Secure File Fragment Allocation in Distributed Storage Systems with Heterogeneous Vulnerabilities

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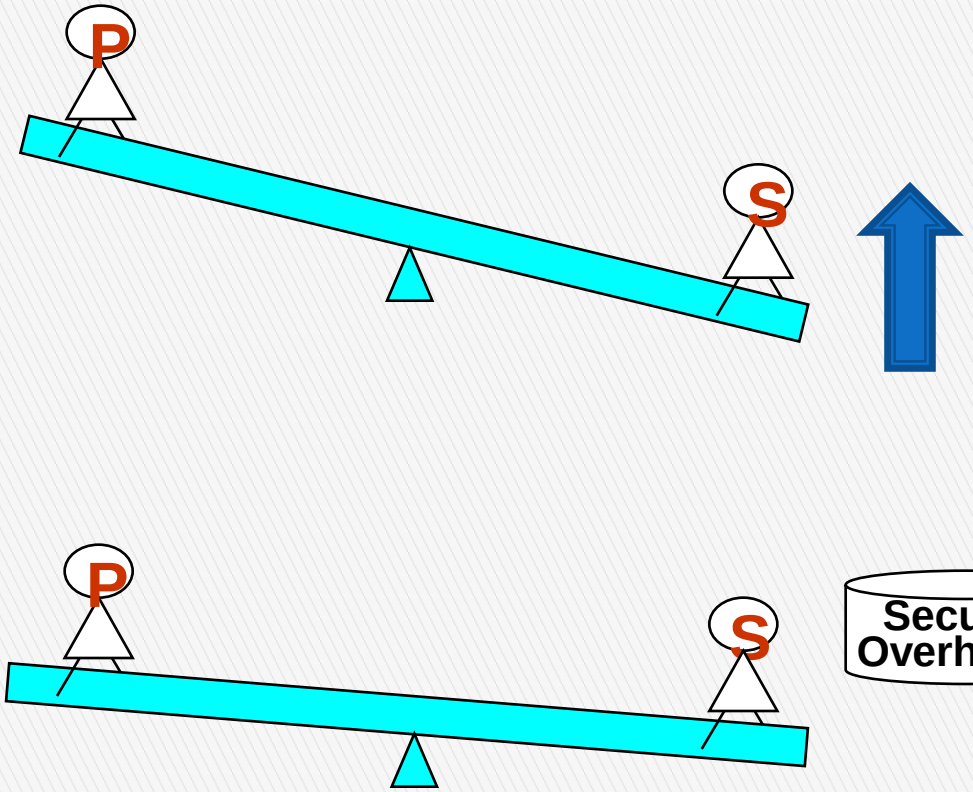
Distributed Storage Systems

- Large-scale data processing
- Scalability, availability, performance, security

Security vs. Performance

Security is achieved at the cost of performance degradation



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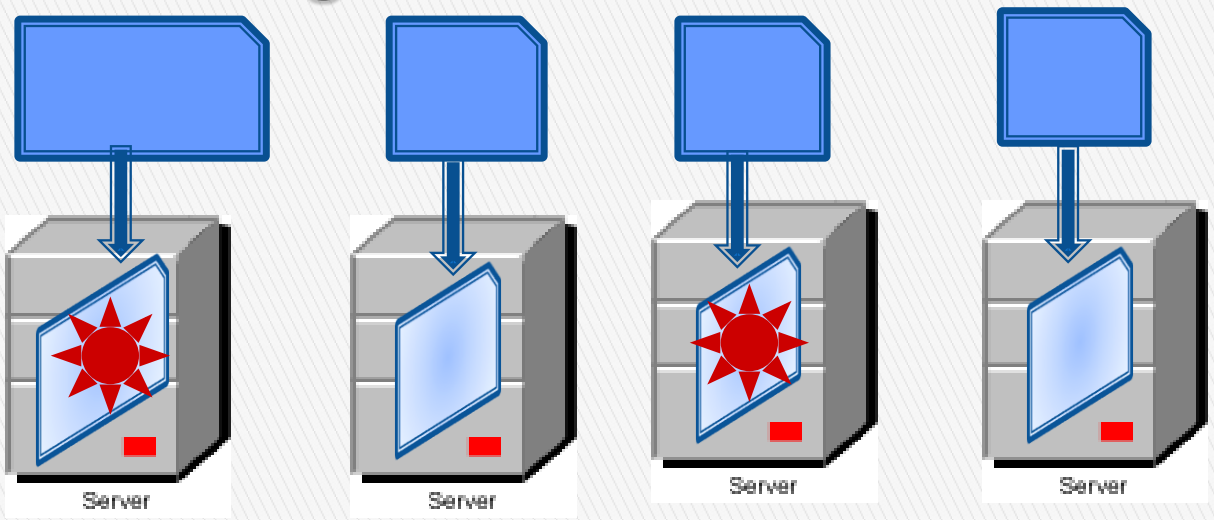
Secret Sharing

- *(m, n)* Secret sharing - e.g., (2, 3)
- File Fragmentation



Motivation: Storage nodes in a distributed system have heterogeneous vulnerabilities.

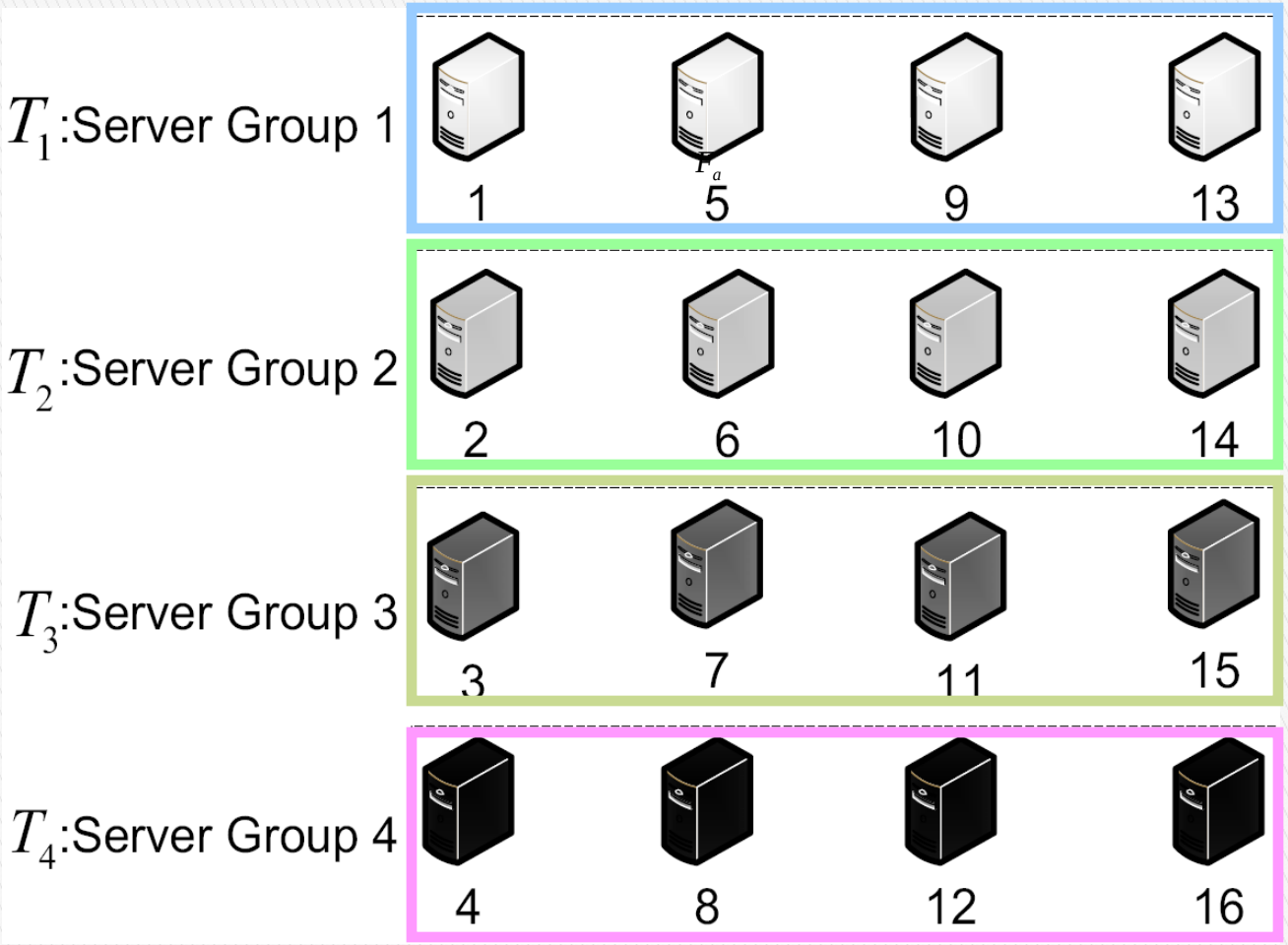
Heterogeneities in Large-Scale Distributed systems

- A wide variety of:
  - Hardware (e.g., SSDs, HDDs, Tapes)
  - Software (e.g, HDFS, Lustre, PVFS)

- Heterogeneities affect performance

Can we leverage heterogeneity features to improve security for distributed systems?

Considering Heterogeneity Issues



File F has 3 fragments: a, b, c

Fragment a

Fragment b

Fragment c

$$F(i) = j \bmod n$$

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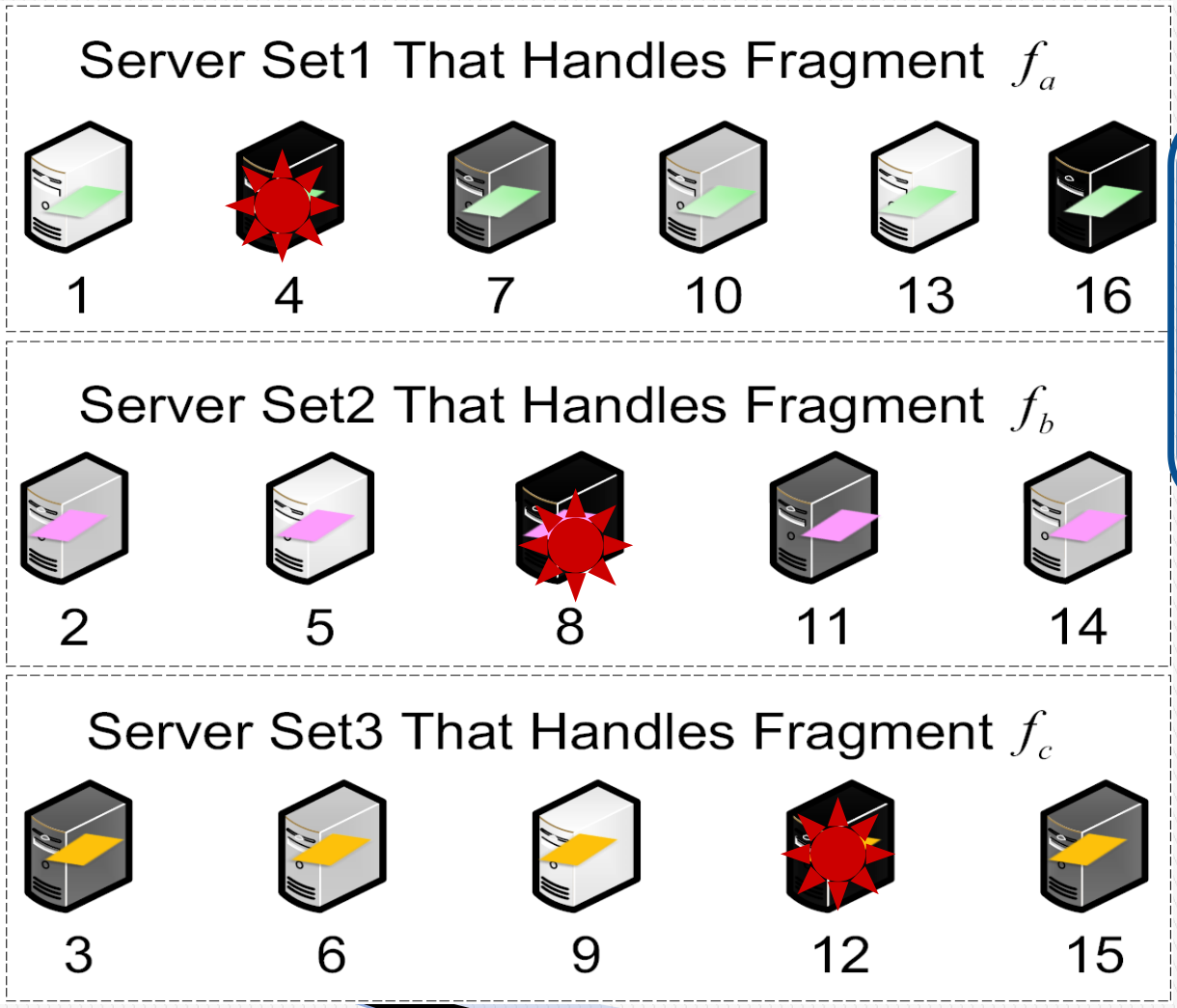
Motivation: File Fragment Allocations



Problem?

Reconstruct

Fragment a

Fragment b

Fragment c

File F

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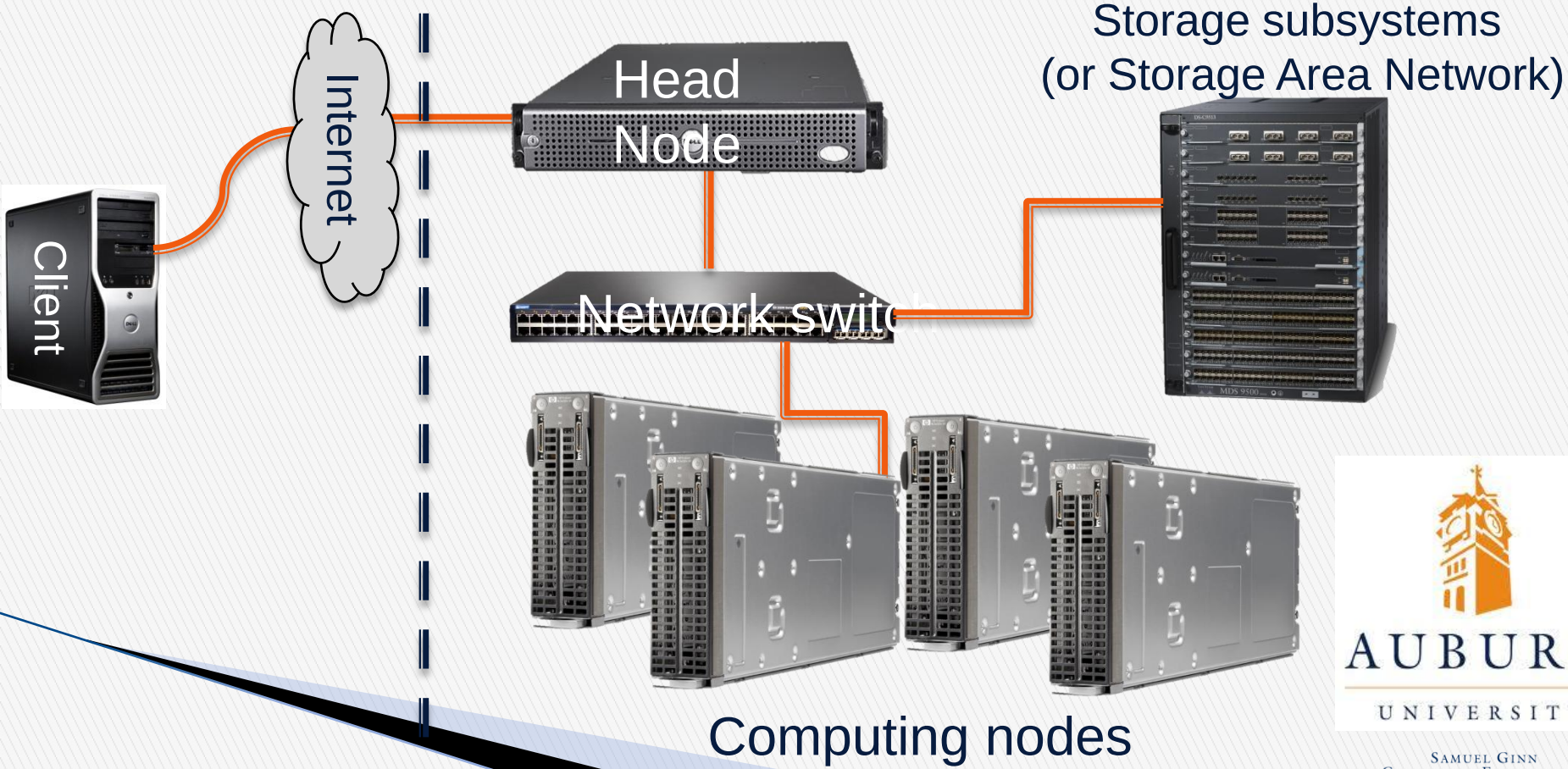
Cluster Storage Systems

- The Architecture of a Cluster



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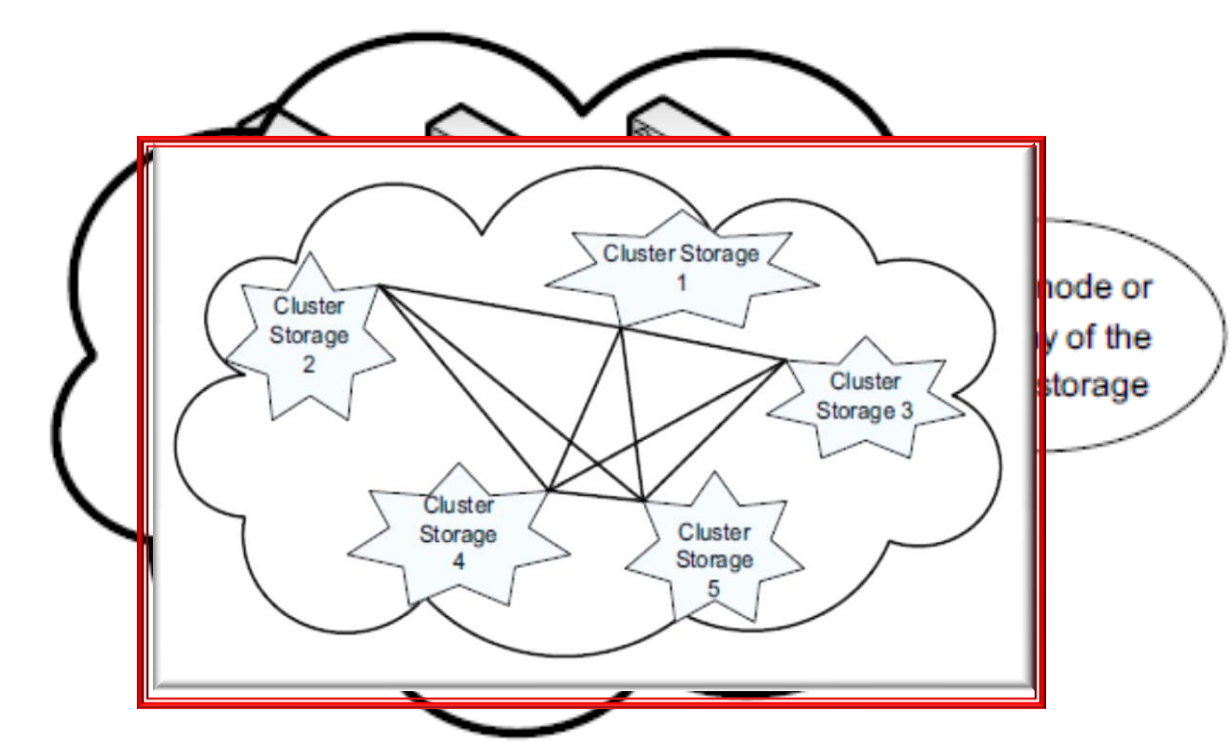
System Model



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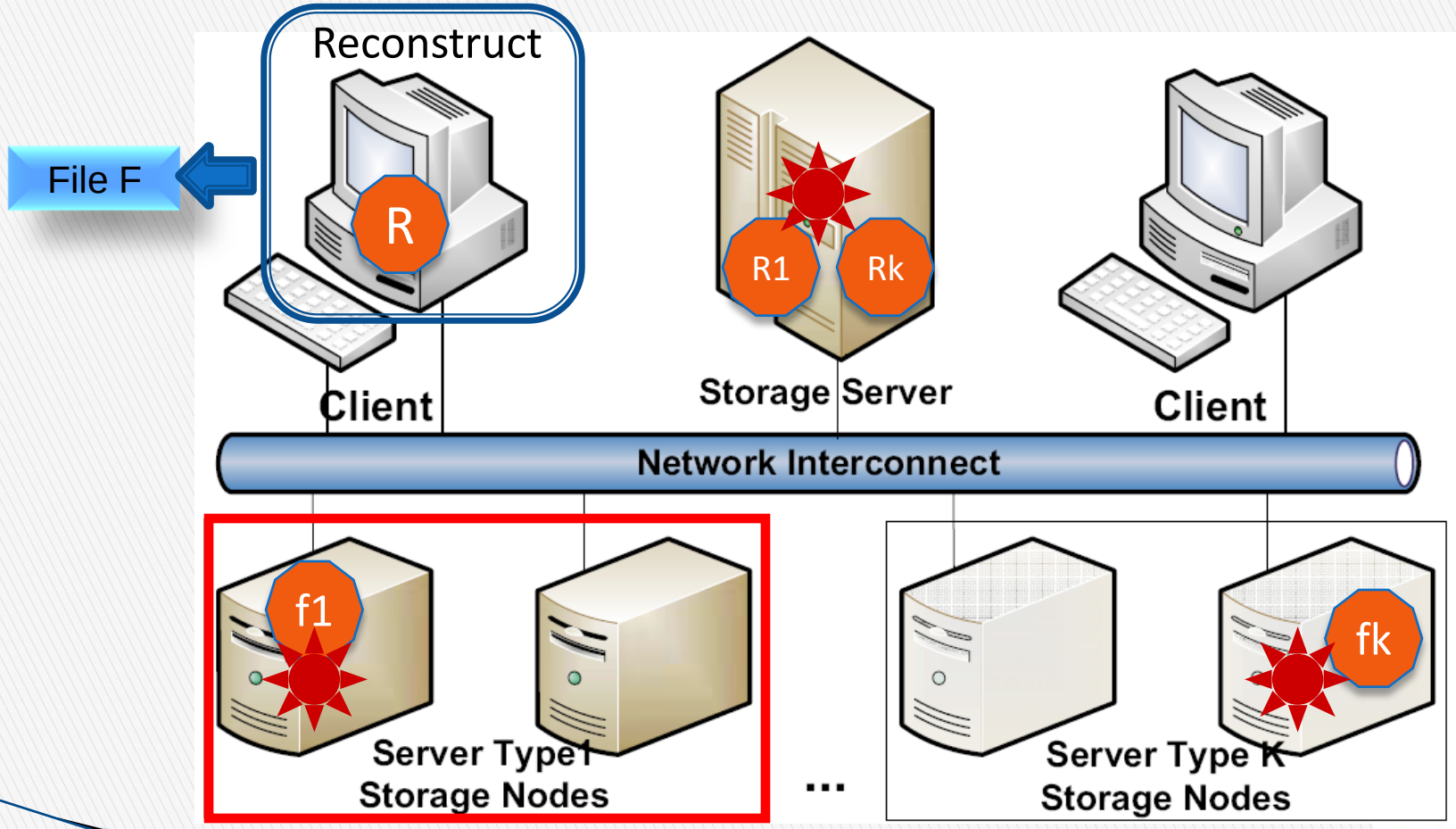
A Prototype System



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The S-FAS Scheme

A file's fragment-allocation decisions are guided by four policies

- Multiple server groups
- Store fragments of a file across as many different server groups as possible
- Integrate the (m n) secret sharing scheme
- Allocate file fragments within a sub-system to improve I/O performance

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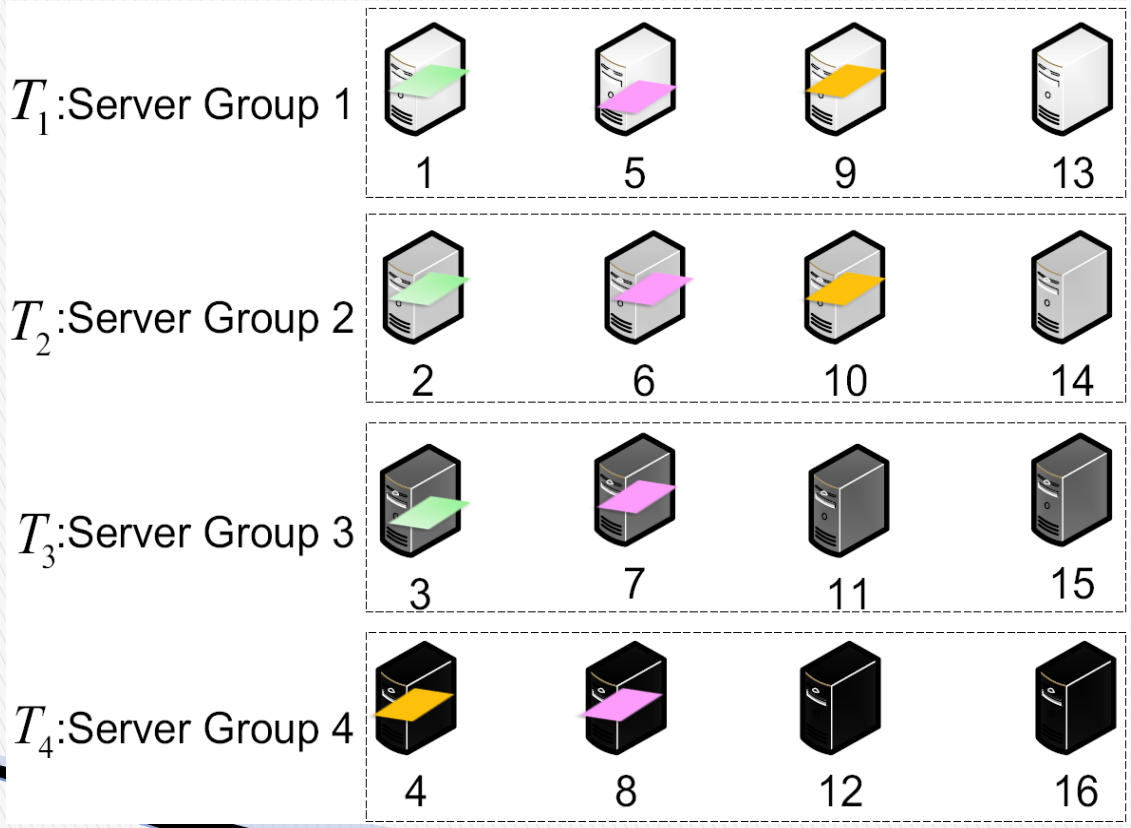
Multiple server-type groups

- Diversity make sense?
  - A team with diversity make creativity;
  - A system with diversity may improve security;
  - We divide storage nodes of a system into different “server type” based on their different security level or strategy caused by hardware or software;

Spread fragment storage of a file

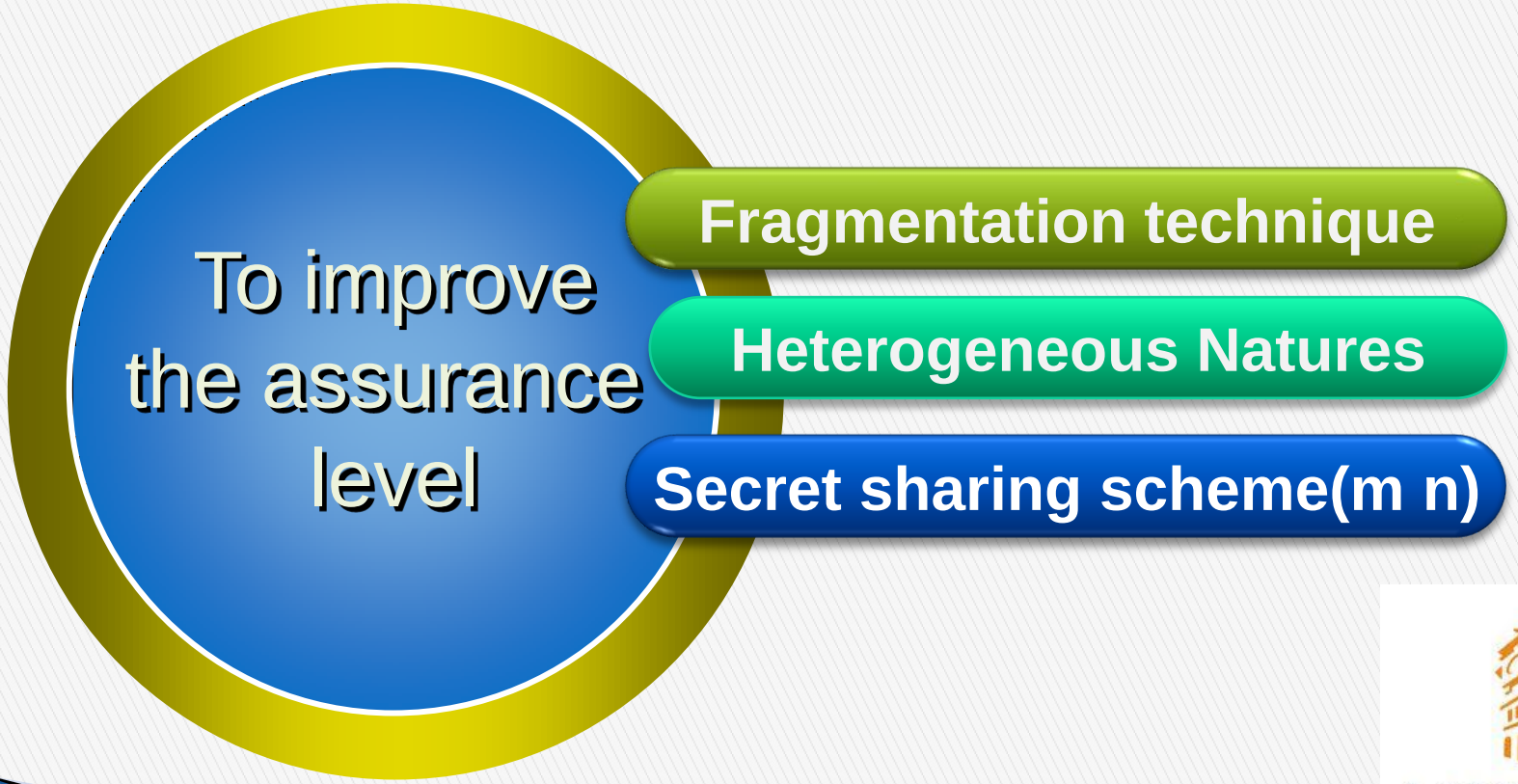
- Store fragments of a file across as many different server-type groups as possible



Allocate fragments of a file Within a Sub-system

- Allocate file fragments to improve I/O performance
  - Allocating fragments of a file into different storage clusters can degrade performance.
  - Our S-FAS scheme attempts to allocate fragments to storage nodes within a cluster.

Integrate the (m n) secret sharing scheme



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Notions and Meaning

Notations	Meaning
N	Number of storage nodes
K	Total number of server types
Sj	Size of a certain server type
(m,n)	Parameters of secret sharing scheme
α	Allocation mapping of file F

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Assurance Models

Static

$$\mathrm{SA}(\alpha) = 1 - \mathrm{P}(\mathrm{V}) = 1 - \sum_{\mathrm{j}=1}^{\mathrm{K}} \left(\frac{\mathrm{S_j}}{\mathrm{N}} \mathrm{P}(\mathrm{Z}) \sum_{\mathrm{i}=\mathrm{m}}^{\mathrm{n}} \frac{\mathrm{C}_{\mathrm{S_j}}^{\mathrm{i}} \mathrm{C}_{\mathrm{N}-\mathrm{S_j}}^{\mathrm{n}-\mathrm{i}}}{\mathrm{C}_{\mathrm{N}}^{\mathrm{n}}} \right)$$

Dynamic

$$DA(\alpha) = 1 - \left(P(V) + \left(\sum_{g=(m-i)}^{q} P_q(g) \right) \sum_{j=1}^{K} \left(\frac{S_j}{N} \times \sum_{i=0}^{m-1} \frac{C_{S_j}^{i} \, C_{N-S_j}^{n-i}}{C_N^n} \right) \right)$$

Heterogeneity Impact

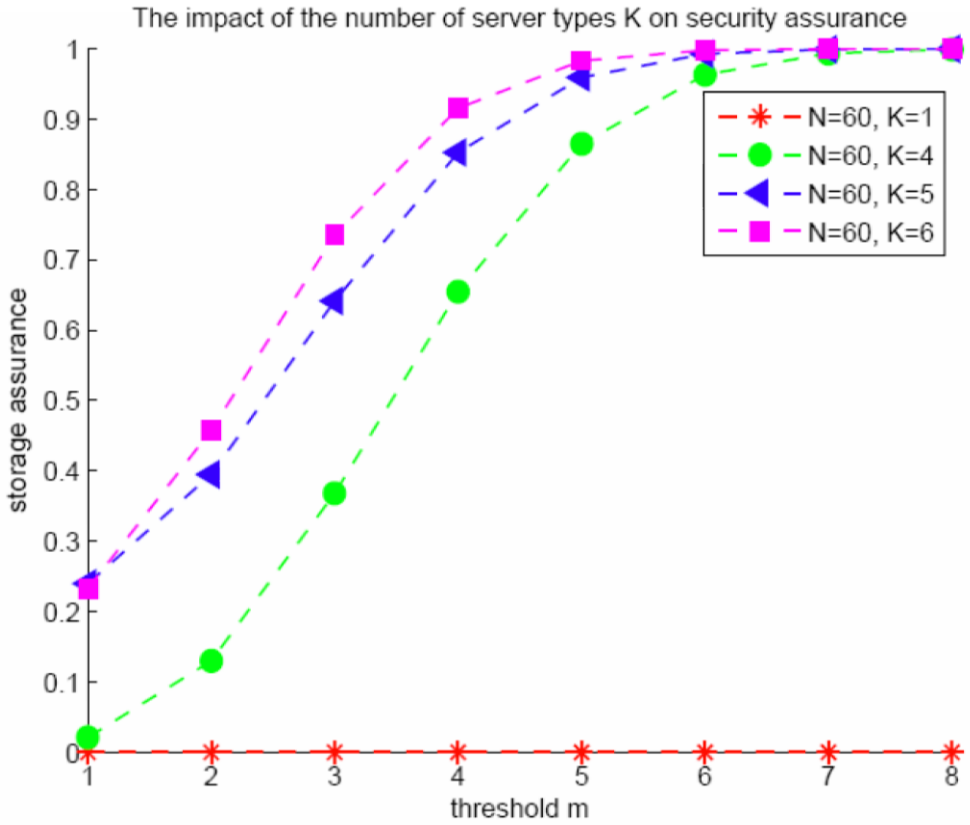

Figure 1.5: Heterogeneous system and homogeneous system using secret sharing scheme.In all the four test cases, N is set to 60. K is set to 1, 4, 5, and 6, respectively. When K is 1, there is only one server group in the system.

Impact of System Size

We gradually increase system size from 45 to 70 by increments of 5, keep *k at 3,and also* vary *m from 4 to 8.*

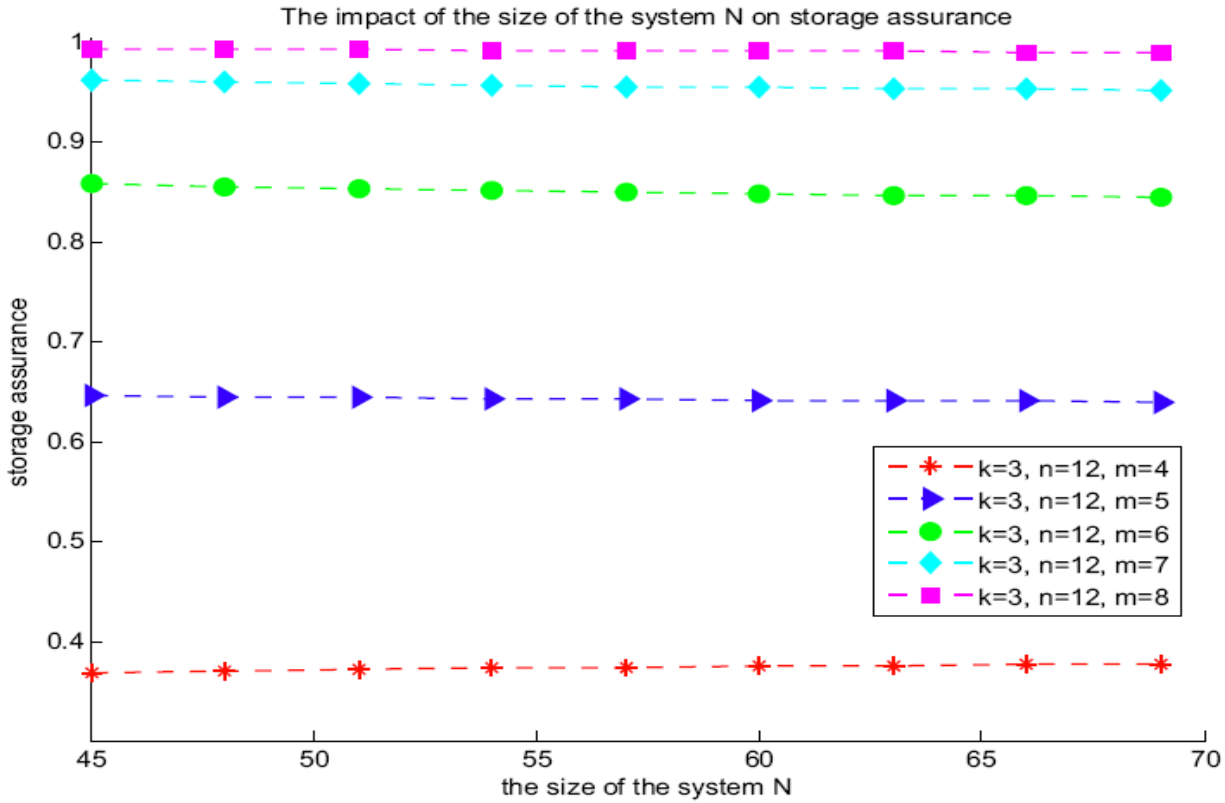

Figure 1.6: The impact of the system size N on storage assurance.

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Impact of Size of Server Groups

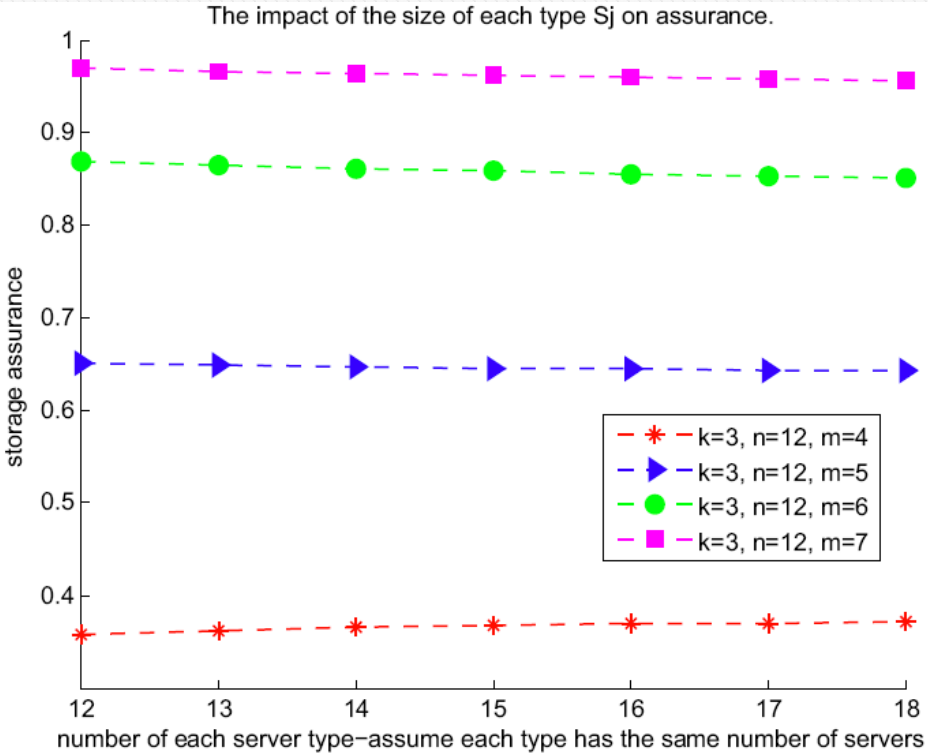

Figure 1.7: The impact of server-group size on data storage assurance. The server-group size means the number of storage nodes in a server-type group. Note that the storage nodes within a server group share the same level of vulnerability. The server-group size varies from 12 to 18 with an increment of 1.

Number n of Fragments of a File

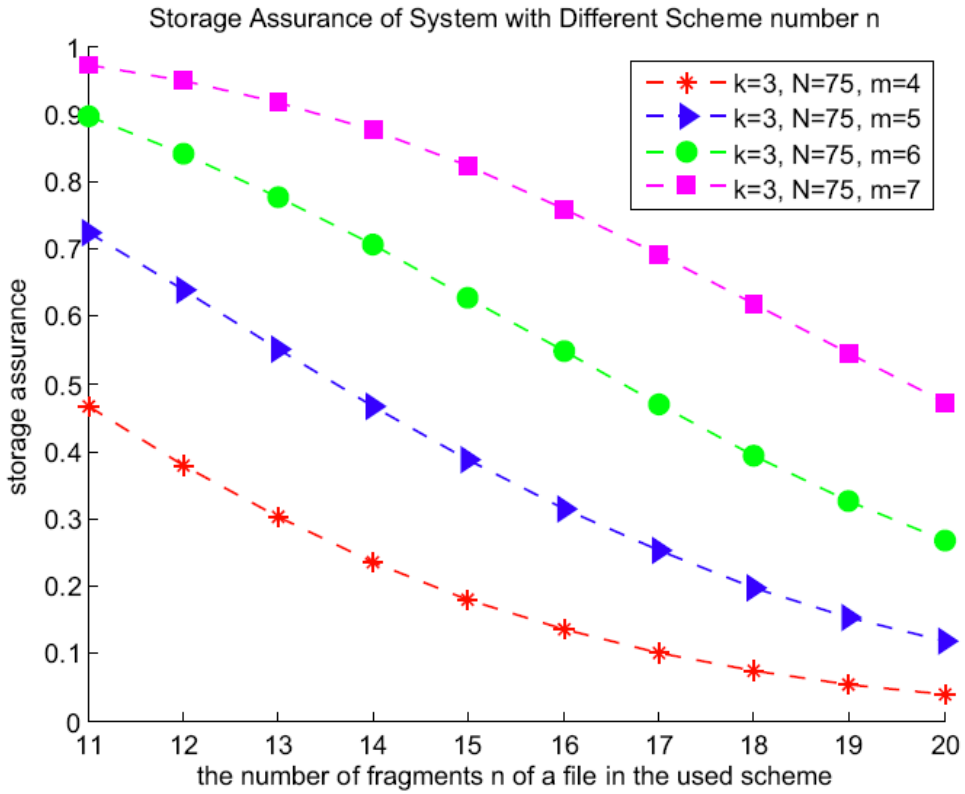

Figure 1.8: The impact of the number n of fragments of a file on storage assurance. We increase the number n of fragments from 11 to 20. The parameters k and N are set to 3 and 75, respectively.

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Impact of PL on Dynamic Assurance

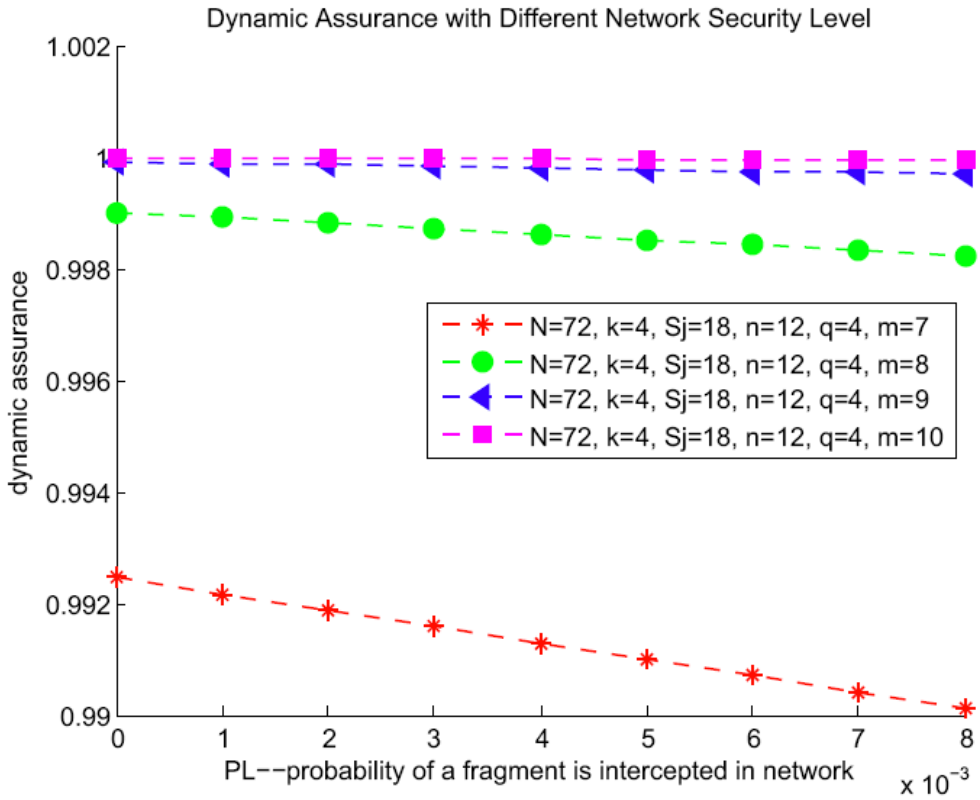

Figure 1.9: Impact of P_L - the probability that a fragment might be intercepted by an attacker during the fragment's transmission through an insecure link. P_L is set from 0 to $8 * 10^{-}3$ with an increment of $1 * 10^{-}3$. Threshold m is set from 7 to 10

Impact of q on Dynamic Assurance

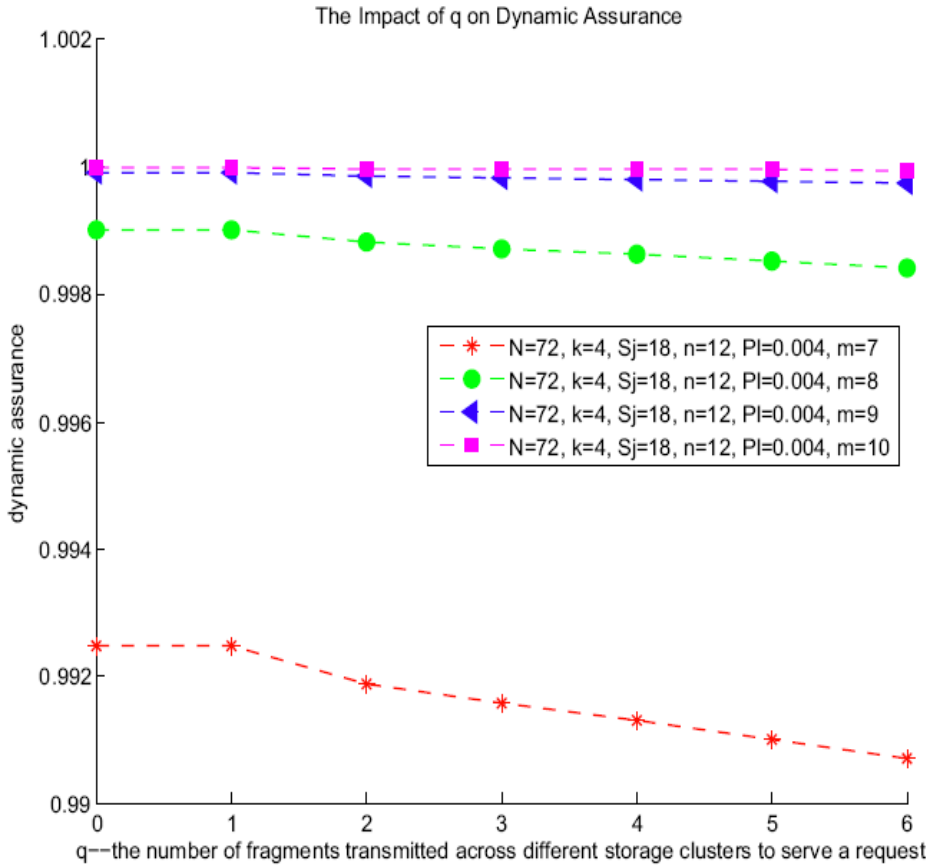

Figure 1.10: Impact of q - the number q of fragments transmitted to and from a storage cluster. q is chosen from 0 to 6 with an increment of 1. Threshold m is set from 7 to 10

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Conclusions

- Heterogeneous vulnerability: storage nodes are classified into different server groups based upon their vulnerabilities
- S-FAS : a secure fragmentation allocation scheme
- Storage assurance and dynamic assurance models
- A prototype in which S-FAS was implemented

New Directions

- Consider data replications to enhance reliability and performance
- Authorization/Authentication mechanisms in the prototype.
- Encryption/Decryption Mechanisms in the prototype.

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Xiao Qin, Associate Professor of Computer Science, Auburn University
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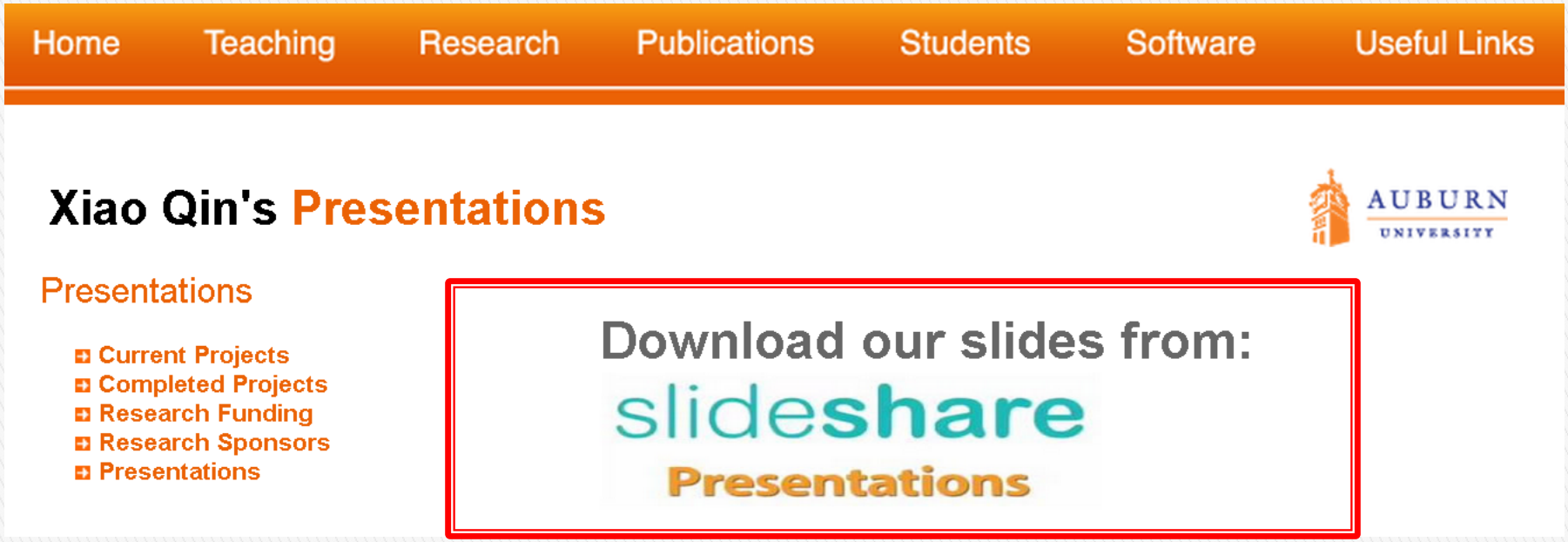

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Thank you!

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Suggestions & Questions?

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