Accelerating Encrypted Deduplication via SGX

Yanjing Ren*, Jingwei Li*, Zuoru Yang#, Patrick P. C. Lee #, and Xiaosong Zhang*

*University of Electronic Science and Technology of China

#The Chinese University of Hong Kong

USENIX ATC 2021

Outsourcing Storage

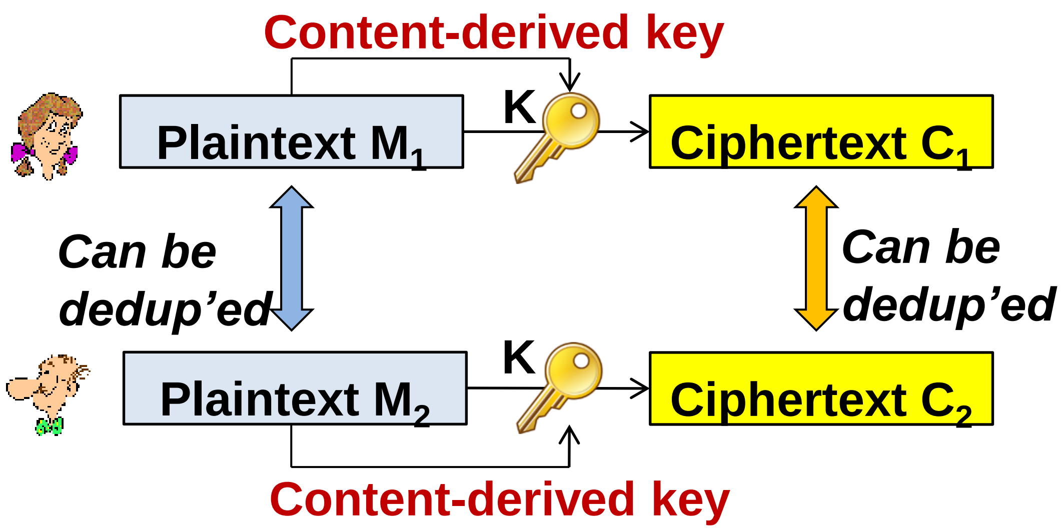
- Outsourcing data management to cloud is common in practice
  - 22% business data are stored in the cloud[*]

- Outsourcing storage should fulfill **security** and **storage efficiency**
  - Security: protect outsourced data against unauthorized access
  - Storage efficiency: reduce storage footprints

[*]https://www.seagate.com/files/www-content/our-story/rethink-data/files/Rethink_Data_Report_2020.pdf

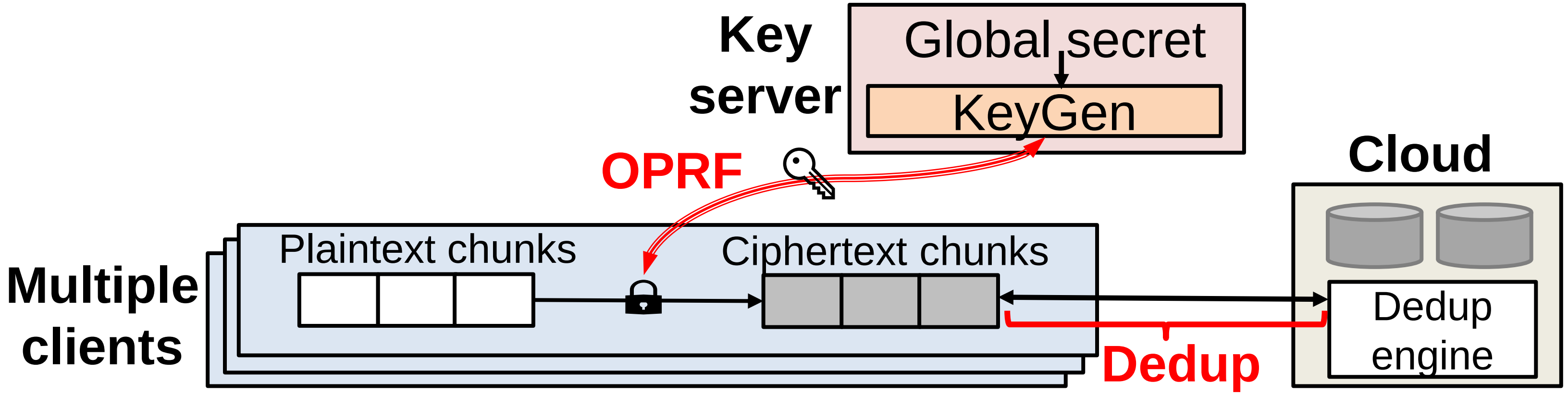
Encrypted Deduplication

- Encrypt plaintext chunks followed by performing deduplication on ciphertext chunks
  - Traditional encryption is incompatible with **cross-user deduplication**
- **Message-locked encryption (MLE)**[Bellare, Eurocrypt'13]: use content-derived keys for encryption, so as to enable cross-user deduplication



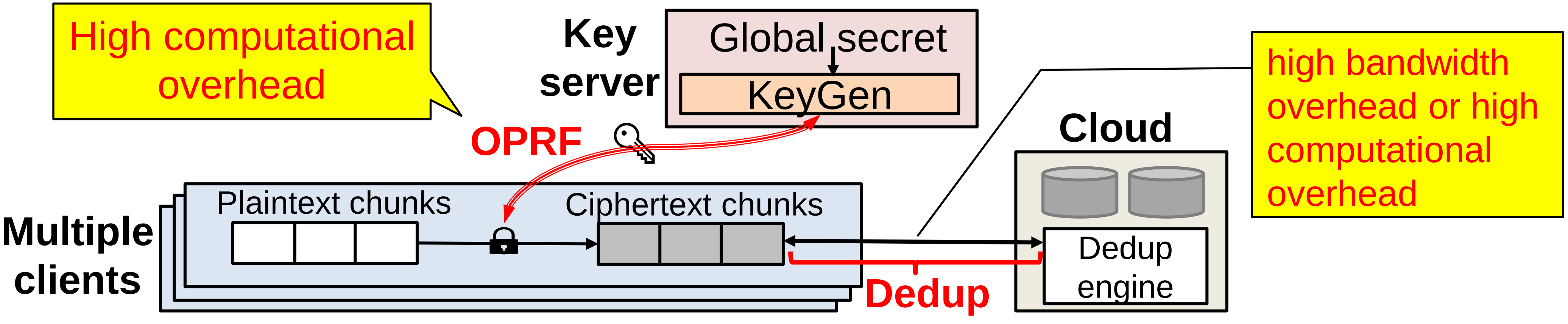
Example:
K = hash of plaintext

MLE-based Implementation



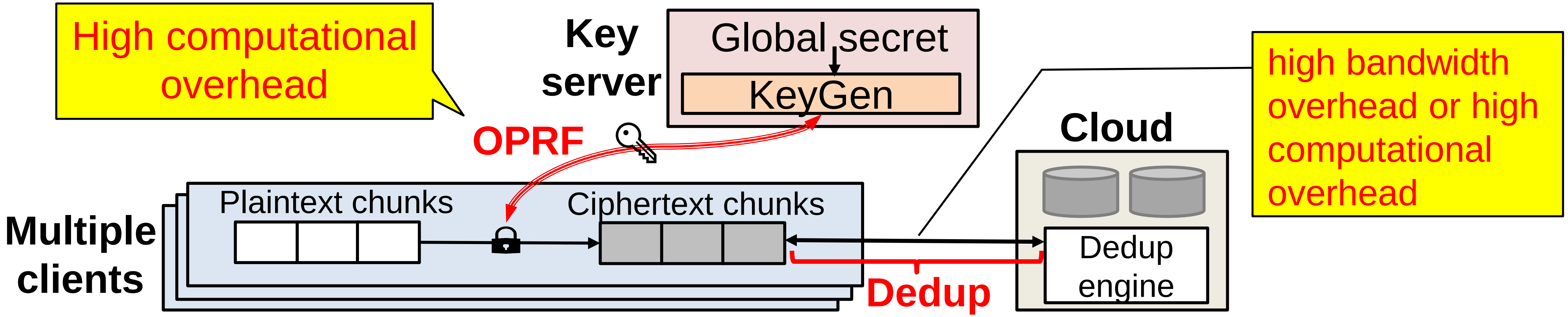
- Use **server-aided architecture** to prevent offline brute-force attacks
- Protect key generation via **oblivious pseudorandom function (OPRF)** to prevent key server from learning plaintext chunks
- Perform **target-based** [Bellare, Security'13] or **source-based** [Halevi, CCS'11] deduplication
  - Target-based: upload all chunks and remove duplicates in the cloud
  - Source-based: upload fingerprints for duplicate check, followed by only non-duplicate chunks

MLE-based Implementation



- OPRF is known to incur **high computational overhead** [Qin, TOS'17]
- Target-based deduplication has **high bandwidth overhead**
- Source-based deduplication incurs information leakage
  - A malicious client can fake fingerprints to learn deduplication patterns of corresponding chunks
  - Need to be protected by **proof-of-ownership (PoW)** [Halevi, CCS'11], which is **computationally expensive**

MLE-based Implementation



- OPRF is known to incur **high computational overhead** [Qin, TOS'17]
- Target-based deduplication has **high bandwidth overhead**
- Source-based deduplication incurs information leakage
  - A malicious client can fake fingerprints to learn deduplication patterns of corresponding chunks
  - Need to be protected by **proof-of-ownership (PoW)** [Halevi, CCS'11], which is **computationally expensive**

How to accelerate encrypted deduplication while preserving security?

Contributions

- **SGXDedup**: use **Intel SGX** to speed up encrypted deduplication
  - Replace expensive cryptographic protection by **hardware-based protection**
  - Three key designs to preserve security and boost performance

- Extensive experiments:
  - **131.9**× key generation and **8.2**× PoW speedups over existing approaches
  - **8.1**× throughput over existing software-based encrypted deduplication [Bellare, Security'13]

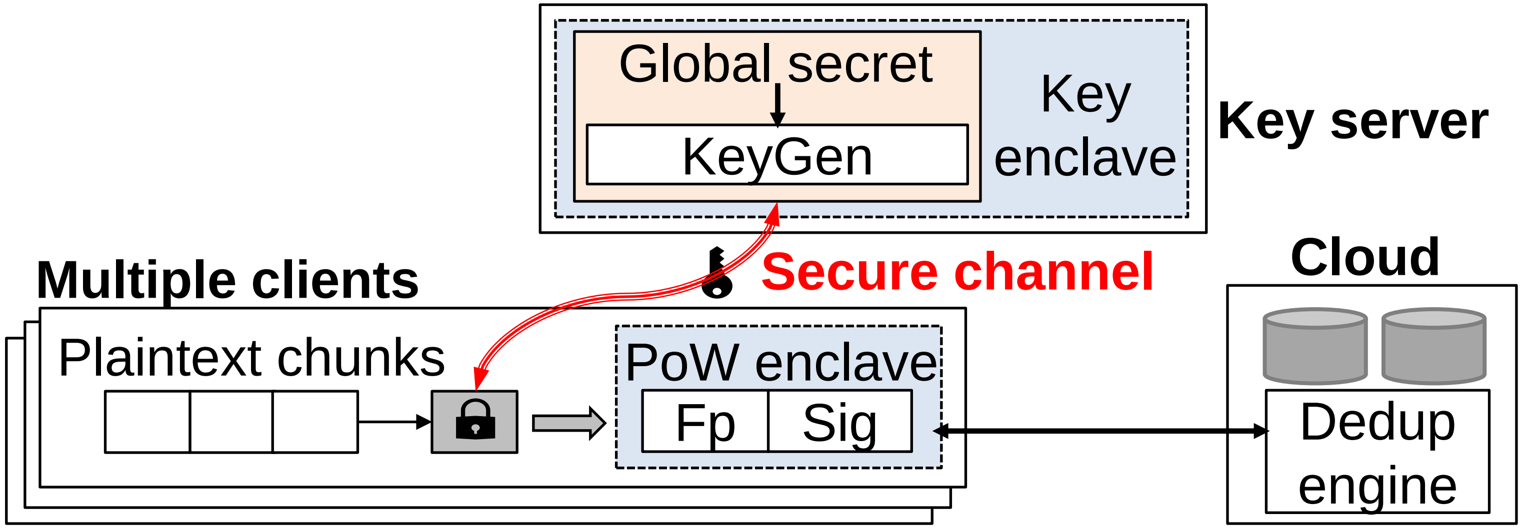
SGX Basics

- **Isolation**: allow to allocate an isolated memory region (enclave) against host system
  - Enclave is of limited size (e.g., 128MB)
- **Attestation**: can attest in-enclave contents via remote attestation
  - Remote attestation incurs huge latency (e.g., ~9s in our region)
- **Sealing**: enclave can securely move in-enclave contents into unprotected memory via encryption
  - Only the same enclave can access its sealed contents

Design Goals

- Preserve goals of software-based encrypted deduplication
  - **Confidentiality**: Protect chunks and keys against unauthorized access
  - **Storage efficiency**: Remove all duplicate chunks
- Boost performance via hardware-based approach
  - **Bandwidth efficiency**: Only need to transfer non-duplicate chunks
  - **Computational efficiency**: Mitigate computational overhead of cryptographic primitives

SGXDedup



➢ Key enclave:

- Connected with each client via **secure channel**
- Perform key generation: K = **H**(fp || GlobalSecret)

Protect key generation without expensive OPRF

➢ PoW enclave:

- Generate signature for each fingerprint, such that cloud can verify authenticity of fingerprints → **lightweight protection on source-based deduplication**

Questions

- Q1: How should enclaves be securely and efficiently bootstrapped?
  - The global secret needs to be securely bootstrapped into key enclave
  - Enclave startup incurs high latencies due to remote attestation
- Q2: How should the secure channel be established?
  - Necessary to enable revocation on clients’ querying key generation
- Q3: How should key enclave reduce its computational overhead of managing secure channels?
  - The computational overhead is high as the number of clients increases

Enclave Management

- Compute global secret from an in-enclave sub-secret (from cloud) and an input sub-secret (from key server)
  - Prevent either cloud or key server from learning the whole global secret
- Attest key enclave and PoW enclave offline
  - After attestation, both cloud and each PoW enclave share a **PoW key** to verify authenticity of fingerprints
- Use sealing to avoid re-attesting PoW enclave after its first bootstrap
  - PoW enclave may be bootstrapped and terminated with client
  - Seal (unseal) PoW key when PoW enclave terminates (bootstraps again)

Renewable Blinded Key Management

- Build secure channel based on a **blinded key** shared by clients and key enclave
- Update blinded key if some clients are revoked
  - Key update is based on key regression [Fu, NDSS'06], so as to support lazy update
- Synchronize blinded keys between key enclave and authorized clients
  - Key enclave derives new blinded keys based on an in-enclave **blinded secret**
  - Authorized clients download up-to-date blinded keys from cloud

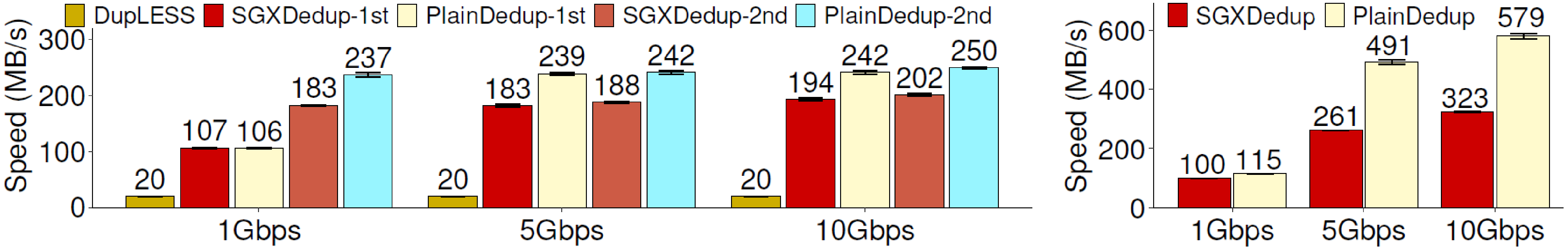
SGX-based Speculative Encryption

- Build on **speculative encryption**[Eduardo, FAST'19] to reduce online computational overhead of key enclave
  - Speculative encryption: fp XOR **E**(blindedKey, nonce||counter) **mask**
  - Allow to compute masks offline
- Manage each nonce and corresponding masks in key enclave
  - Each client is associated with a nonce
  - Manage an in-enclave **nonce index** to ensure unique nonce for each client
  - Take up to 3MB enclave space for nonce index to serve 112K clients
- Pre-compute masks of each nonce automatically
  - Store pre-computed masks in a 90MB **mask buffer** that can be used to process the fingerprints of 11.25GB data

Experimental Setup

- ➢ Implement SGXDedup in Linux
  - ~14.2K line of C++ code
- ➢ Real-world datasets:
  - FSL: users' home directory backups (56.2TB, 431.9GB after deduplication)
  - MS: windows file system snapshots (14.4TB, 2.4TB after deduplication)
- ➢ Testbed:
  - Multiple machines connected with 10GbE
  - Each machine has Intel Core i5-7400 3.0GHz CPU and 8GB RAM

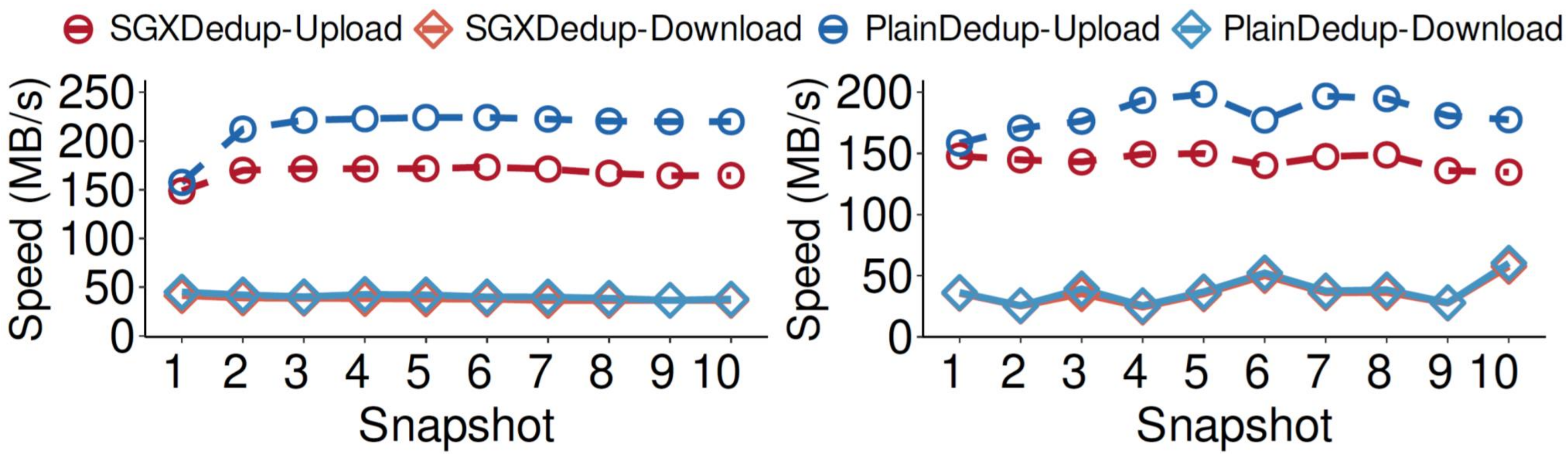
Overall System



(a) Upload (b) Download

- **8.1x** and **9.6x** speedups over DupLESS in first and second uploads
  - The performance of DupLESS is bounded by OPRF-based key generation
  - The second upload is faster than the first upload due to source-based deduplication
- **17.5%** upload and **44.2%** download performance drops over PlainDedup
  - Overhead comes from key generation, encryption, PoW and decryption
- More results in our paper:
  - **637.0 MB/s** aggerate upload speed for 10 clients
  - **9.7x** speedup over DupLESS in real-cloud deployment

Trace-driven Performance



(a) FSL dataset (b) MS dataset

- ➢ SGXDedup incurs **21.4%** upload performance drop from PlainDedup
  - To replay trace, chunking is disabled
  - The bottleneck of SGXDedup is PoW while that of PlainDedup is fingerprinting
- ➢ The download speed is bounded due to chunk fragmentation

Conclusion

- **SGXDedup**: mitigate performance overhead of encrypted deduplication via SGX
  - Offload expensive cryptographic operations by directly running sensitive operations in enclaves
  - Three designs:
    - Secure and efficient enclave management
    - Renewable blinded key management
    - SGX-based speculative encryption for lightweight computations
- Source code: ***http://adslab.cse.cuhk.edu.hk/software/sgxdedup***