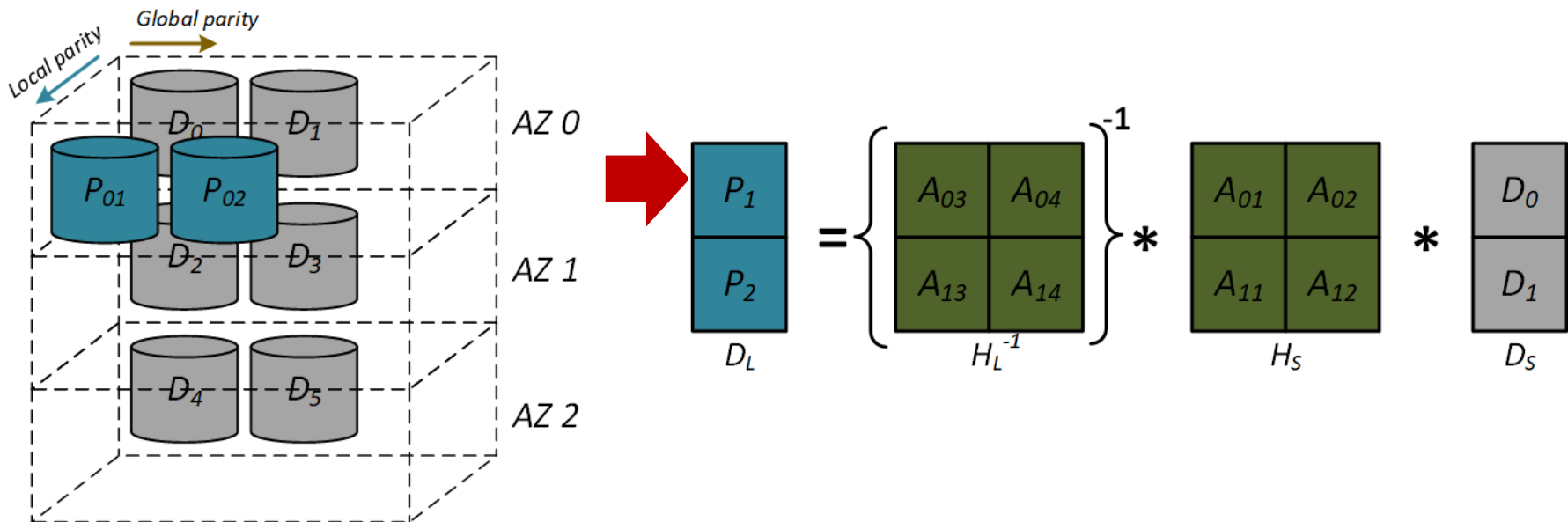
Construction of AZ-Code: PCM[SRDS'15](1)

- Encoding Local Parities: Parity Check Matrix(PCM)
 - PCM method can significantly reduce the size of matrix on encoding and decoding process.



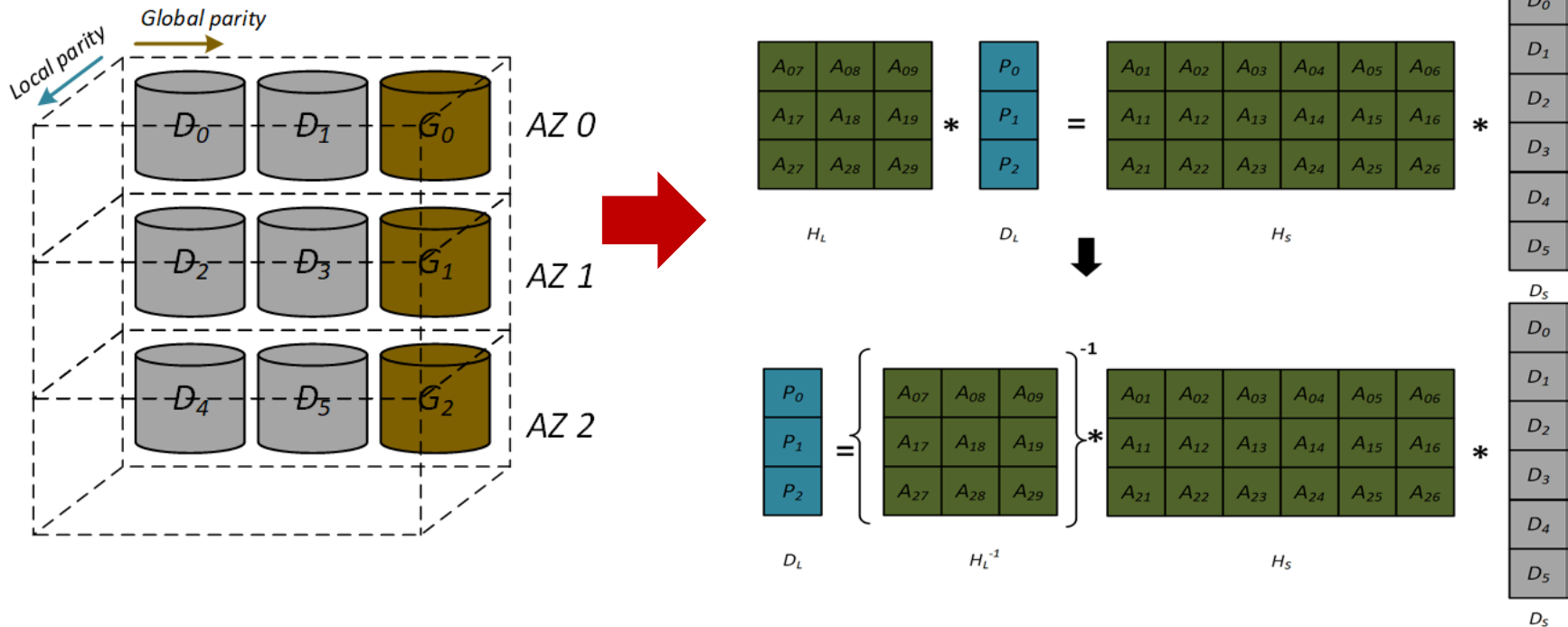
Construction of AZ-Code: PCM[SRDS'15](1)

- Encoding Local Parities: Parity Check Matrix(PCM)
 - PCM method can significantly reduce the size of matrix on encoding and decoding process.



Construction of AZ-Code: PCM(2)

- Encoding Global Parities: Parity Check Matrix(PCM)

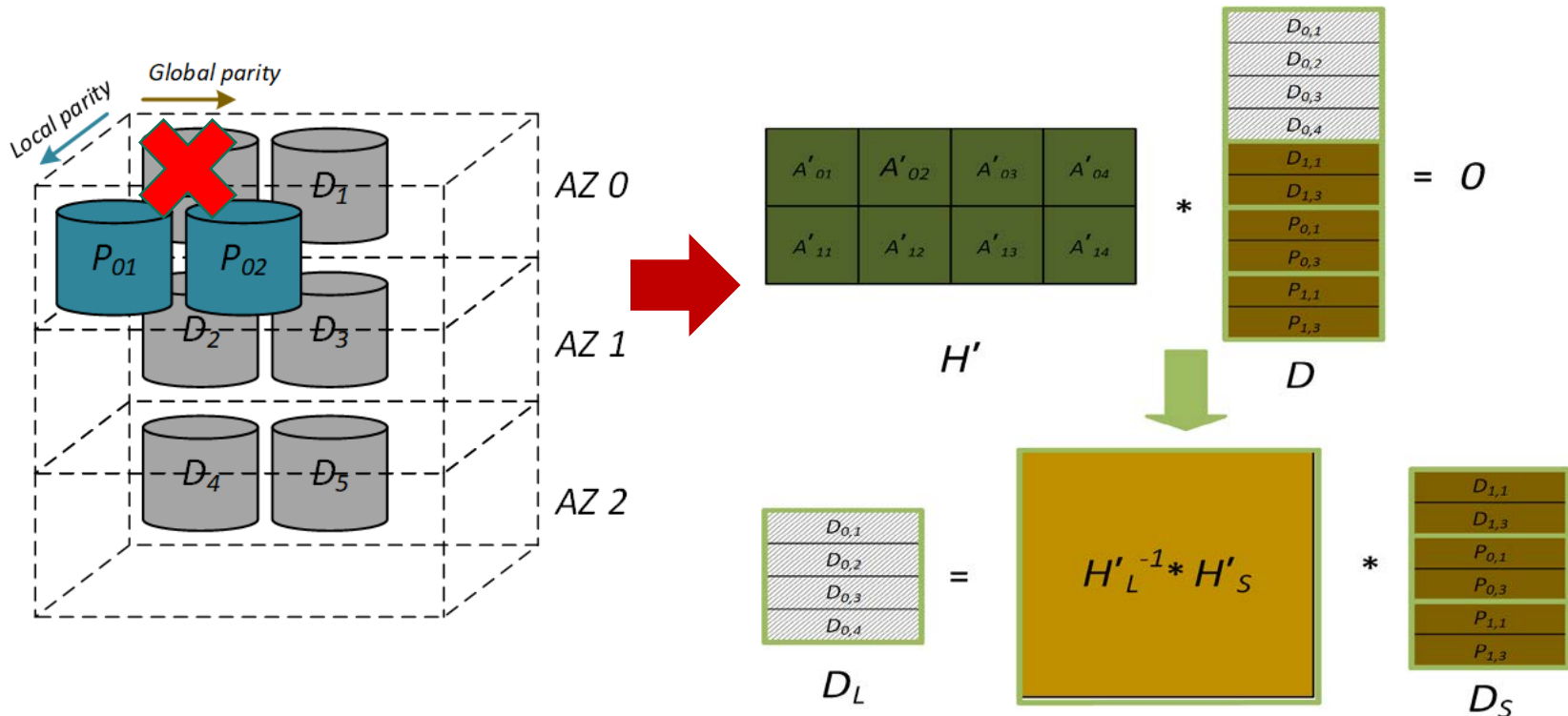


AZ-Code Reconstruction: three conditions

1. Decoding with Local Parities:
 - Single node failure: reduce the recovery cost
 - Multiple node failure: similar to RS code
2. Decoding with Global Parities
3. Decoding with Global and Local Parities (Combined method).

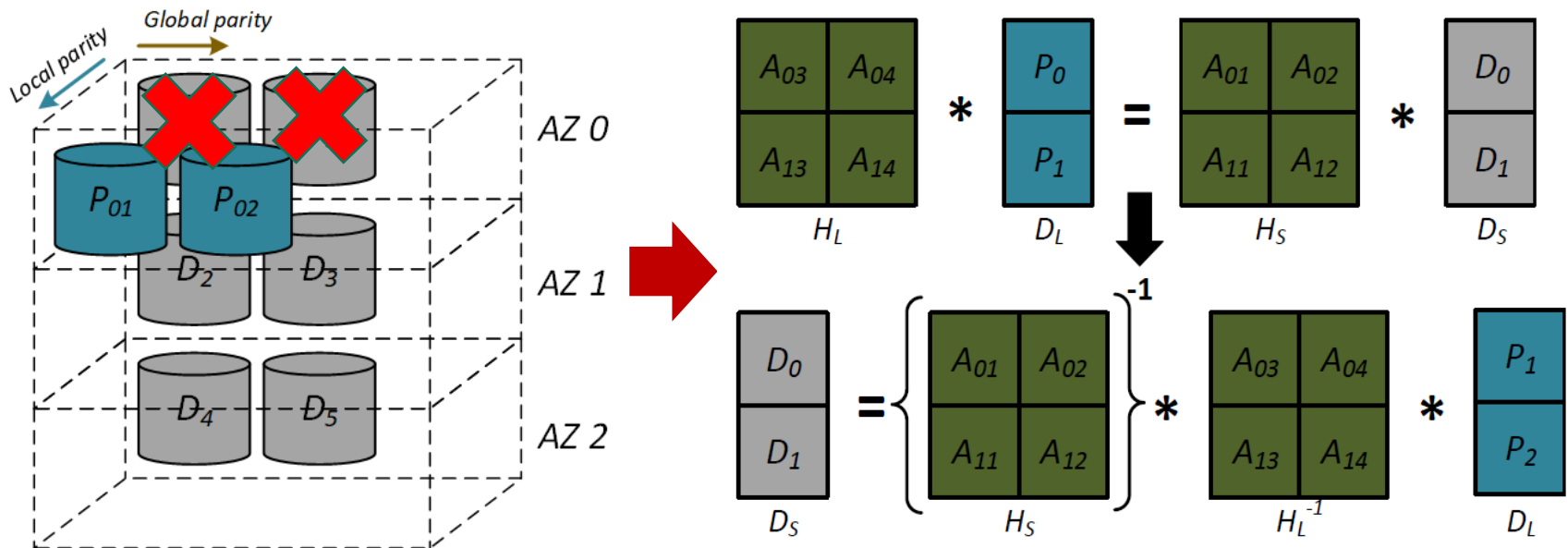
Reconstruction with Local Parities (1)

- Single node failure: Assume D_0 failed, the other three nodes D_1 , P_{01} and P_{02} are used to recover the lost data together, and each node only need $1/2$ data (marked as brown).



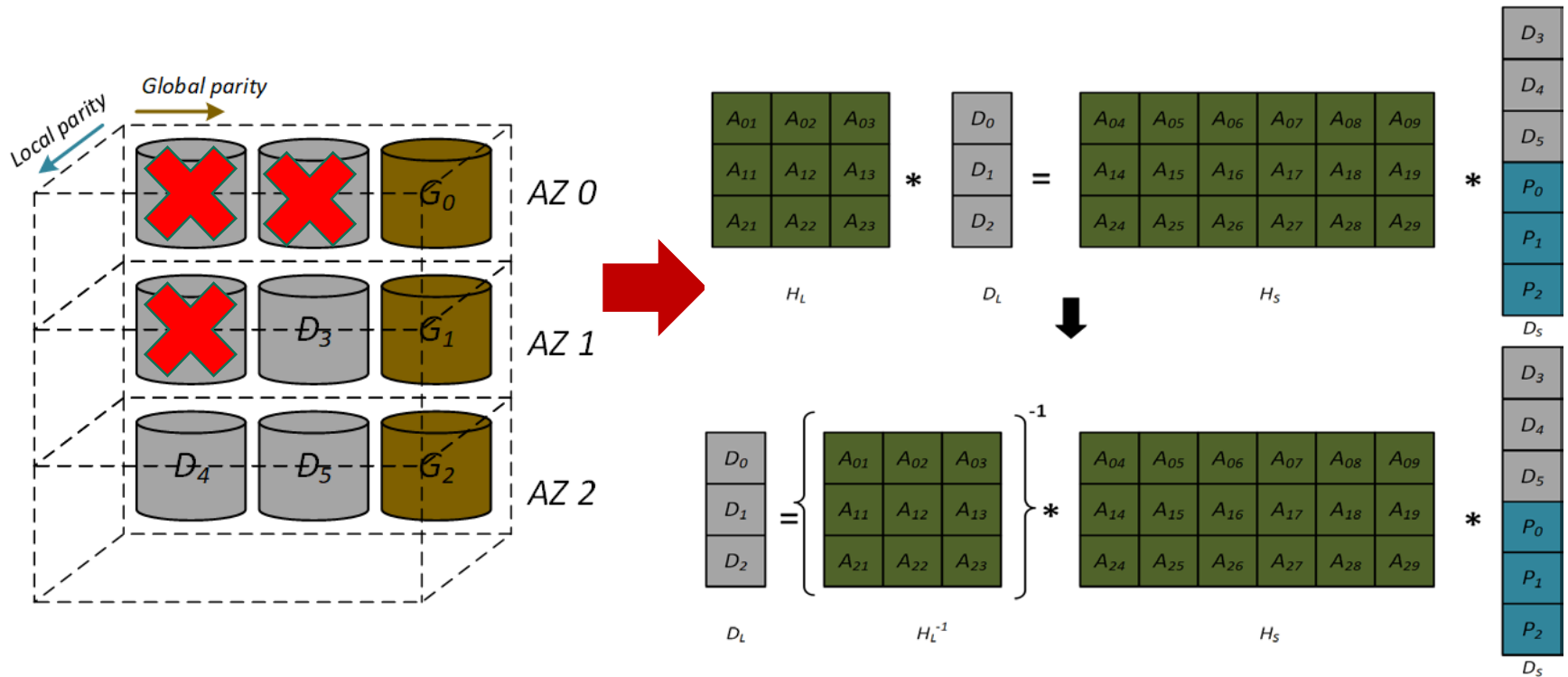
Reconstruction with Local Parities (2)

- Multiple node failures: Assume D_0 and D_1 failed. Use P_{01} and P_{02} to recover. Each node need **all** data



Reconstruction with Global Parities

- Arbitrary node-failures: Assume D_0 , D_1 and D_2 failed. Use Parity Check Matrix (PCM) to recover.



Reconstruction by Local and Global Parities concurrently(1)

- Decoding with both local and Global parities: Parity Check Matrix(PCM)
- J: new encoding matrix
- G is global parities and P is local parities

R_{01}	R_{02}	R_{03}	R_{04}	R_{05}	R_{06}	1	0	0	0	0
R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	0	1	0	0	0
R_{21}	R_{22}	R_{23}	R_{24}	R_{25}	R_{26}	0	0	1	0	0
A_{01}	A_{02}	0	0	0	0	0	0	0	A_{03}	A_{04}
A_{11}	A_{12}	0	0	0	0	0	0	0	A_{13}	A_{14}

J

D_0
D_1
D_2
D_3
D_4
D_5
G_0
G_1
G_2
P_0
P_1

$Data$

*

= 0

Reconstruction by Local and Global Parities concurrently(2)

- Assume that D_0 , D_1 , P_0 , P_1 and G_1 failed. The process is the same as before.

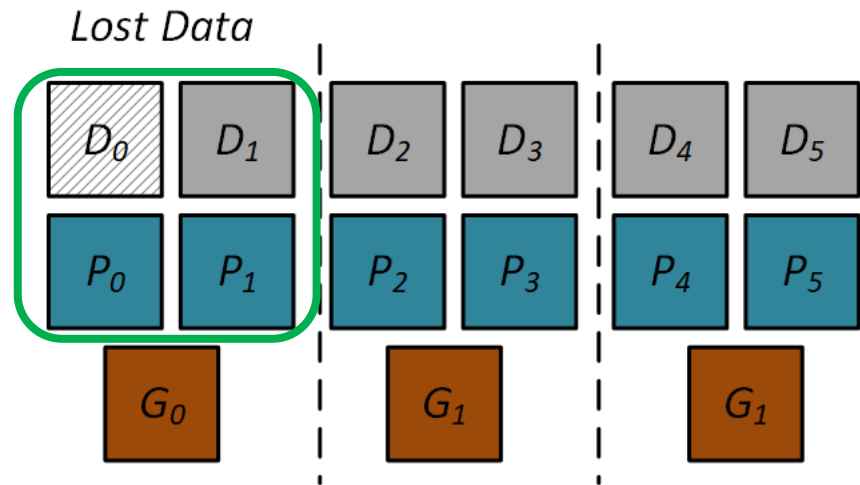
$$\begin{array}{|c|c|c|c|c|} \hline R_{01} & R_{02} & 1 & 0 & 0 \\ \hline R_{11} & R_{12} & 0 & 0 & 0 \\ \hline R_{21} & R_{22} & 0 & 0 & 0 \\ \hline A_{01} & A_{02} & 0 & A_{03} & A_{04} \\ \hline A_{11} & A_{12} & 0 & A_{13} & A_{14} \\ \hline \end{array}
 \quad
 \begin{array}{|c|} \hline D_0 \\ \hline D_1 \\ \hline G_0 \\ \hline P_0 \\ \hline P_1 \\ \hline \end{array}
 \quad
 =
 \quad
 \begin{array}{|c|c|c|c|c|c|} \hline R_{03} & R_{04} & R_{05} & R_{06} & 0 & 0 \\ \hline R_{13} & R_{14} & R_{15} & R_{16} & 1 & 0 \\ \hline R_{23} & R_{24} & R_{25} & R_{26} & 0 & 1 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 \\ \hline \end{array}
 \quad
 \begin{array}{|c|} \hline D_2 \\ \hline D_3 \\ \hline D_4 \\ \hline D_5 \\ \hline G_1 \\ \hline G_2 \\ \hline \end{array}$$

H_L
 D_L
 H_S
 D_S

Reconstruction Cost Analysis: decoding by local parities (1)

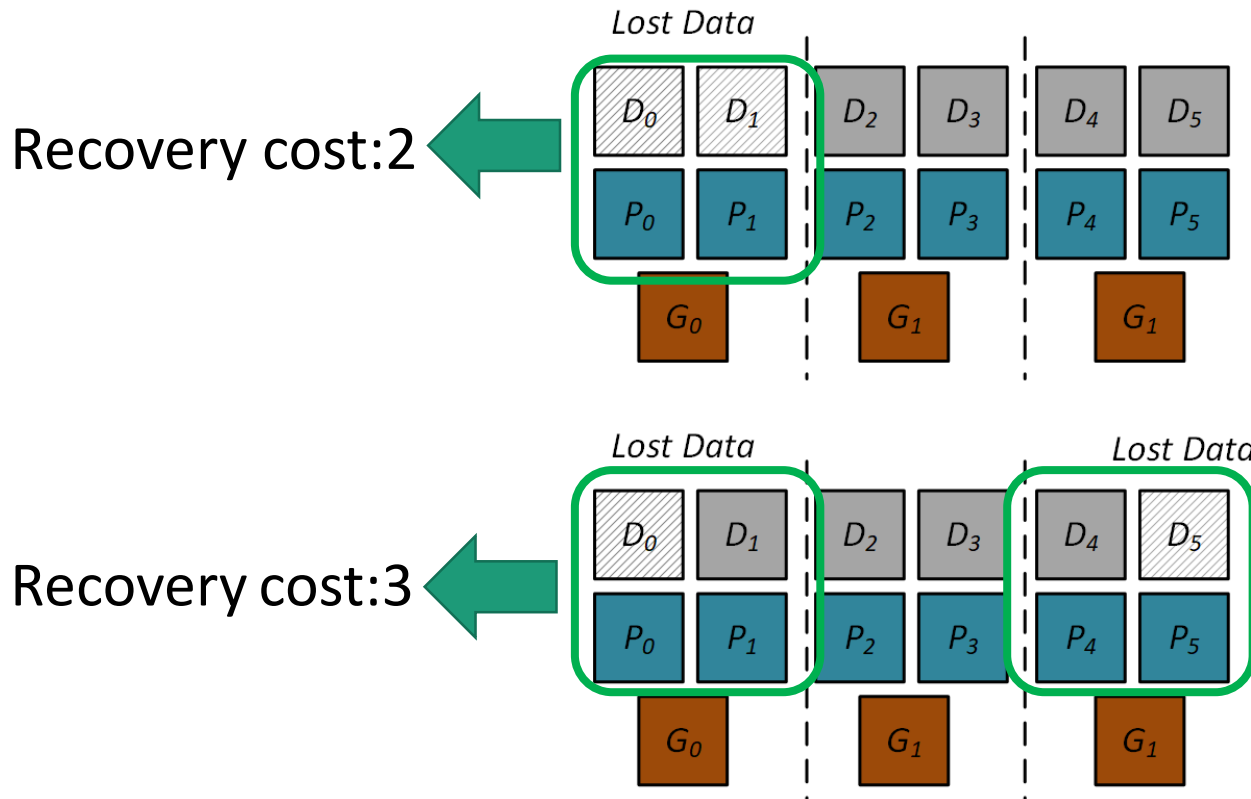
- Single Node Fault: using **Local Parity** for recovery.
recovery cost: $3/2=1.5$

- Using the 3 survivors for recovery
- Each node only needs to transmit **half** of its data



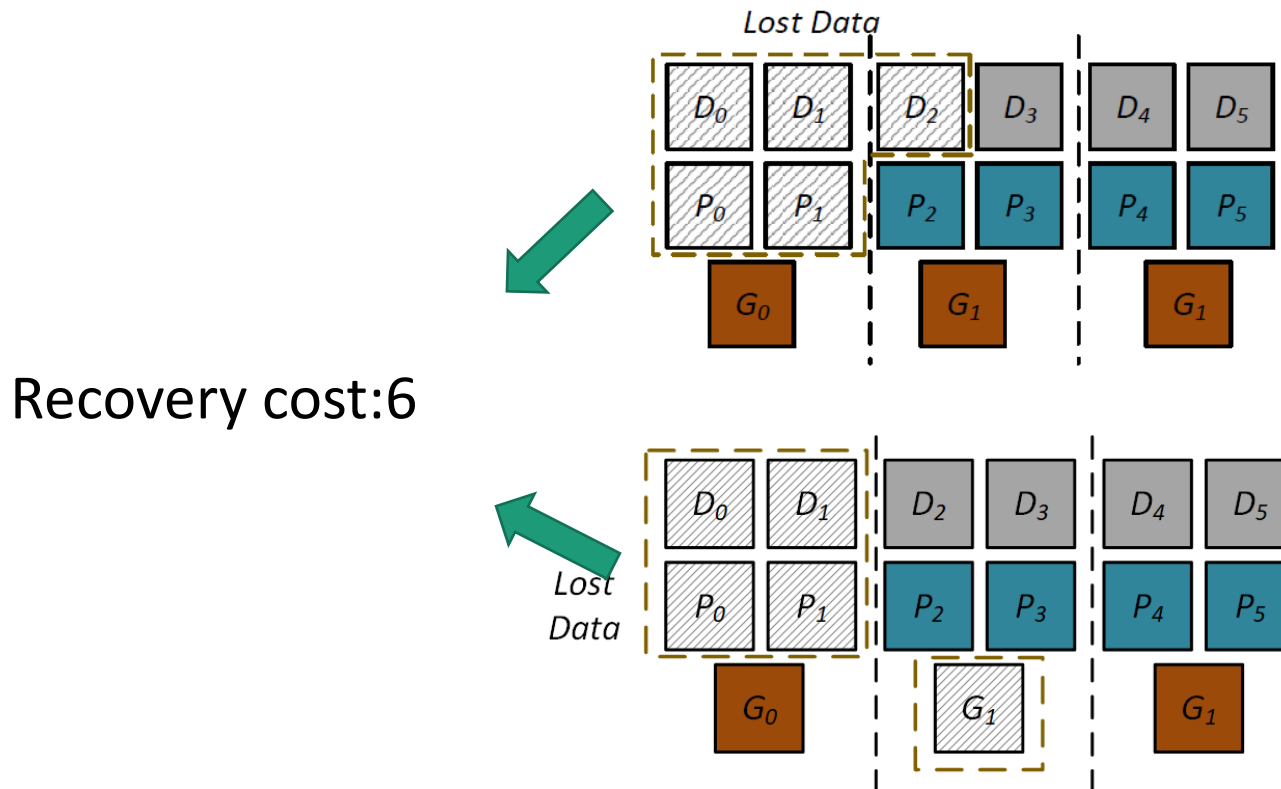
Reconstruction Cost Analysis: decoding by local parities (2)

- Two Node Fault: using **Local Parity** for recovery.



Reconstruction Cost Analysis: decoding by Global parities

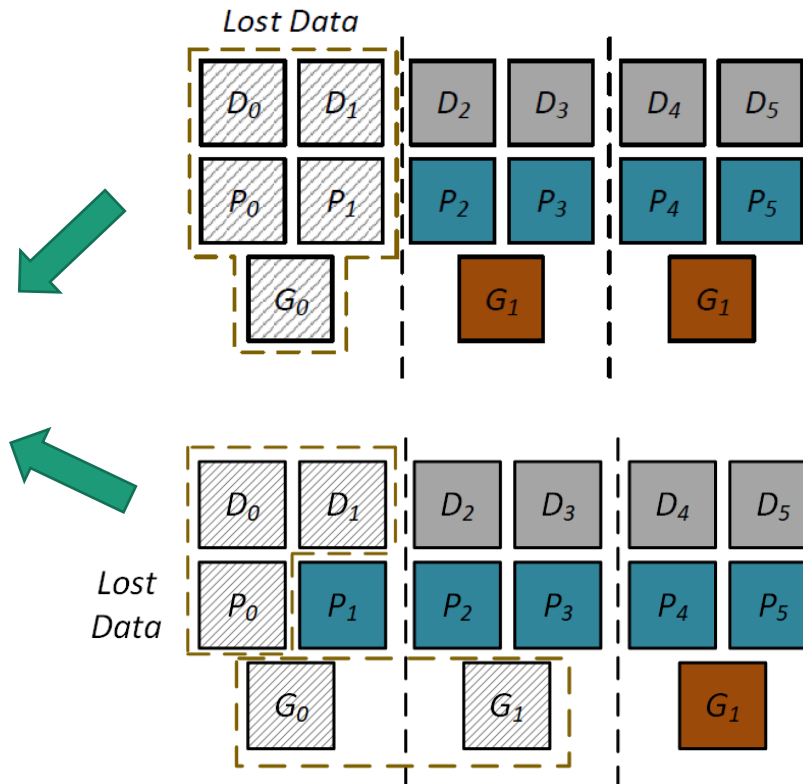
- Multiple Node Fault : using **global** parity



Reconstruction Cost Analysis: decoding by local and global parities

- Multiple Node Fault : using both **local and global** parity for recovery.

Recovery cost:6



Configuration of AZ-Code

- By changing the erasure code parameters configuration, we can trade off storage cost, fault tolerance and single-node recovery bandwidth.

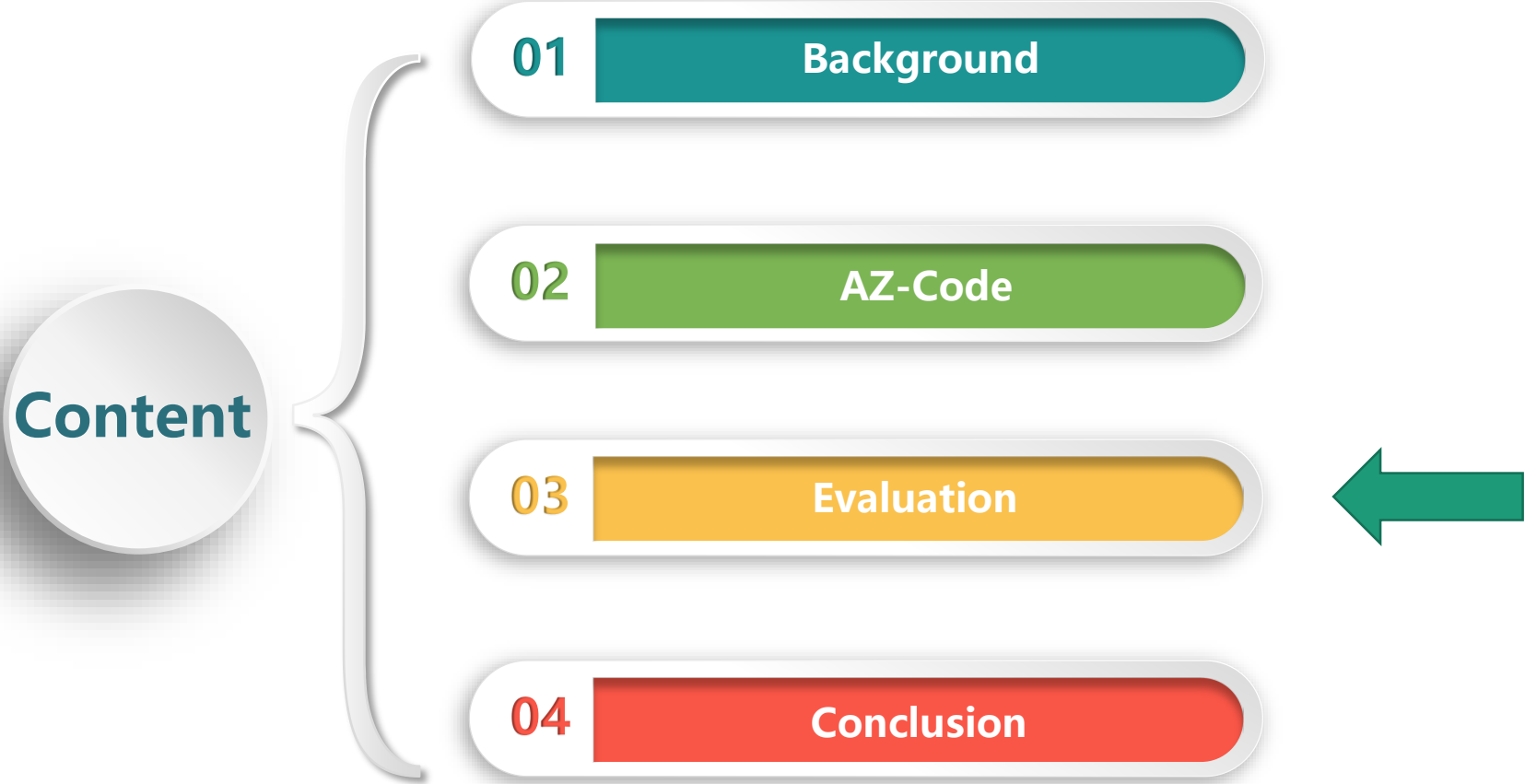
	Storage Efficiency	Fault Tolerance (maximum concurrent fail nodes)	Recovery Cost (single node)
AZ(k, z, p, g)	$k/(k+z*p+g)$	$g + p$	$(k/z+p-1)/p$
AZ(6,3,2,3)	0.40	1AZ (5 nodes)	1.5
AZ(12,3,2,6)	0.50	1AZ (8 nodes)	2.5
AZ(12,3,2,9)	0.44	1AZ+2 (11 nodes)	2.5
AZ(18,3,2,6)	0.60	1AZ-2 (8 nodes)	3.5
AZ(18,3,2,9)	0.55	1AZ(11 nodes)	3.5
AZ(18,3,2,12)	0.50	1AZ+2 (14 nodes)	3.5

Lowest
Recovery
Cost

Best

Storage
Efficiency

Content



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graph LR; Content((Content)) --- B[01 Background]; Content --- AZ[02 AZ-Code]; Content --- E[03 Evaluation]; Content --- C[04 Conclusion]; Arrow[Green Arrow] --> E
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Evaluation Methodology

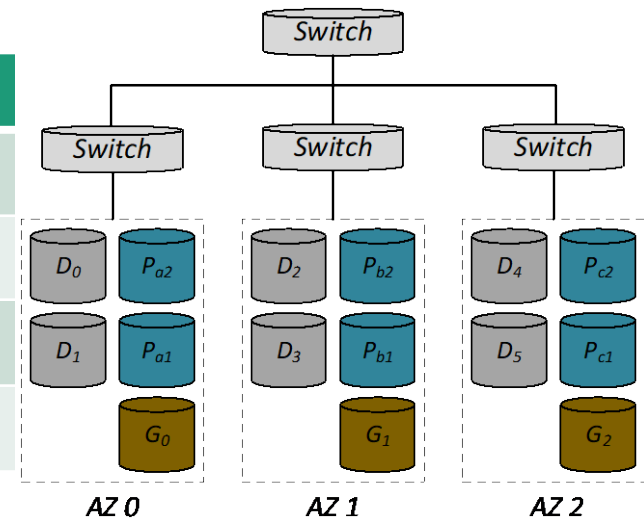
- Erasure codes in our evaluation
 - AZ-Code, EVENODD [ToC'95], STAR [FAST'05], RS code, LRC[ATC'2012], MSR Code[FAST'2018])
- Metric:
 - Reconstruction Cost: The number of nodes required to reconstruct the lost nodes
 - Recovery Time, including
 - computation time
 - I/O overhead
 - transmission time

Experimental Environment

- Build a Hadoop Cluster of three Data Nodes and one Name Node
- All Four nodes are DELL R730 Servers

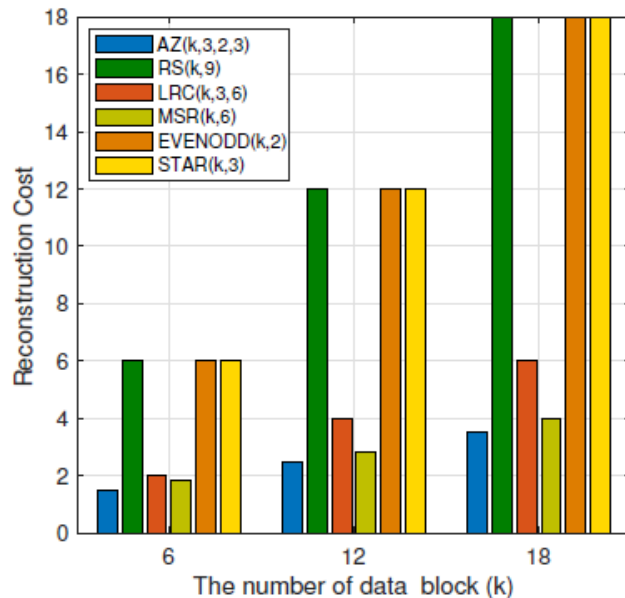
	Configuration
Operating System	Linux 3.19
C Compiler	gcc 5.4.0
CPU	Intel Xeon 3.0GHz
Memory	32GB

DELL R730 Server

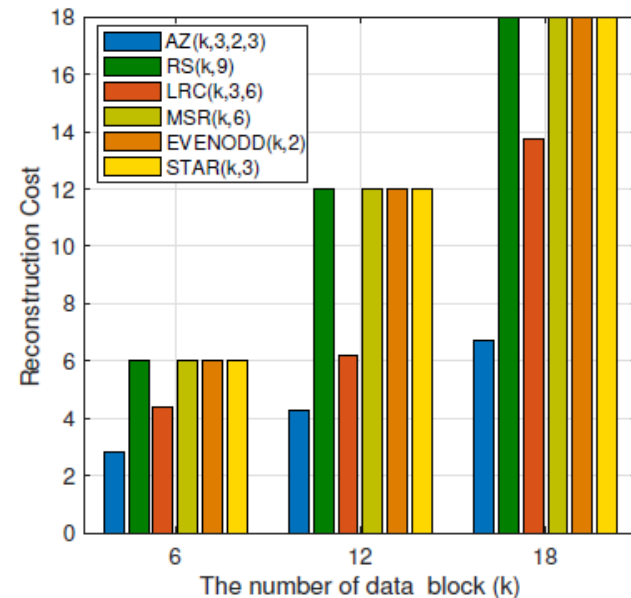


Mathematical analysis: reconstruction cost

- We Change k from 6 to 18 and consider single and double data node failure conditions.
 - save the reconstruction cost by up to 81% compared with RS code, EVENODD and STAR, 51% compared with LRC and 63% compared with MSR.



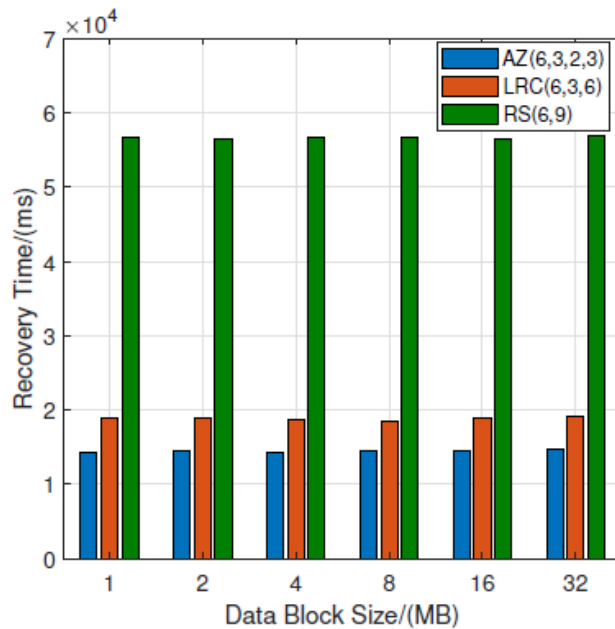
(a) Single Data Node Failure.



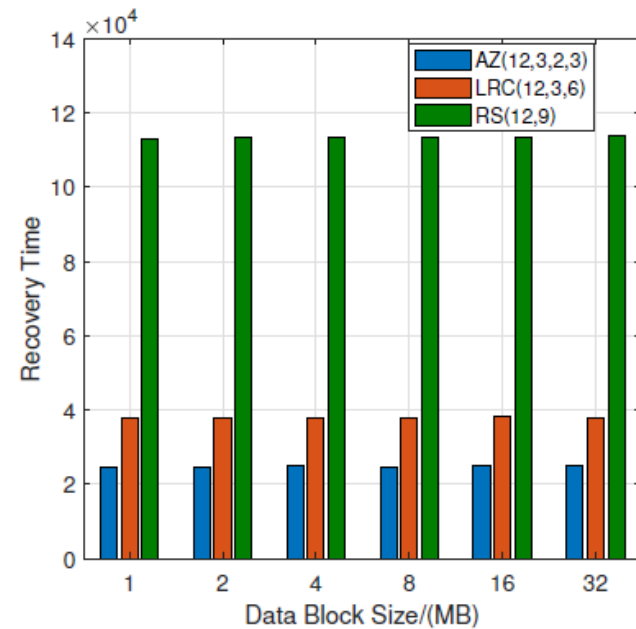
(b) Double Data Nodes Failure.

Experimental Results: Recovery time on Single Data Node Failure(1)

- Change k from 6 to 12 and block size from 1MB to 32 MB
 - save the recovery time by up to 34% compared with LRC
 - save the recovery time by up to 78% compared with RS



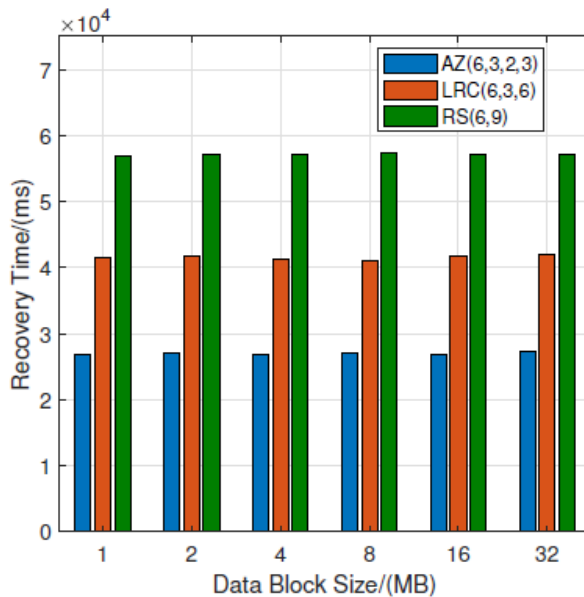
(a) $k=6$



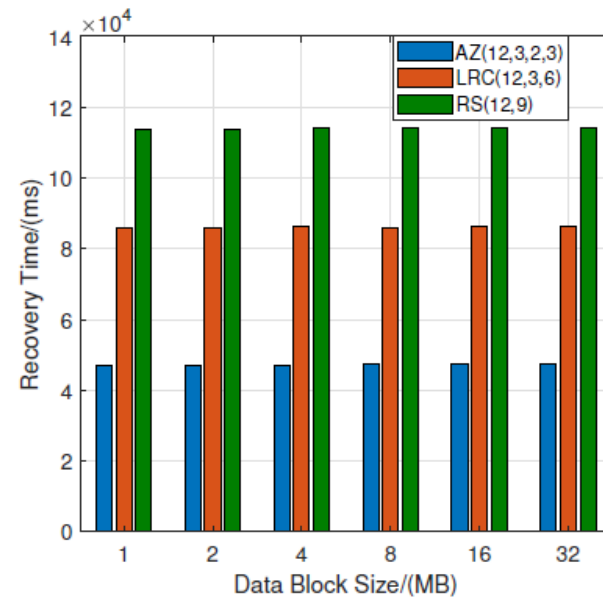
(b) $k=12$

Experimental Results: Recovery time on Double Data Node Failure(2)

- Change k from 6 to 12 and block size from 1MB to 32 MB
 - save the recovery time by up to 45% compared with LRC
 - save the recovery time by up to 58% compared with RS



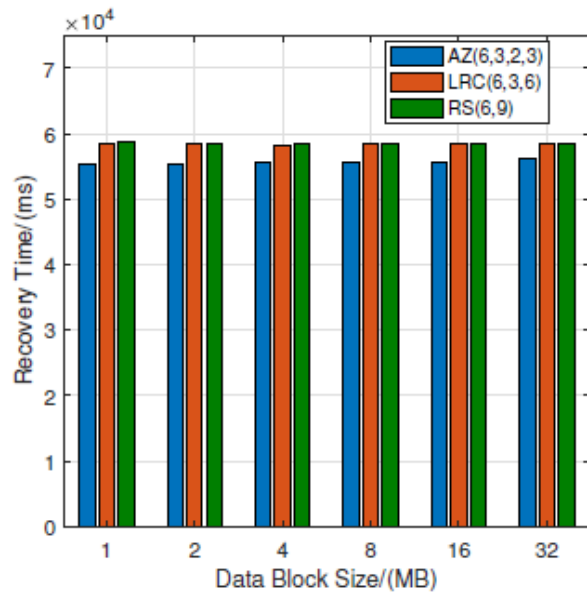
(a) $k=6$



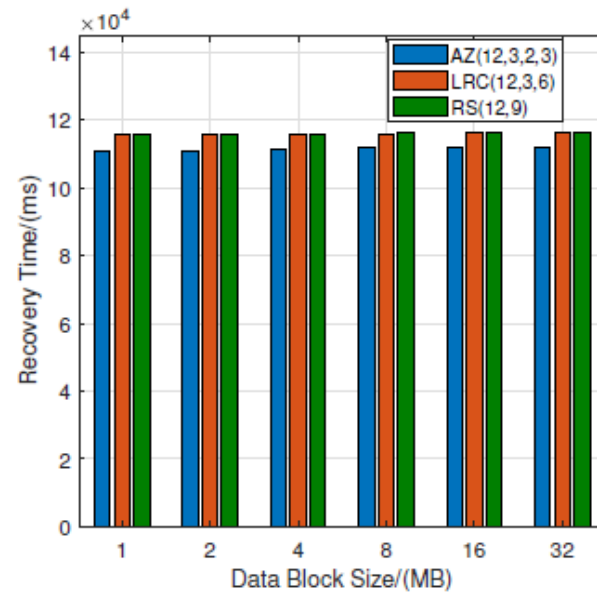
(b) $k=12$

Experimental Results: Recovery time on Double Data Node Failure(2)

- Change k from 6 to 12 and block size from 1MB to 32 MB
 - save the recovery time by up to 5% compared with LRC
 - save the recovery time by up to 6% compared with RS



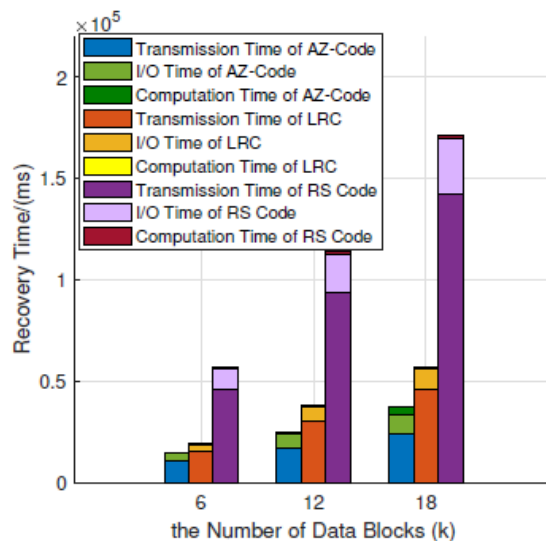
(a) $k=6$



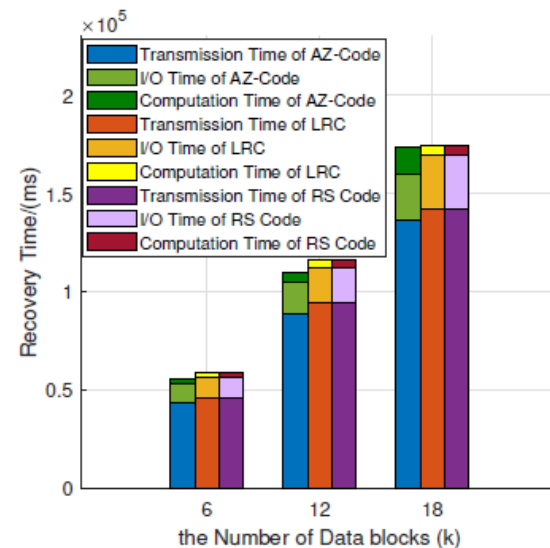
(b) $k=12$

Experimental Results of Recovery Time

- We analysis the components of recovery time
 - transmission time is about 8.71x of computation time
 - transmission time is about 5.45x of I/O overhead
 - **transmission time is the major component of recovery time**



(a) Detailed recovery time of full system recovery in terms of Single node failure



(b) Detailed recovery time of full system recovery in terms of Multiple nodes failure

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Conclusion

- Availability Zone Level Erasure Code (AZ-Code) has the following advantages
 - Supporting the Multiple AZ environment well and provide AZ level reliability.
 - Improving the recovery performance in AZ environment
 - reducing the recovery time up to 78.24% compared with RS code
 - reducing the recovery time up to 34.81% compared with LRC code
 - Ensuring high scalability

Thank you!



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Q & A