FADE: A Secure Overlay Cloud Storage System with Access Control and Assured Deletion

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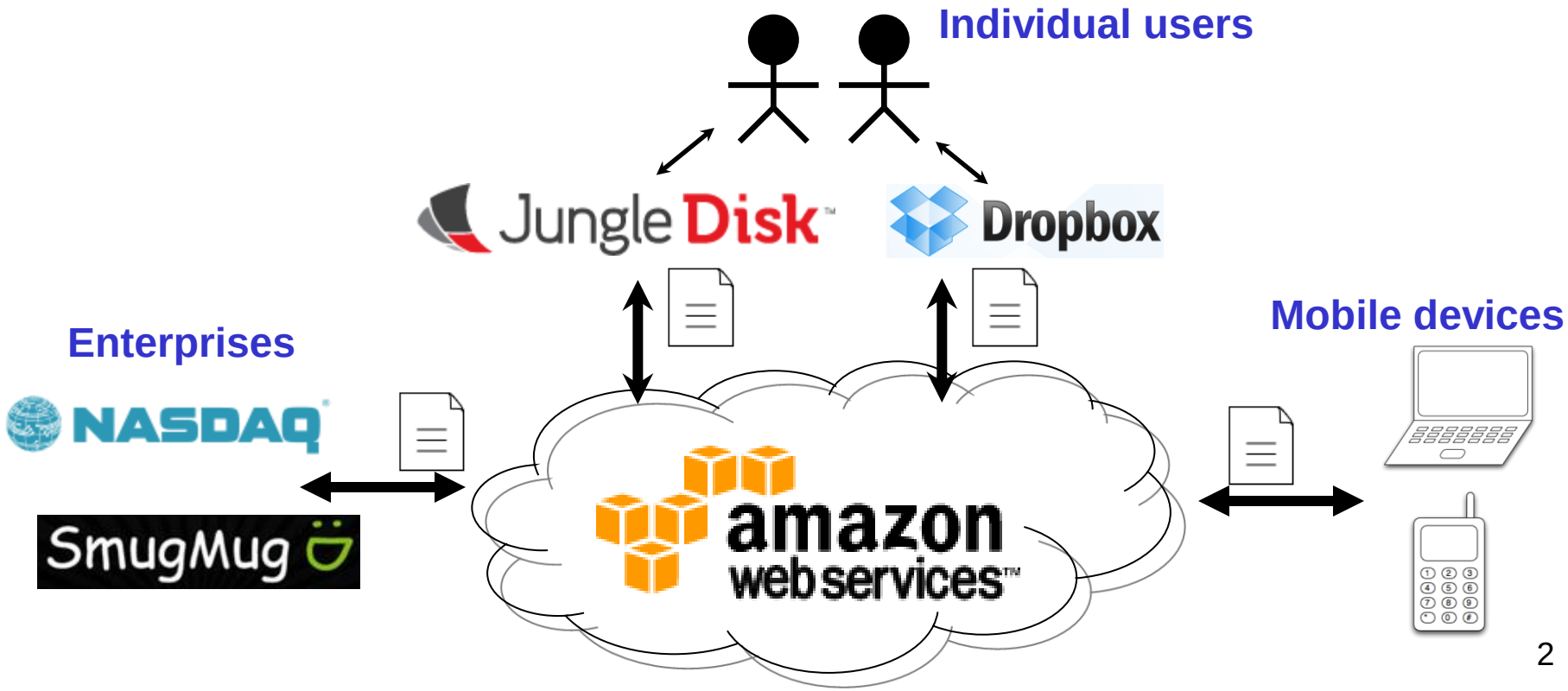
Cloud Storage is Emerging

- Cloud storage is now an emerging business model for data outsourcing



Case Studies

- Smugmug: hosting terabytes of photos since 2006
  - Savings: USD 500K per year as in 2006
  - More savings are expected with more photos
- NASDAQ: hosting historical market data since 2008
- More clients are found on: http://aws.amazon.com/solutions/case-studies/

References:
•http://don.blogs.smugmug.com/2006/11/10/amazon-s3-show-me-the-money/
•http://www.infoq.com/articles/nasdaq-case-study-air-and-s3?

Cloud Storage Cost Model

Amazon S3 Rackspace Windows Azure

	S3	RS	Azure
Storage (per GB)	$0.14	$0.15	$0.15
Data transfer in (per GB)	free	free	free
Data transfer out (per GB)	$0.12	$0.18	$0.15
PUT,POST (per 10K requests)	$0.10	free	$0.01
GET (per 10K requests)	$0.01	free	$0.01

Monthly price plan as of Sep 2011

- Components of cloud storage cost:
  - Storage space
  - Data transfer
  - Number of requests

Implications of Cloud Storage

- Cloud storage will be a cost-saving business solution:
  - Save cost for unused storage
  - Save technical support for data backups
  - Save electric power and maintenance costs for data centers
- Yet, as a cloud client, how do we provide security guarantees for our outsourced data?

Security Challenges

- Can we protect outsourced data from improperly accessed?
  - Unauthorized users must not access our data
  - We don't want cloud providers to mine our data for their marketing purposes
- We need **access control**:
  - Only authorized parties can access outsourced data

Security Challenges

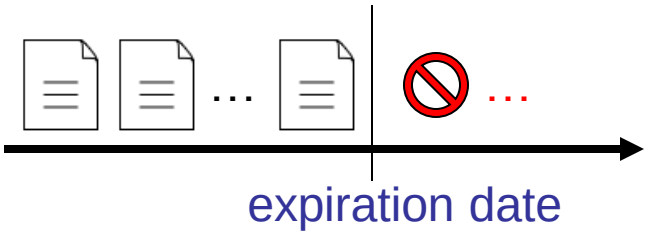
- Can we reliably remove data from cloud?
  - We don't want backups to exist after pre-defined time
    - e.g., to avoid future exposure due to data breach or error management of operators
  - If an employee quits, we want to remove his/her data
    - e.g., to avoid legal liability
- Cloud makes backup copies. We don't know if all backup copies are reliably removed.
- We need **assured deletion**:
  - Data becomes inaccessible upon requests of deletion

Previous Work

- Cryptographic protection on outsourced data storage
  [Ateniese et al., SecureComm'08; Wang et al., CCSW'09]
  - Require new protocol support on the cloud infrastructure
- Security solutions compatible with existing cloud (e.g., Cumulus, JungleDisk)
  [Yun et al., CCSW'09; Vrable et al., ToS'09]
  - No guarantees of reliable deletion of data

Previous Work

- Perlman's Ephemerizer [NDSS'07]
  - A file is encrypted with a data key
  - The data key is further encrypted with a time-based control key
  - The control key is deleted when expiration time is reached
  - The control key is maintained by a separate key manager (aka Ephemerizer)



- Weaknesses:
  - Target only time-based assured deletion
    - No fine-grained control of different file access policies
  - No implementation

Previous Work

- Vanish [USENIX'09]
  - Divide the data key into many key shares
  - Store key shares in nodes of a deployed P2P network
  - Nodes remove key shares that reside in cache for 8 hours
- Weaknesses:
  - Time-based, no fine-grained control

Our Work

FADE: a secure overlay cloud storage system with **f**ile **a**ssured **de**letion

- Design feature of FADE:
  - work atop today's cloud as an overlay
- Security features of FADE:
  - Fine-grained access control: files are accessible only when authorized
  - Fine-grained file assured deletion: files are permanently inaccessible and unrecoverable based on policies

Our Work

- We propose a new policy-based file assured deletion scheme that reliably deletes files of revoked file access policies
  - A generalized version of time-based delete

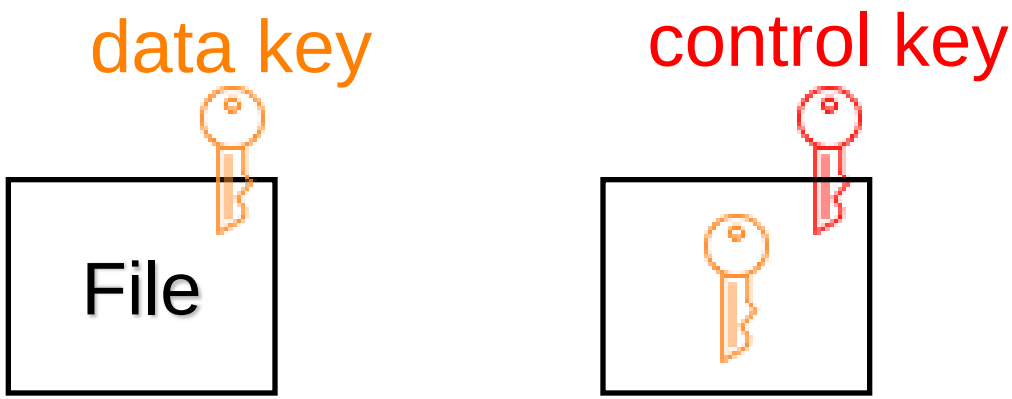
- We implement and evaluate a working prototype of FADE atop Amazon S3
  - FADE respects REST interface for cloud
  - FADE works feasibly in practice

Policy-based File Assured Deletion

- Each file is associated with a data key and a file access policy
- Each policy is associated with a control key
- All control keys are maintained by a key manager
- When a policy is revoked, its respective control key will be removed from the key manager

Policy-based File Assured Deletion

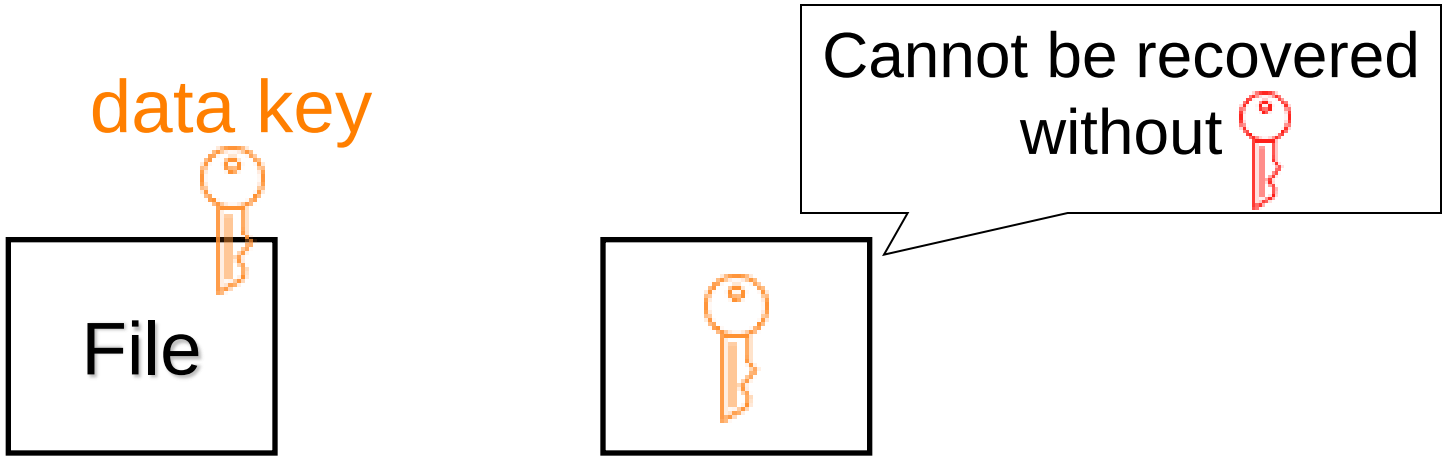
- Main idea:
  - File protected with data key
  - Data key protected with control key



 is maintained by the key manager

Policy-based File Assured Deletion

- When a policy is revoked, the control key is removed. The encrypted data key and hence the encrypted file cannot be recovered



- The file is deleted, i.e., even a copy exists, it is encrypted and **inaccessible by everyone**

Scenarios: Defining Policies

- Scenario 1: storing files for permanent employees
  - For each employee (e.g., Alice), define a user-based policy

P: Alice is an employee

User-based policy

  - If Alice quits her job, the key manager will remove the control key of policy P

Scenarios: Defining Policies

- Scenario 2: storing files for contract-based employees
  - e.g., Bob's contract expires on 2010-01-01. Define two policies

P_1: *Bob is an employee*	P_2: *valid before 2010-01-01*
User-based policy	Time-based policy

  - Files of Bob are associated with policy combination $P_1 \wedge P_2$

Scenarios: Defining Policies

- Scenario 3: storing files for a team of N employees
  - Each employee *i* is assigned a policy combination $P_{i1} \wedge P_{i2}$
    - P_{i1} = policy for employment status
    - P_{i2} = policy for valid time for access
  - Associate team's files with disjunctive combination

$$(P_{11} \wedge P_{12}) \vee (P_{21} \wedge P_{22}) \vee \ldots \vee (P_{N1} \wedge P_{N2})$$

Scenarios: Defining Policies

- Scenario 4: switching a cloud provider
  - Define a customer-based policy

> *P: customer of cloud provider X*

  - All files outsourced on X are tied with policy P
  - If the company switches to a new cloud provider, it simply revokes policy P

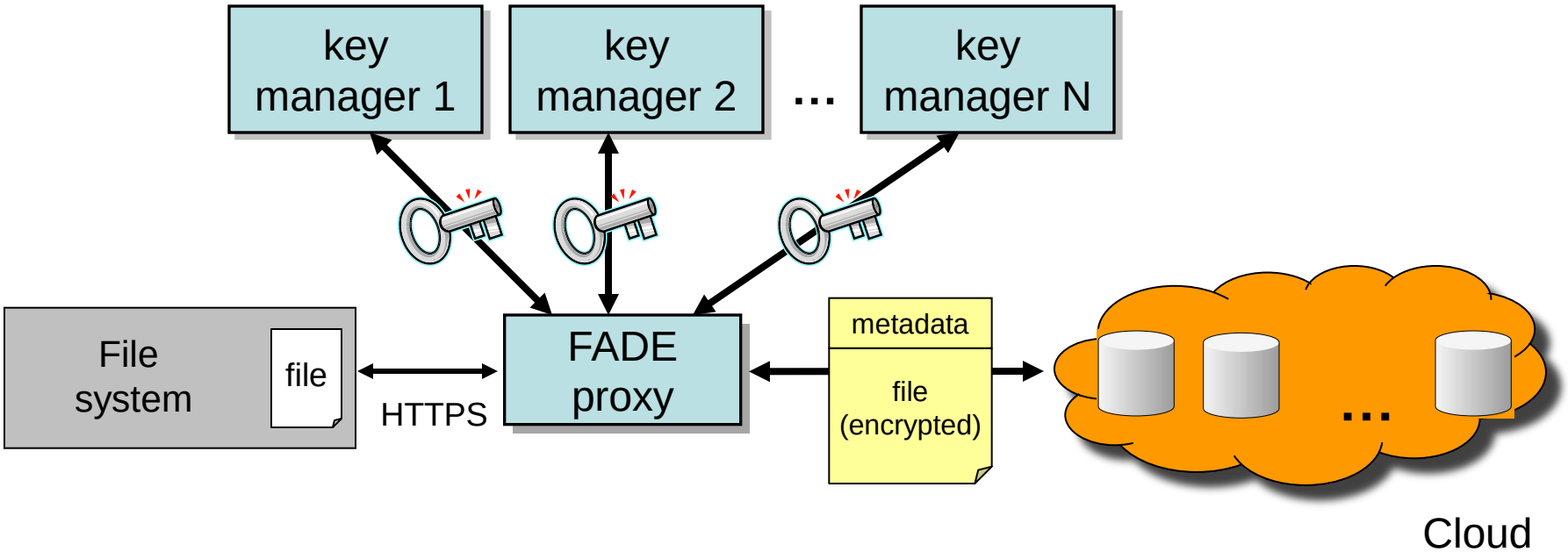
Lessons Learned

- Policy-based file-assured deletion allows a fine-grained control of how to delete files
- Similar to Attribute-Based Encryption (ABE)
  - ABE focuses on accessing data and distribute keys to users that satisfy attributes (policies)
  - We focus on deleting data, and need to manage/delete keys in a centralized manner

System Entities

- Data owner: the entity that originates data to be stored on cloud
- Key manager: maintains policy-based control keys for encrypting data keys
- Cloud: third-party cloud provider (e.g., Amazon S3) that stores data

Architecture of FADE



- FADE decouples key management and data management
- Key manager can be flexibly deployed in another trusted third party, or deployed within data owner
- No implementation changes on cloud

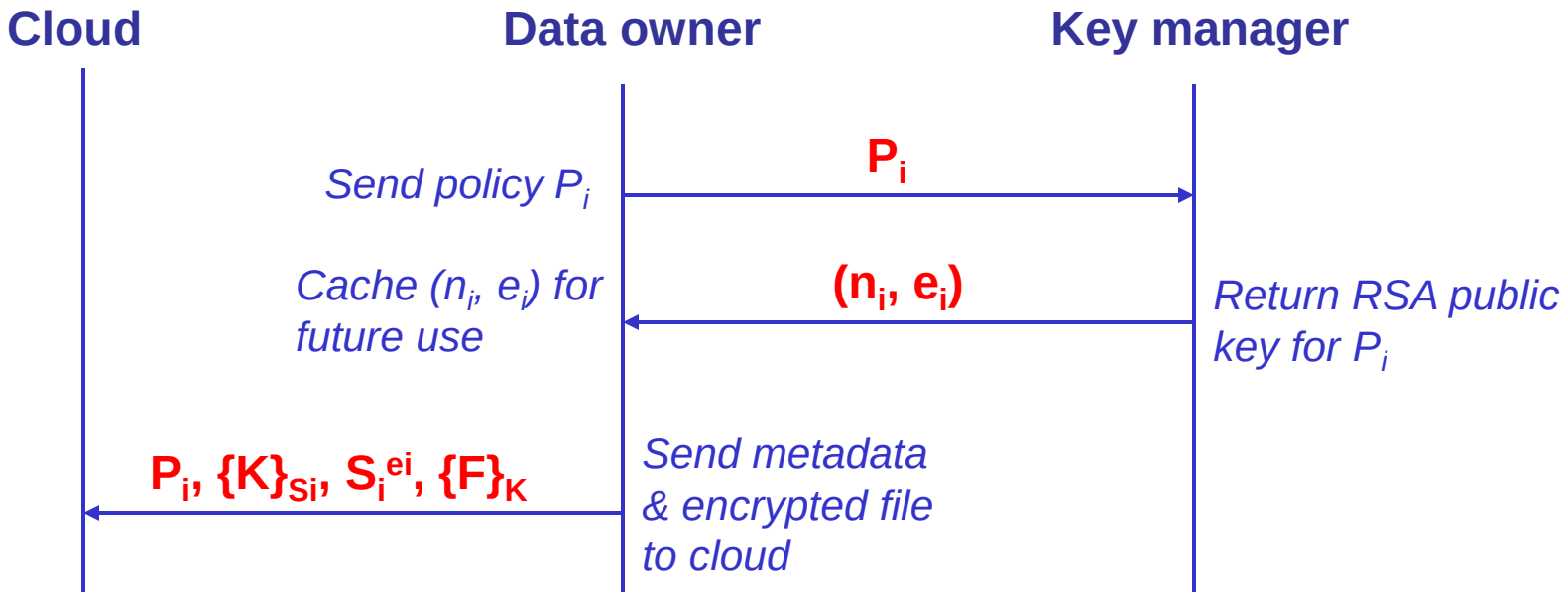
Threat Models and Assumptions

- File assured deletion is achieved
  - If we request to delete a file, it is inaccessible
- Key manager is minimally trusted
  - can reliably remove keys of revoked policies
  - can be compromised, but only files with active policies can be recovered
  - only knows the control keys, but should never know the data key used to encrypt a file
- Data owner forms an authenticated channel with key manager for key management operations

Key Management Operations

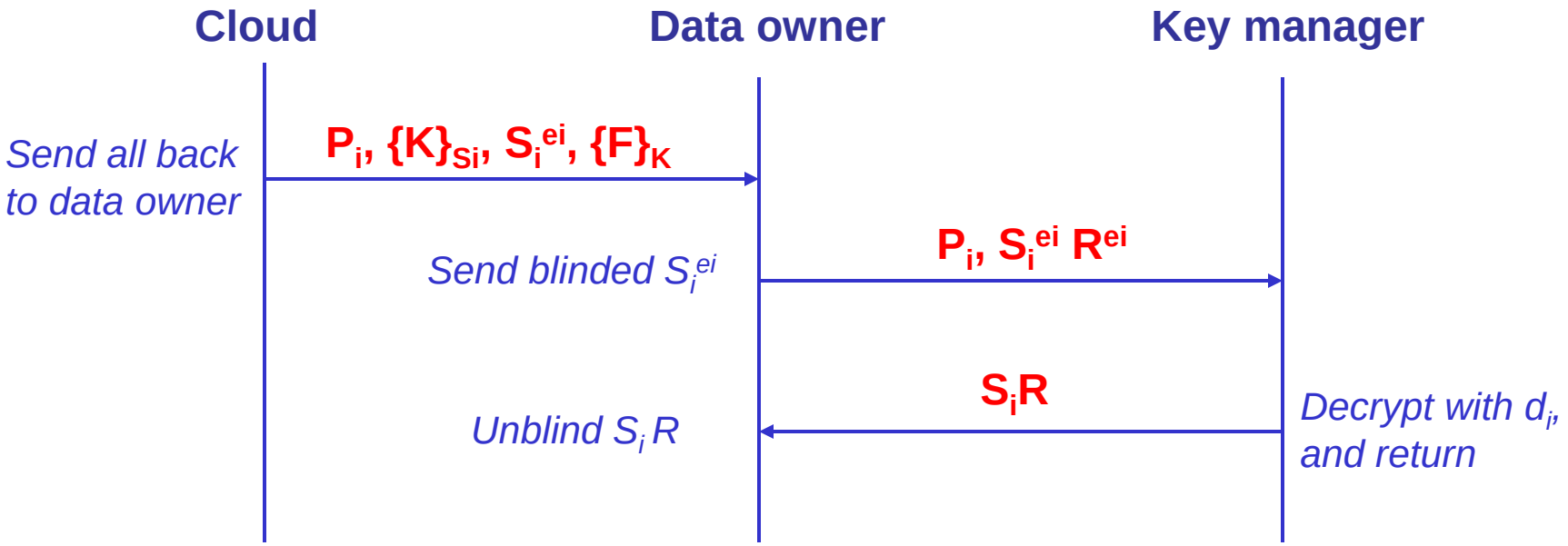
- Idea: use key management operations to decide how files are accessed while achieving file assured deletion
- Operations:
  - File upload
  - File download
  - Policy revocation
  - Policy renewal
- Built on blinded RSA

File Upload



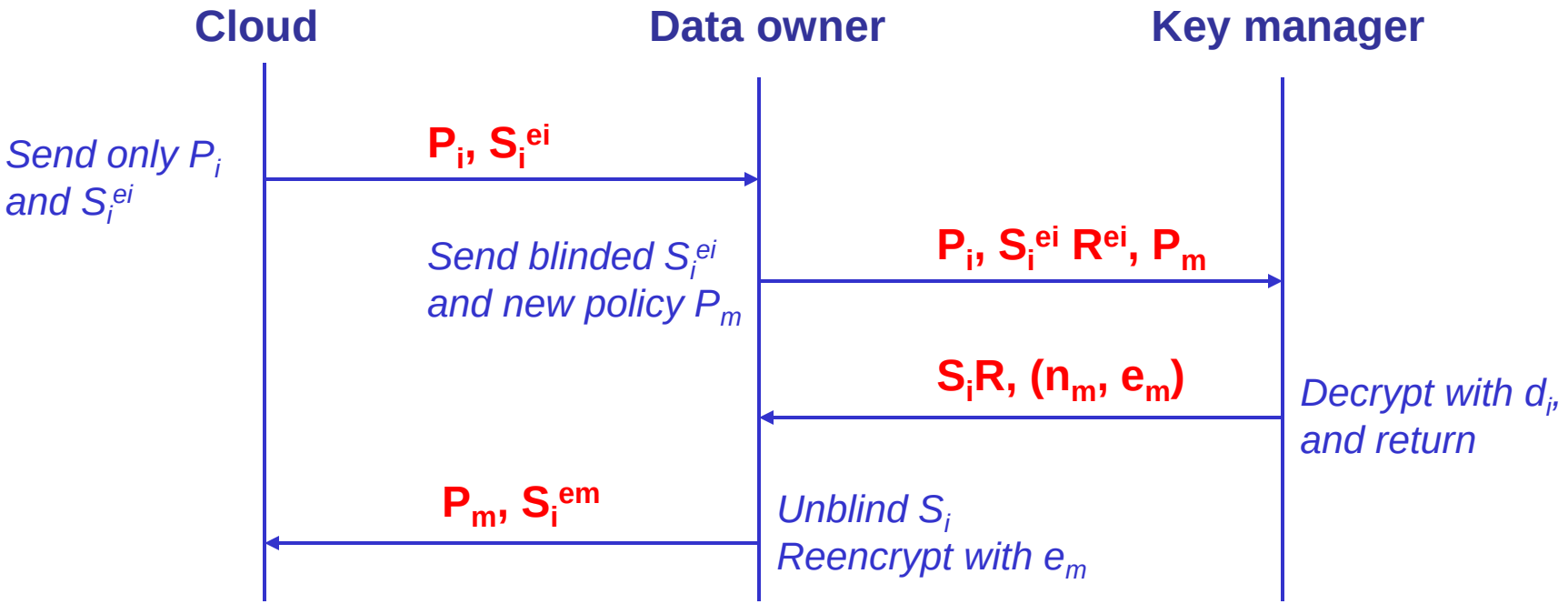
- Data owner randomly chooses (i) K for file F and (ii) S_i for policy P_i.
- Things sent to cloud
  - P_i = policy P_i
  - $\{K\}_{Si}$ = data key K encrypted with S_i using symmetric key crypto
  - S_i^{ej} = secret key S_i encrypted with e_i using public key crypto
    - S_i is used for policy renewal
  - $\{F\}_K$ = file encrypted with data key K using symmetric key crypto

File Download



- Data owner randomly picks a number R, and blinds S_i^{ei} with R^{ei}
- It unblinds S_iR, and recovers K and F

Policy Renewal



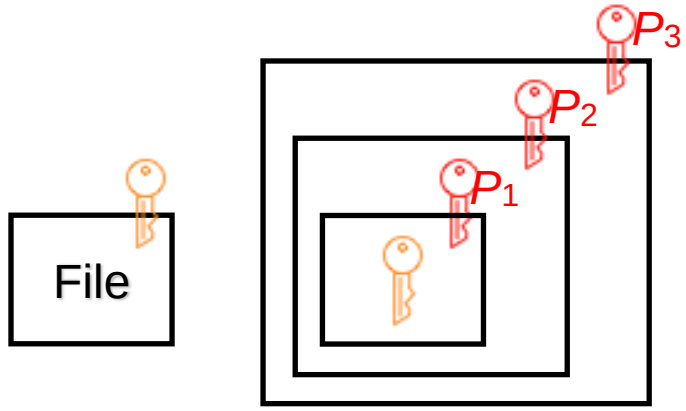
- Main idea: S_i re-encrypted into S_i^{em}
- $\{K\}_{Si}$ and $\{F\}_K$ remain unchanged on cloud

Policy Revocation

- Revoke policy P_i
  - Key manager removes all keys (n_i, e_i, d_i)
  - All files tied with policy P_i become inaccessible

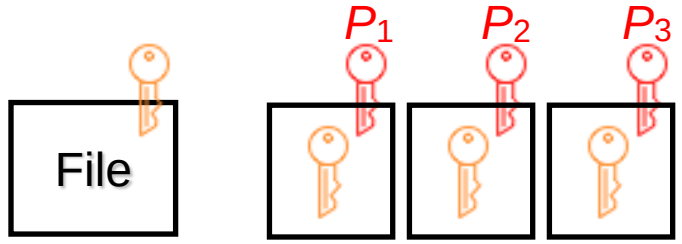
Multiple Policies

- Conjunctive policies
  - Satisfy all policies to recover file



$\{F\}_K$ $\{\{K\}_{S1}\}_{S2\ ...}\}_{Sm}$ $S_1^{e1}, S_2^{e2}, \ldots, S_m^{em}$

- Disjunctive policies
  - Satisfy only one policy to recover file



$\{F\}_K$ $\{K\}_{S1}, \{K\}_{S2}, \{K\}_{Sm}, S_1^{e1}, S_2^{e2}, \ldots, S_m^{em}$

FADE Implementation

- Use Amazon S3 as our backend (but can use other clouds)
- Use C++ with OpenSSL and libAWS++
- Each file has its own metadata:
  - File metadata: file size and HMAC
  - Policy metadata: policy information and encrypted keys

Interfaces of Data Owner

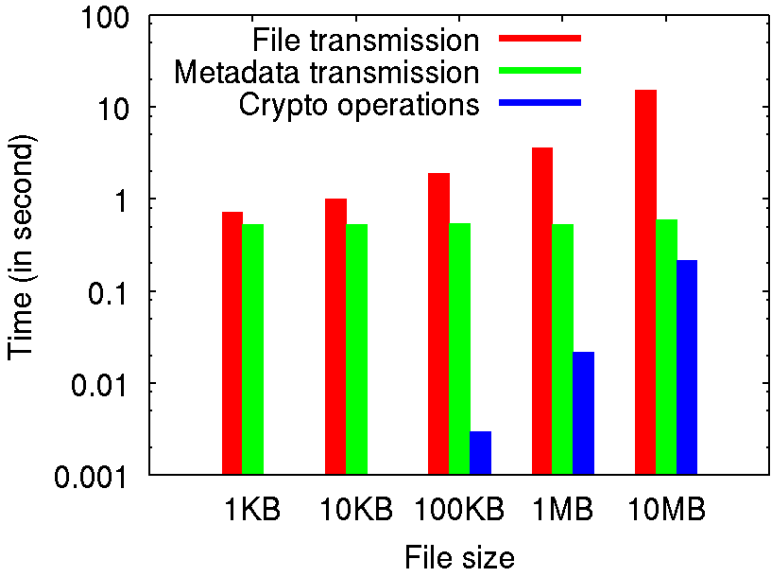
- Interfaces to interact with cloud:
  - **`Upload(file, policy)`**
  - **`Download(file)`**
  - **`Delete(file)`**
  - **`Delete(policy)`**
  - **`Renew(file, new_policy)`**
- Can be exported as library APIs for other implementations of data owner

Experiments

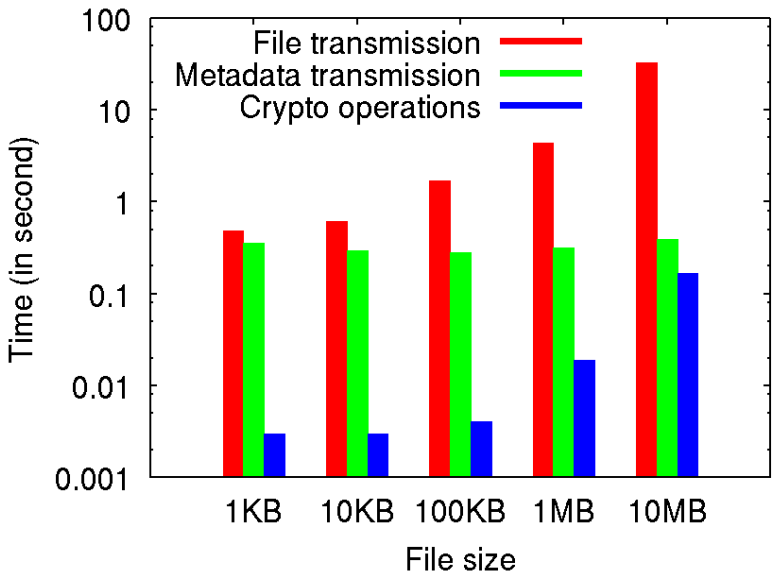
- What is the performance overhead of FADE?
  - e.g., metadata, cryptographic operations
- Performance overhead:
  - Time
    - File transmission time
    - Metadata transmission time
    - Time for cryptographic operations (e.g., AES, HMAC, key exchanges)
  - Space
    - Metadata

File Upload/Download

File upload



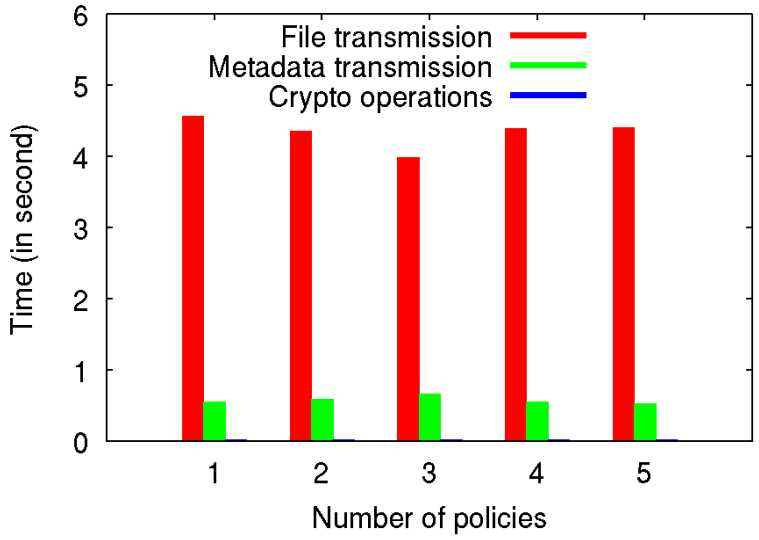
File download



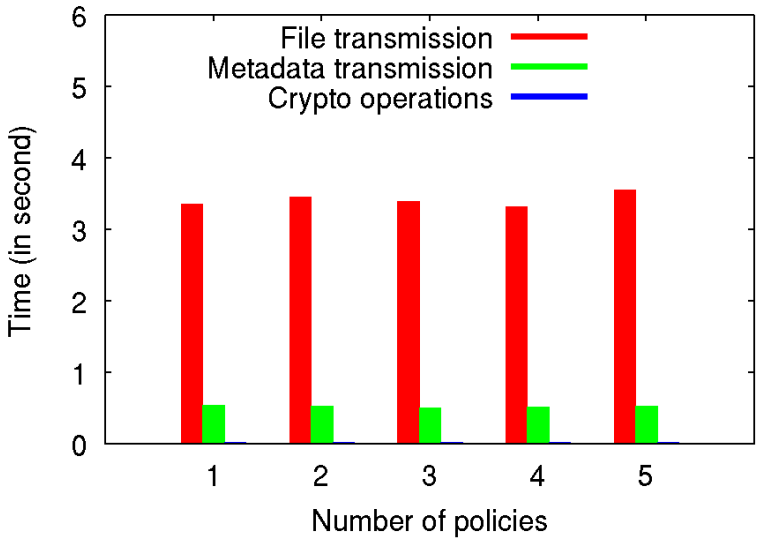
- Overhead of metadata is less if file size is large
- Time for cryptographic operations is small

Multiple Policies

Conjunctive Policies



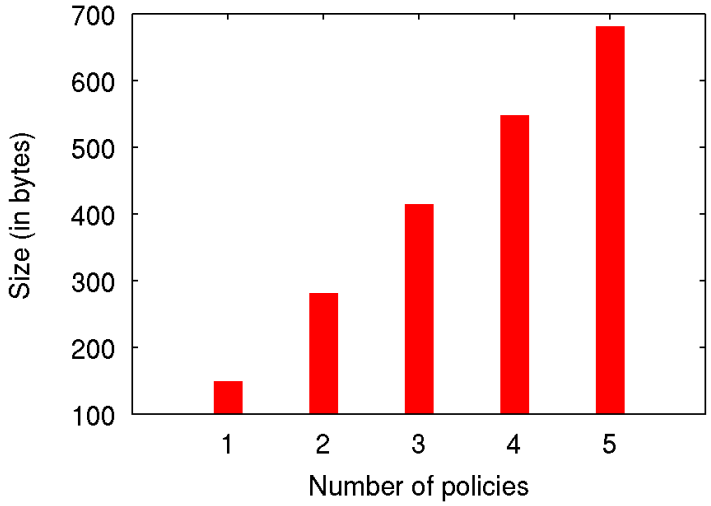
Disjunctive Policies



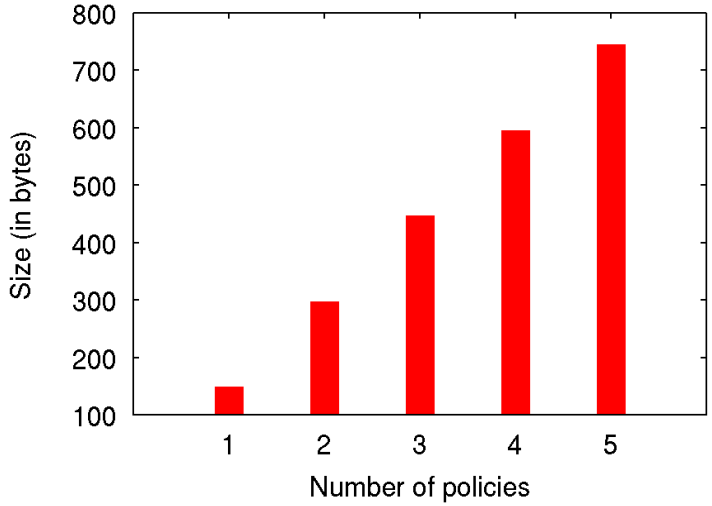
- File size is fixed at 1MB
- Time for cryptographic operations remain low (order of milliseconds) where there are more policies

Space Usage of Metadata

Conjunctive Policies



Disjunctive Policies



- Metadata overhead is less than 1KB for no more than 5 policies

Conclusions

- FADE, an overlay cloud storage system with access control and assured deletion
- Cryptographic operations for policy-based file assured deletion
- Implement a FADE prototype atop Amazon S3
- FADE is feasible in practice

Extensions

- Quorum scheme of multiple key managers
  - Threshold secret sharing
  - k out of n key shares to recover keys
- Integration with ABE for communication between data owner and key managers

References

- Publication:
  - Yang Tang, Patrick P. C. Lee, John C. S. Lui, and Radia Perlman, "**Secure Overlay Cloud Storage with Access Control and Assured Deletion.**" IEEE Transactions on Dependable and Secure Computing (TDSC), 9(6), pp. 903-916, November 2012.
- Source code:
  - http://ansrlab.cse.cuhk.edu.hk/software/fade/