CDStore: Toward Reliable, Secure, and Cost-Efficient Cloud Storage via Convergent Dispersal

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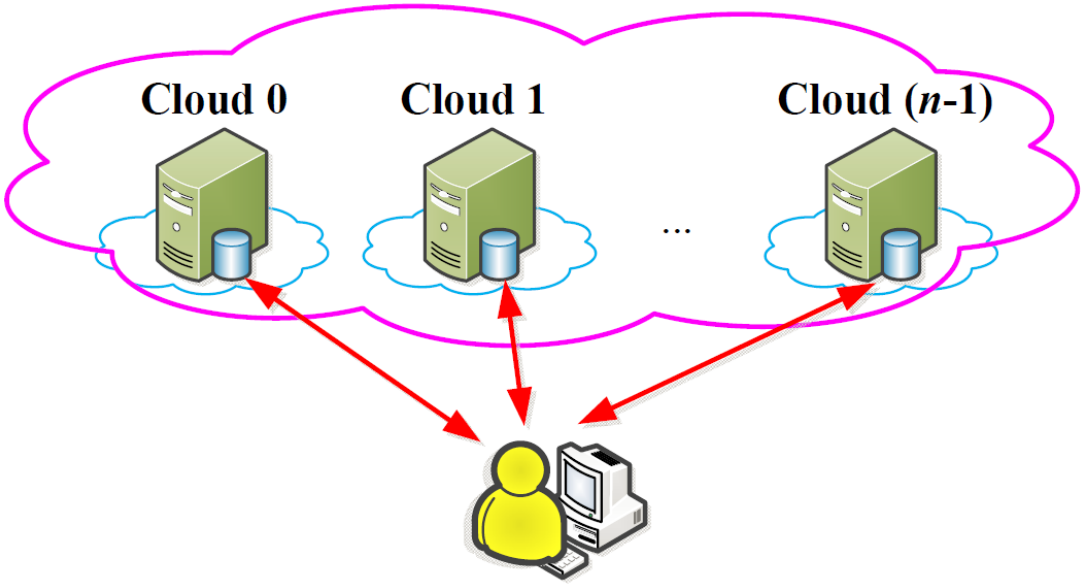
USENIX ATC'15

Multiple-Cloud Storage



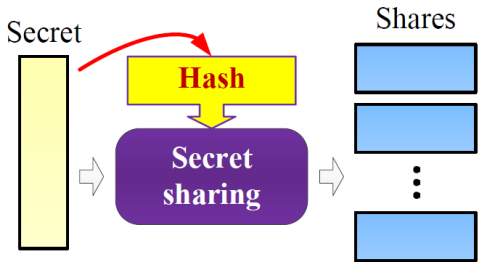
- Exploits diversity of multiple-cloud storage:
  - Reliability
    - Fault tolerance
    - No vendor lock-in [Abu-Libdeh, SOCC'10]
  - Security

Secret Sharing

- Input: secret; output: multiple shares
- Properties:
  - **Reliability**: secret is recoverable from enough shares
  - **Security**: secret is inaccessible without enough shares
- Examples:
  - Shamir's [CACM'79]; Ramp's [Crypto'84]; AONT-RS [FAST'11]

Challenges

- Secret sharing prohibits deduplication
  - Reason: Security builds on embedded randomness
  - → Identical secrets lead to different shares
  - → High bandwidth and storage overhead
- Our HotStorage'14 paper **convergent dispersal**:
  - Replaces random input with deterministic hash derived from original secret

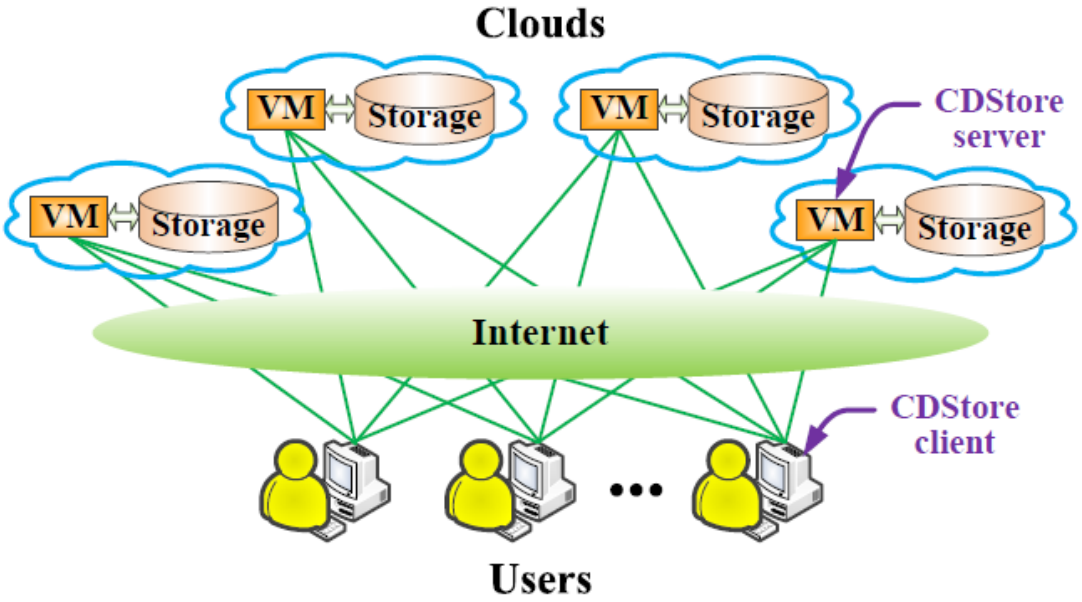


- *How to deploy in a real system?*

Our Contributions

- **CDStore**: a unified multi-cloud storage system with reliability, security, and cost efficiency
  - Also applicable for distributed storage systems
- A new instantiation of convergent dispersal
  - Higher throughput than our prior approach
- Two-stage deduplication
  - Bandwidth and storage savings
  - Secure
- Trace-driven experiments and cost analysis

CDStore Architecture



- Client-server model
- For whom? an organization that needs storage outsourcing for users' data
- For what workload? backup and archival

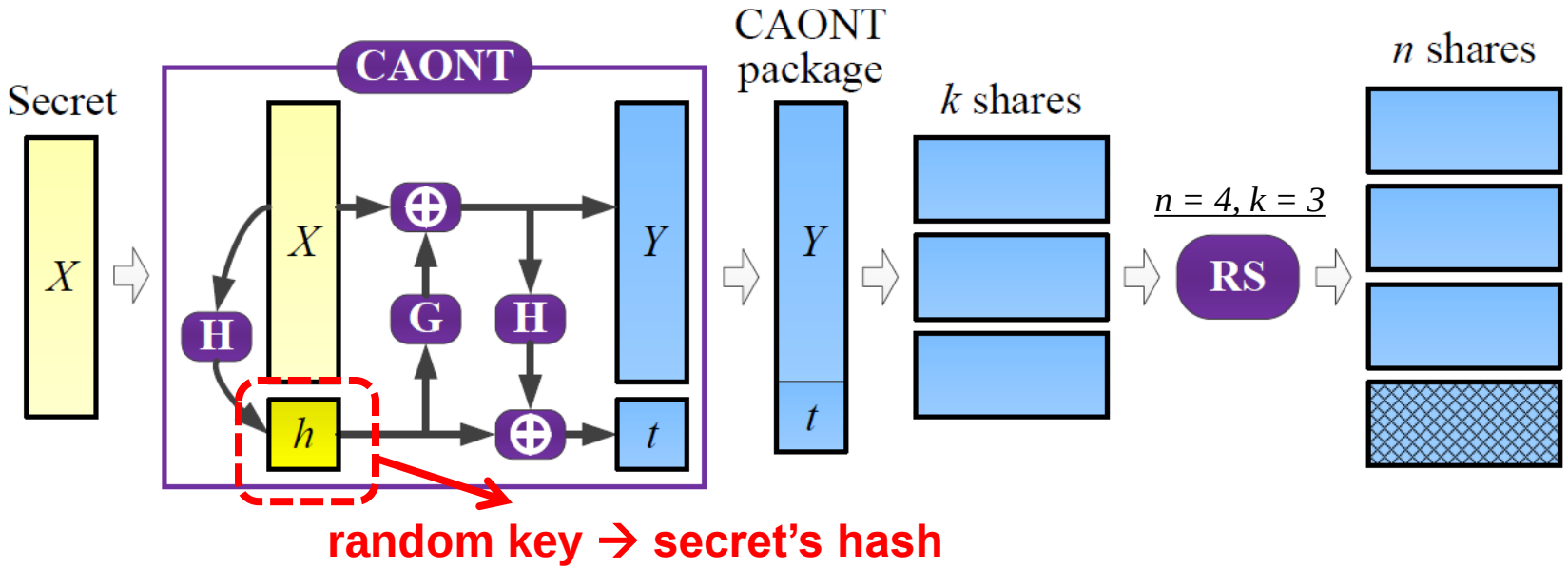
Goals

- Reliability:
  - Availability if some clouds are operational
  - No metadata loss if CDStore clients fail
- Security:
  - Confidentiality (i.e., data is secret)
  - Integrity (i.e., data is uncorrupted)
  - Robust against side-channel attacks
- Cost efficiency:
  - Low storage cost via deduplication
  - Low VM computation and metadata overheads

Assumptions

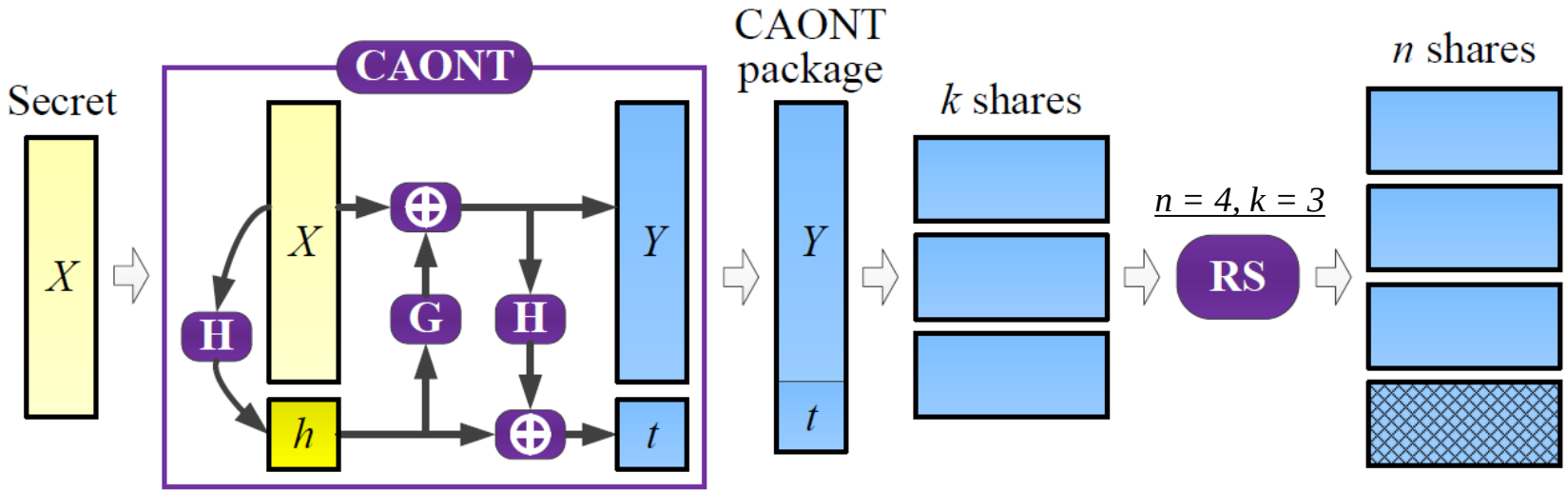
- Reliability:
  - Efficient repair is not considered
- Security:
  - Secrets drawn from large message space, so brute-force attacks are infeasible [Bellare, Security'13]
  - Encrypted and authenticated client-server channels
- Cost efficiency:
  - No billing for communication between co-locating VMs and storage

Convergent AONT-RS (CAONT-RS)



- Extension of AONT-RS [Resch, FAST'11]
- Optimal asymmetric encryption padding (OAEP) AONT
  - Single encryption on a large block
- Other instantiations in our prior HotStorage'14 paper on Ramp's and Rivest's AONT

CAONT-RS Encoding



- Generate CAONT package (Y, t):
  - $h = \mathbf{H}(X)$
  - $Y = X \oplus \mathbf{G}(h)$
  - $\mathbf{G}(h) = \mathbf{E}(h, C)$
  - $t = h \oplus \mathbf{H}(Y)$

$\mathbf{H}(.)$: hash function (e.g., SHA-256)
$\mathbf{G}(.)$: generator function
$\mathbf{E}(.)$: encryption function (e.g., AES-256)
C: constant value block

- Encode CAONT package with Reed-Solomon codes

Deduplication

- Deduplication at the secret level
  - Same secret → same shares that are dedup'ed
  - Ensure the same share in the same cloud
    - Share i stored in cloud i, where $i = 0, 1, ..., n\text{-}1$
- Naïve approach: client-side global deduplication
  - Saves most upload bandwidth and storage
  - Susceptible to side-channel attacks
    - Attackers can infer if other users have stored same data

Two-Stage Deduplication

- Decomposes deduplication into two stages:
  - **Client-side intra-user deduplication**
    - Each CDStore client uploads unique shares of same user
    - Effective for backup workloads
  - **Server-side Inter-user deduplication**
    - Each CDStore server dedups same shares from different users
    - Effective if many users share similar data (e.g., VM images)
- Fingerprint index maintained by CDStore servers

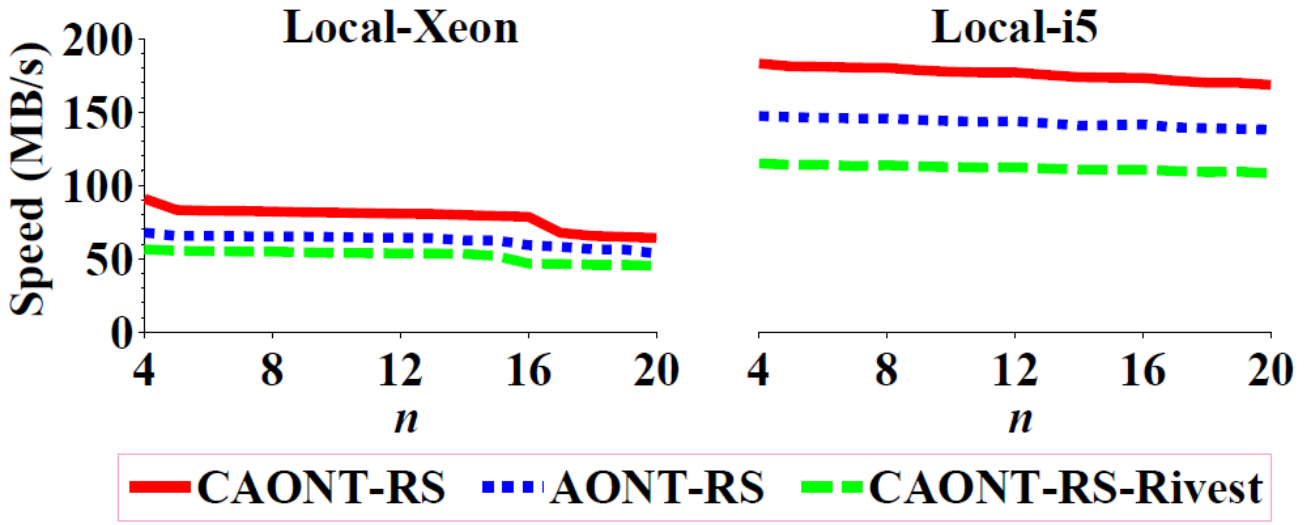
CDStore Implementation

- C++ implementation on Linux
- Features:
  - Content-defined chunking (avg size = 8KB)
  - Parallelization of encoding and I/O operations
  - Batched network and storage I/Os
- Open issues:
  - Storage reclaim via garbage collection and compression
  - Multiple CDStore servers per cloud
  - Consistency due to concurrent updates

Experimental Setup

- Testbeds:
  - **Local machines**: Xeon 2.4GHz (slow), i5 3.4GHz (fast)
  - **LAN**: Multiple i5 machines via 1Gb switch
  - **Cloud**: Google, Azure, AWS and Rackspace
- Datasets:
  - Synthetic unique and fully duplicate data
  - FSL dataset from Stony Brook University
    - Weekly file system snapshots
  - Our own 156 VM images in a programming course
    - Weekly VM image snapshots

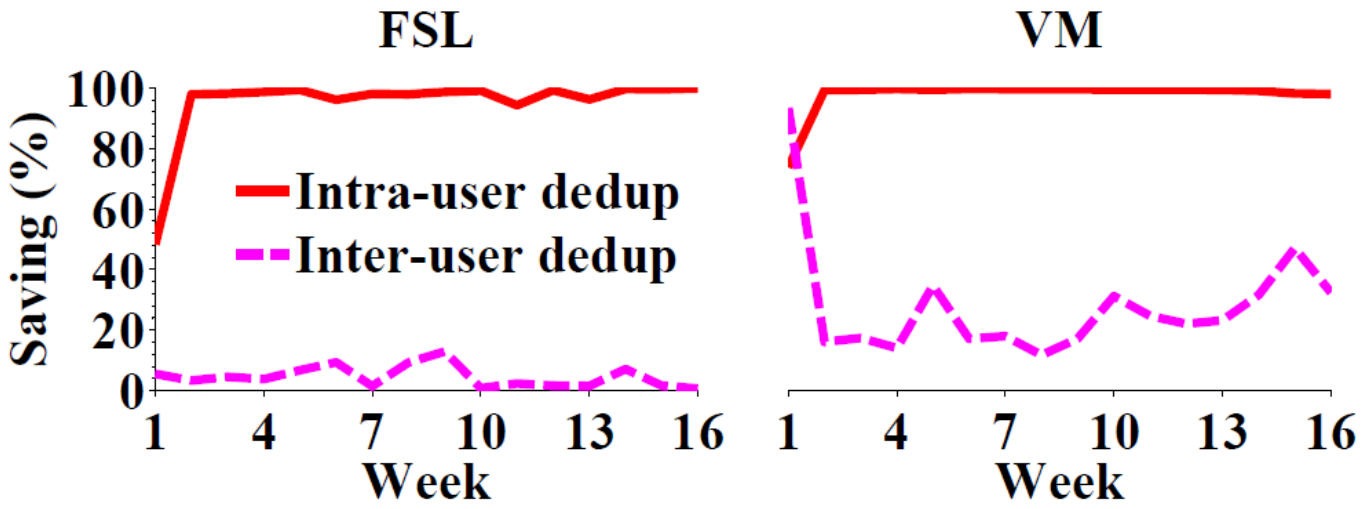
Encoding Speeds



Largest k with $k/n \leq 3/4$

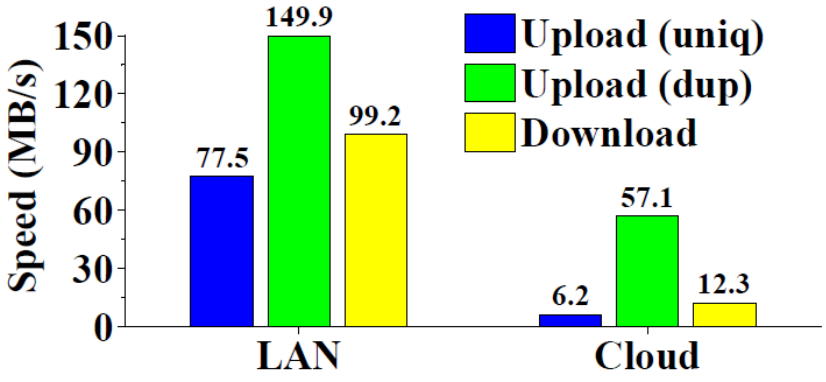
- OAEP-based AONT brings high performance gain
  - CAONT-RS achieves 183MB/s on Local-i5
- Encoding speed slightly decreases with n
  - RS coding has small overhead
- Multi-threading boosts speed (details in paper)

Storage Savings

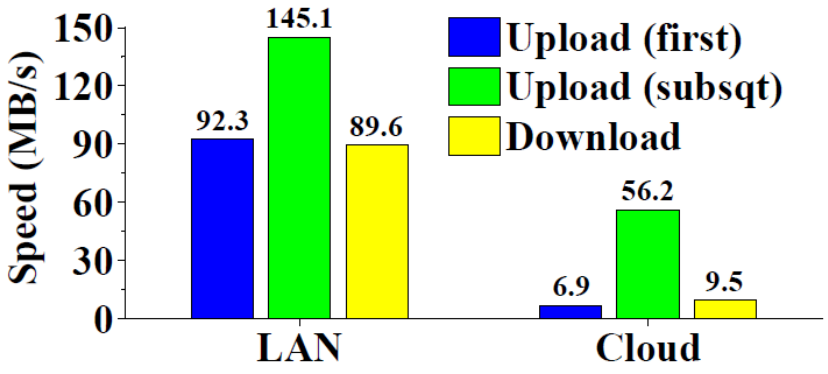


- Intra-user dedup achieves high saving
  - At least 98% after Week 1
- Inter-user dedup is effective for VM dataset
  - Week 1: 93.4%
  - After Week 1: 11.8% - 47.0%

Transfer Speeds



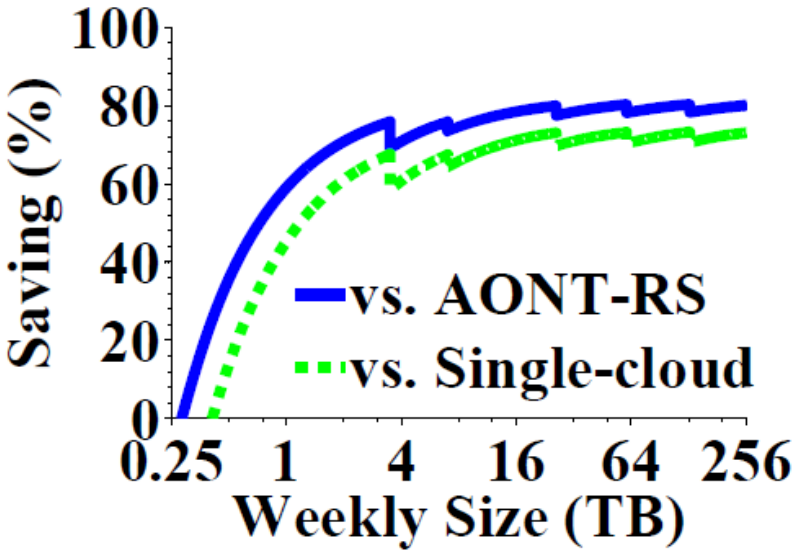
(a) Baseline results

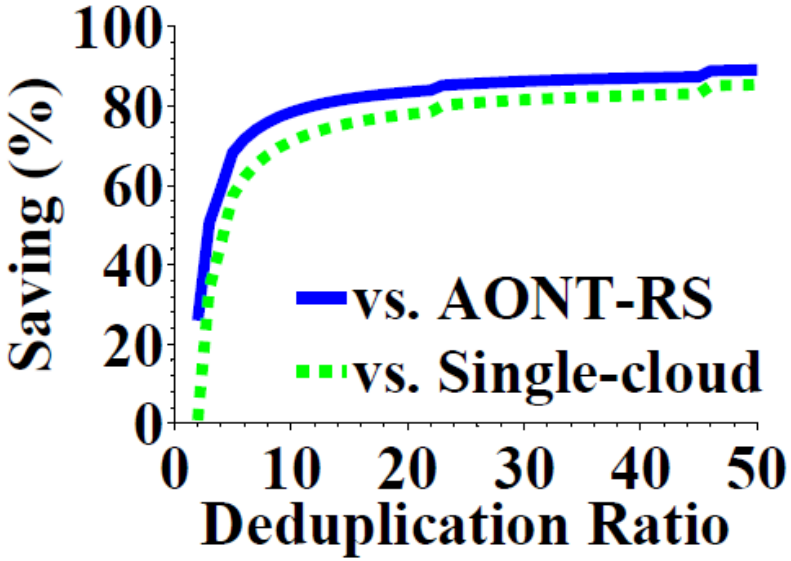


(b) Trace-driven results

- (Single-client) upload speeds in LAN:
  - Unique data ~ 77MB/s (network bound)
  - Duplicate data ~ 150MB/s (bounded by encoding + chunking)
- Performance in cloud bounded by Internet bandwidth
- Aggregate upload speeds increase with number of clients (details in paper)

Cost Analysis





- Compared to solutions w/o dedup:
  - (1) single cloud; (2) multiple clouds with AONT-RS
- At least 70% savings when dedup ratio is 10x – 50x
- Jagged curves due to switching cheapest VM instances

Conclusions

- **CDStore**: a unified multi-cloud storage system with three goals in mind: reliability, security, and cost efficiency
- Building blocks:
  - Convergent dispersal
  - Two-stage deduplication
- Source code:
  - **http://ansrlab.cse.cuhk.edu.hk/software/cdstore**