Security of Cloud Computing

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Syllabus

- Cloud Computing Introduction
  - Definitions
  - Economic Reasons
  - Service Model
  - Deployment Model
- Supporting Technologies
  - Virtualization Technology
  - Scalable Computing = Elasticity
- Security
  - New Threat Model
 - New Attacks   ⟵ Cloud provider
  - Countermeasures

Introduction

- Not only Software as a Service but also "Storage-as-a-service" becoming a more common business model
  - Client pays server to store file F

F

- Without retrieving file, how can client be sure that server still has it?
  - Or, more generally, can provide it within an agreed response time?

- *Archiving* is a typical case: Client retains only metadata
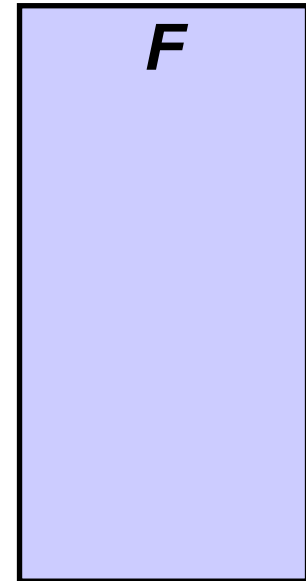
Adversarial Model

Erasing adversary may fail to store parts of file, or store at less than agreed tier

Corrupting adversary may also modify parts of file

Motivations:

> Reduce cost / increase profit ("freeloading" in a p2p contest)

> Hide "evidence"

> Change content – though typically detectable by integrity checks

> Or, just hardware, software, or human error

Assume that adversary has deleted or corrupted ε fraction of file, up to time that test is run

Proofs of Possess Retrievability

- A *proof of Posses - Retrievability* (POP, POR) provides assurance that a party possesses a file, without actually retrieving it

- Objective: Provide "early warning" of deletion, corruption, or other failure to meet service levels, in time to remediate e.g., exclude this server and add another one

- Since adversary can distinguish POR (= modest number of queries) from actual retrieval (= large number), can always pass test, then deny service

- POR shows that at time of test, adversary's state is sufficient (with high probability) to enable retrieval – thereby limiting time period during which undetected corruption may occur
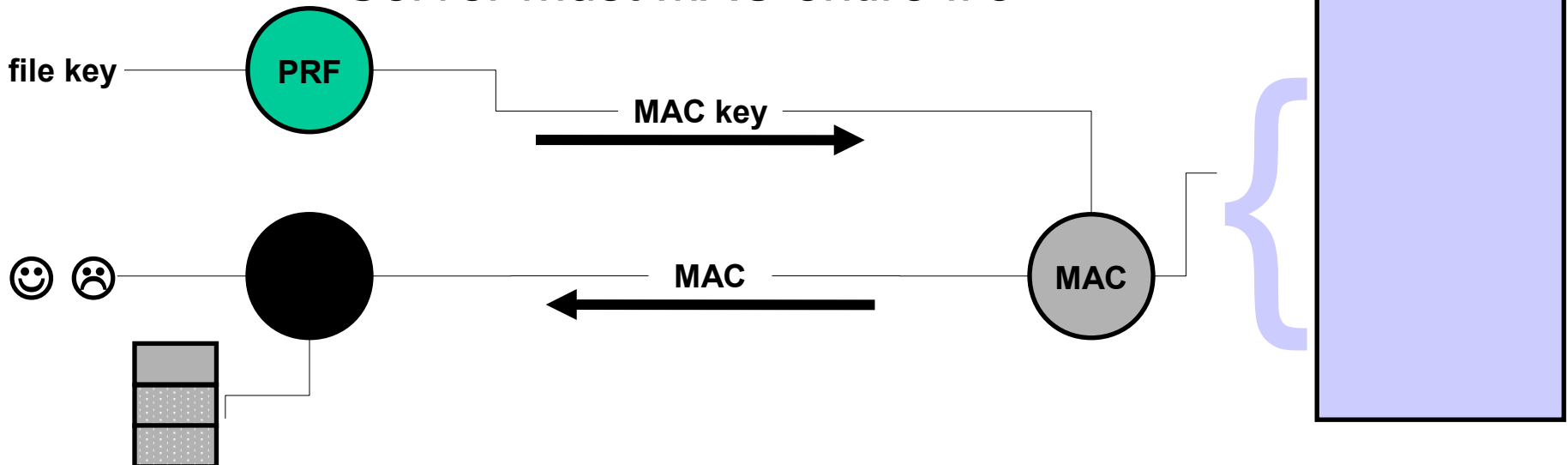
A Challenge-Response MACs

- MAC file with different keys, try one at a time

file key —— **PRF**

MAC keys

MAC
MAC
MAC

F
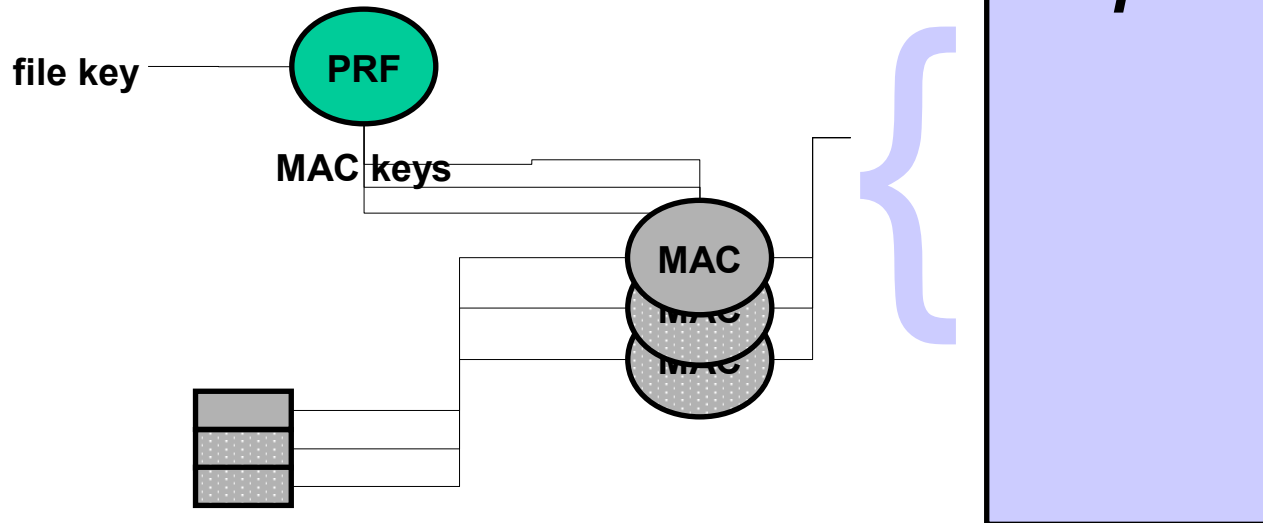
Simple Approach, cont'd

- MAC file with different keys, try one at a time

- # runs limited by client storage

- Server must MAC entire file

file key —— PRF

MAC key →

☺ ☹ ●

MAC ←

MAC

F

Block approach

- The file is splitted into d blocks

- We check whether some blocks is still there
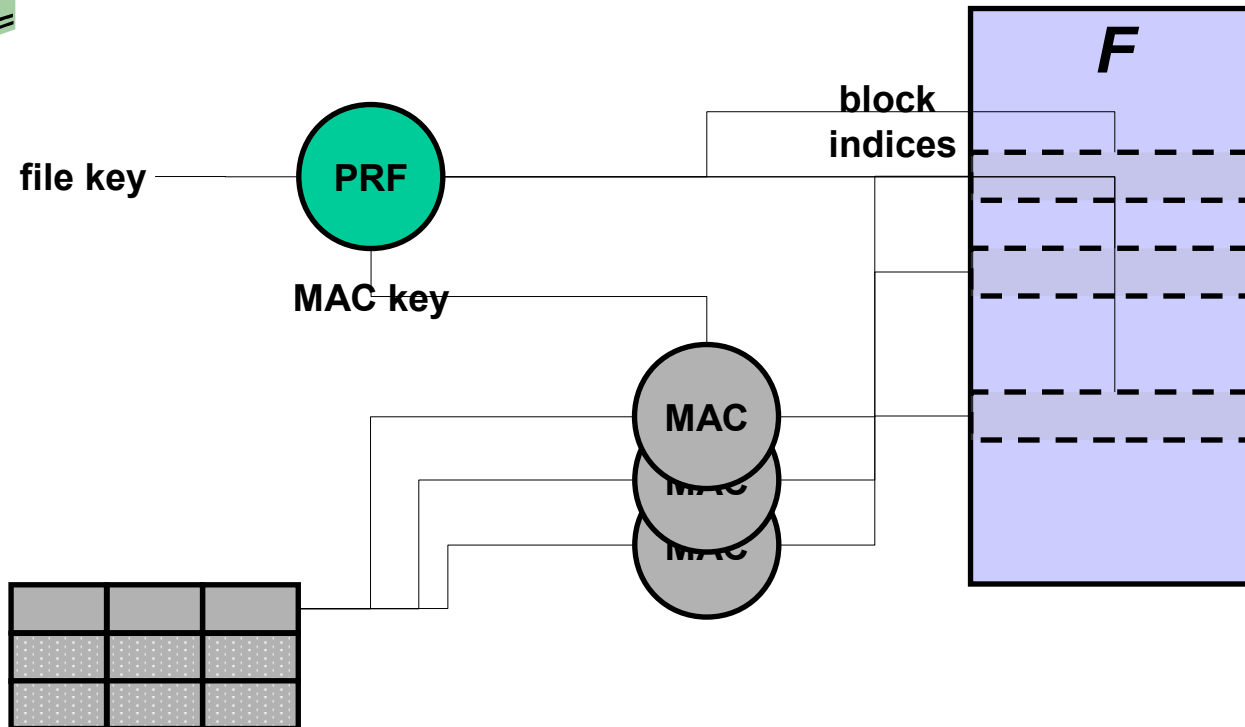
- The probability of non detecting an eraser is

$$P_{esc} = \left(1 - \frac{m}{d}\right)^r$$

where

- r is the number of blocks we control

- m is the number of blocks that have been erased

- 1-m/d is the probability of selecting one block that has not been erased
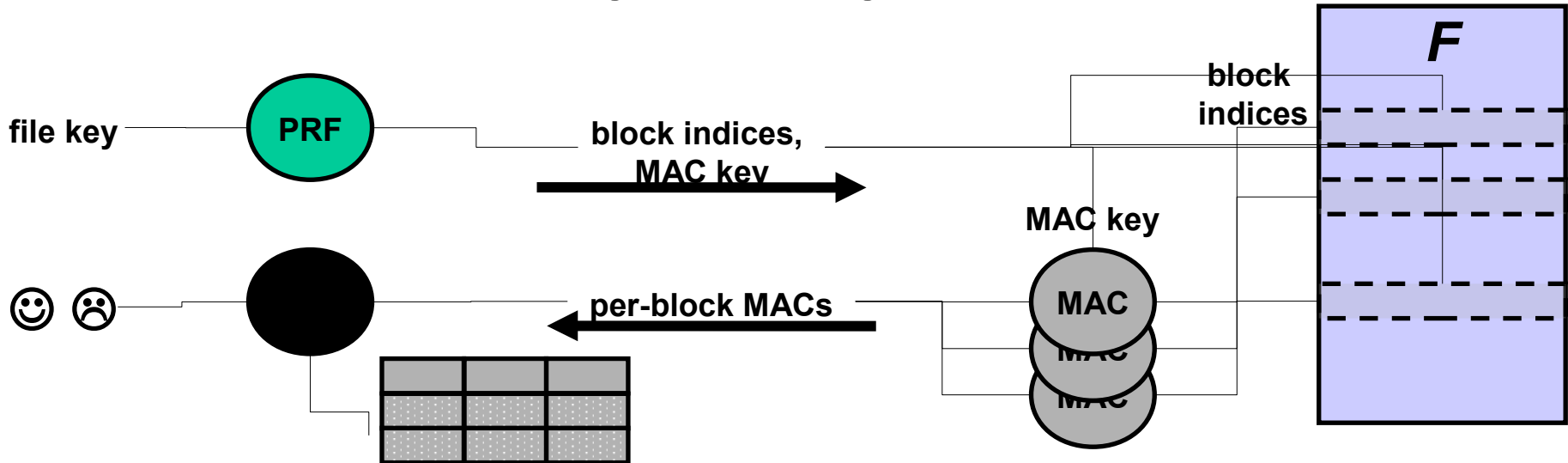
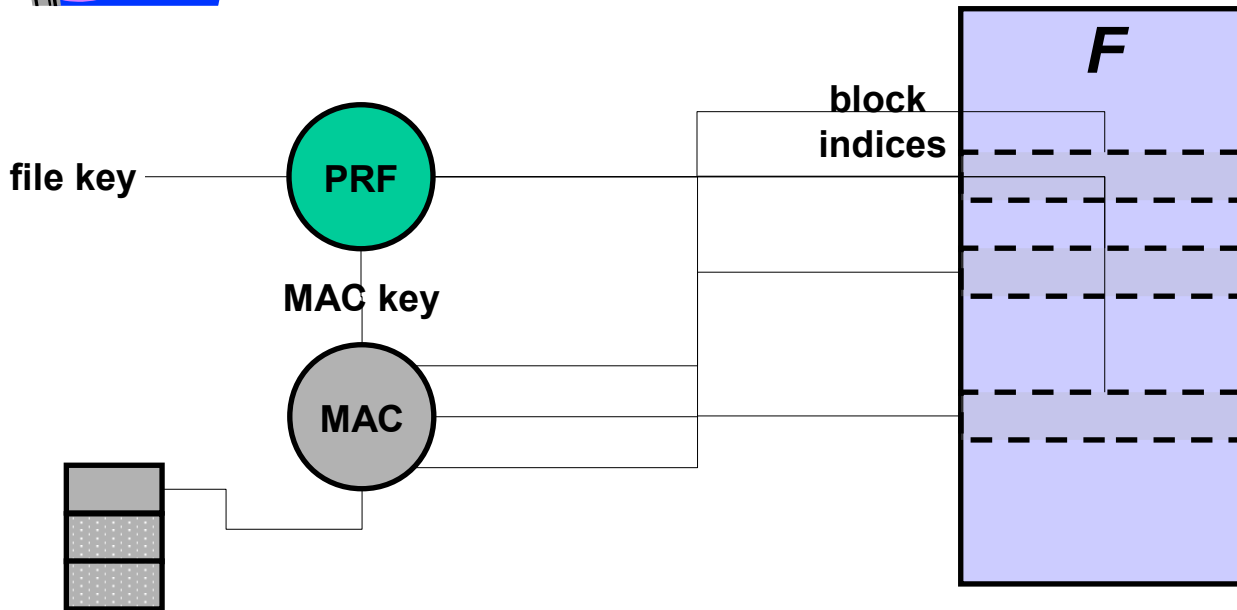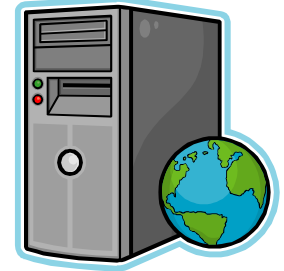# Per-Block MACs

- MAC selected blocks, and sample q

F.Baiardi – Security of Cloud Computing – Proof of Retrievability

Per-Block MACs, cont'd

- MAC selected blocks, and sample q

- Server work now only q MACs / run

- But message exchange ~ q

- With error rate ε, Pr [undetected] $\leq (1 - \varepsilon)^q$

Group MACs

- MAC group of sampled blocks

file key ——— **PRF**

MAC key

MAC

block indices

F
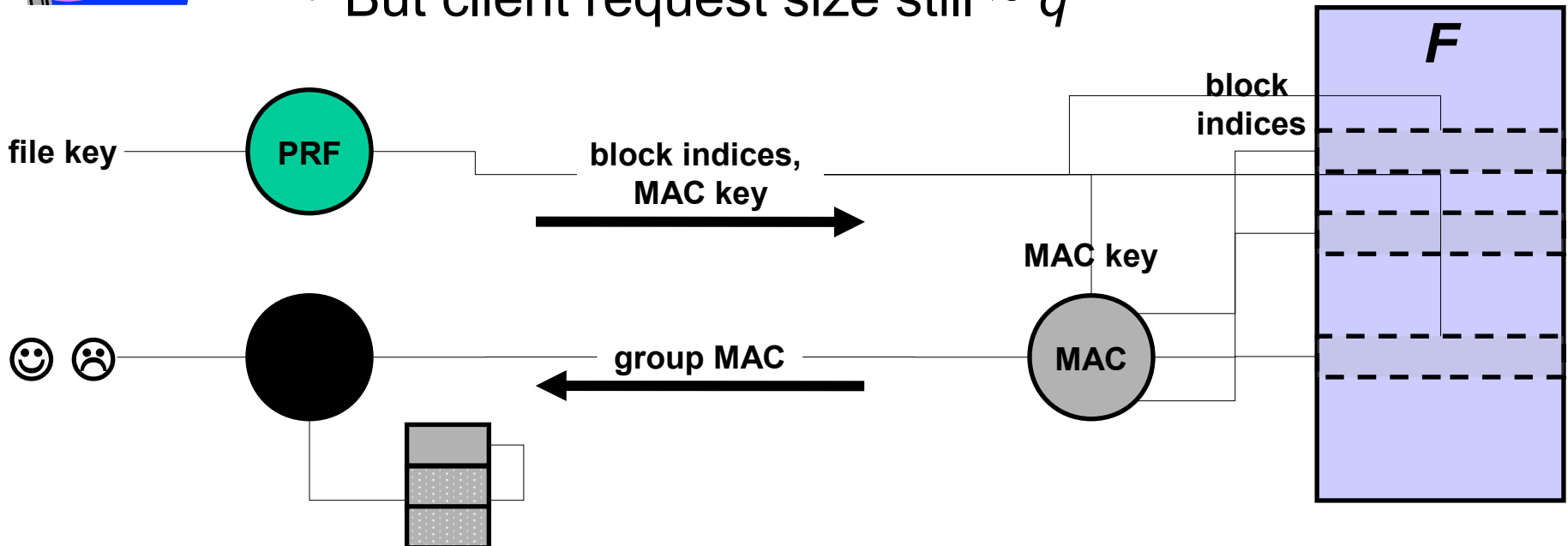
Group MACs, cont'd

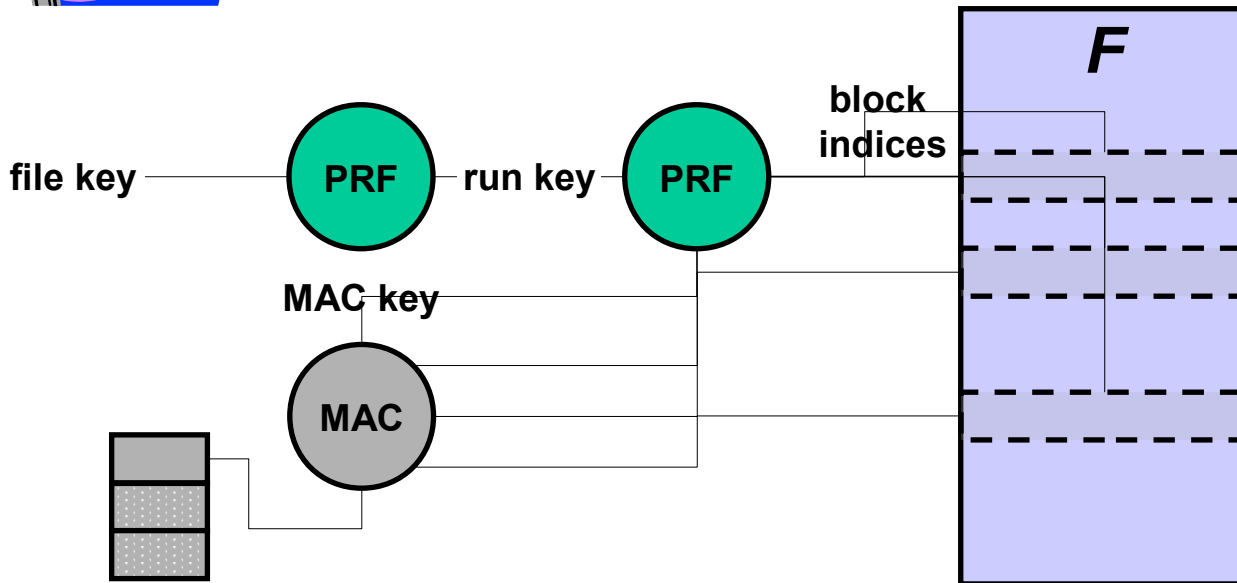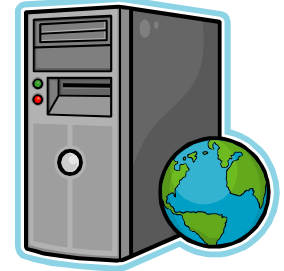- MAC group of sampled blocks
- Server response now constant size
- But client request size still ~ q

file key

PRF

block indices,
MAC key

block
indices

F

MAC key

MAC

☺ ☹

group MAC

Index Derivation

- Derive block indices from *run key*
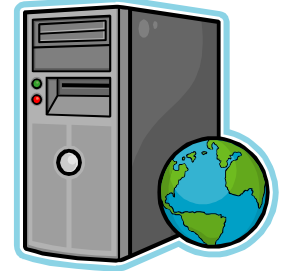
file key —— PRF —— run key —— PRF —— block indices —— **F**

MAC key

MAC

Index Derivation, cont'd
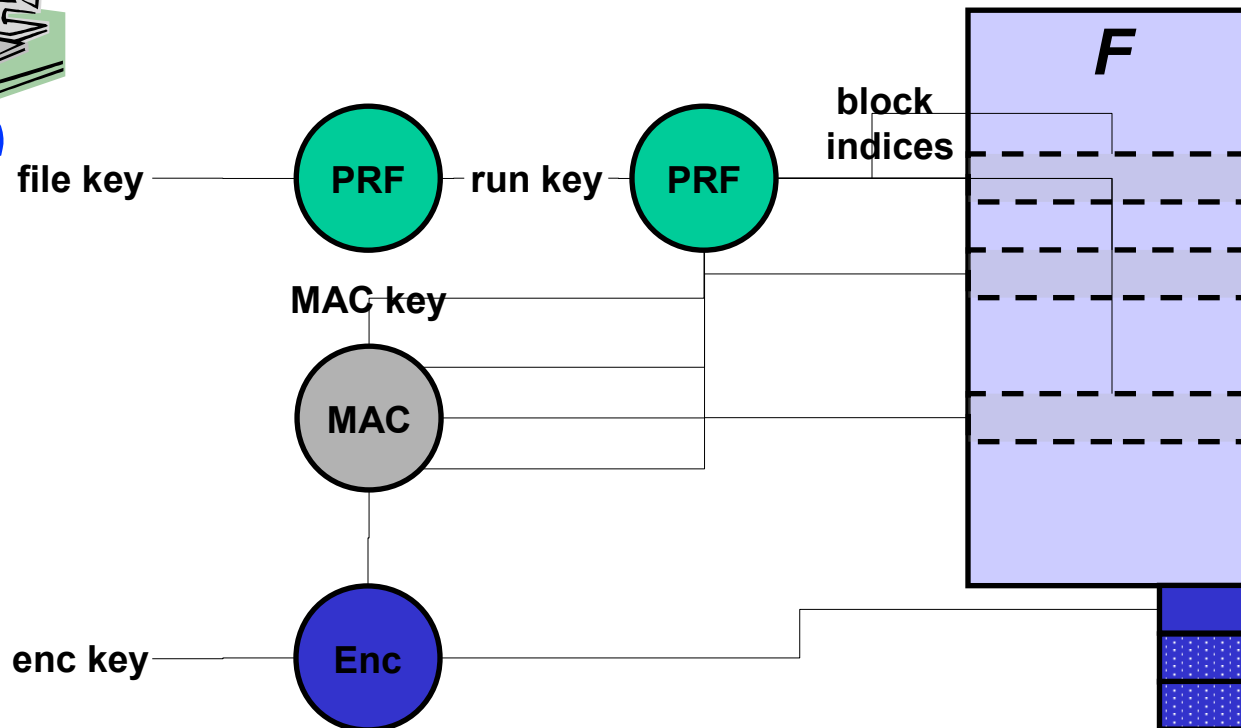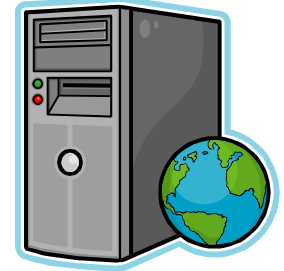
- Derive block indices from run key

- Both message exchanges now constant size

- But client storage still ~ # runs

file key — PRF — **run key** → PRF — **block indices** → F
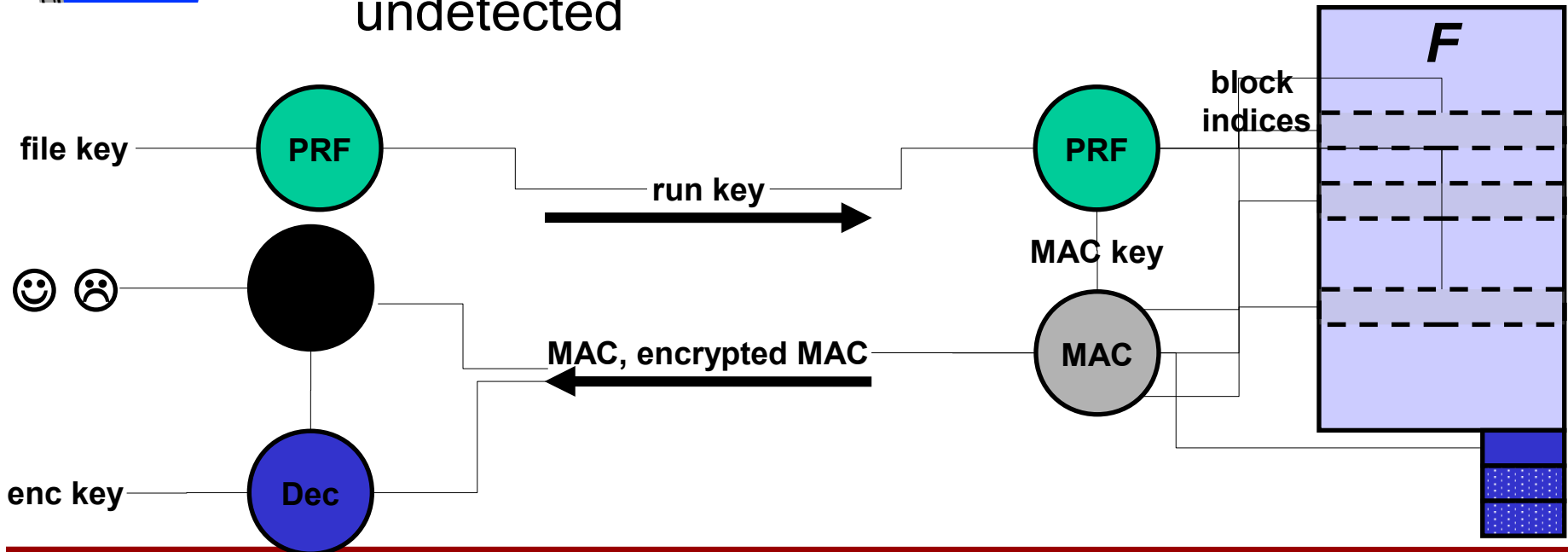
MAC key
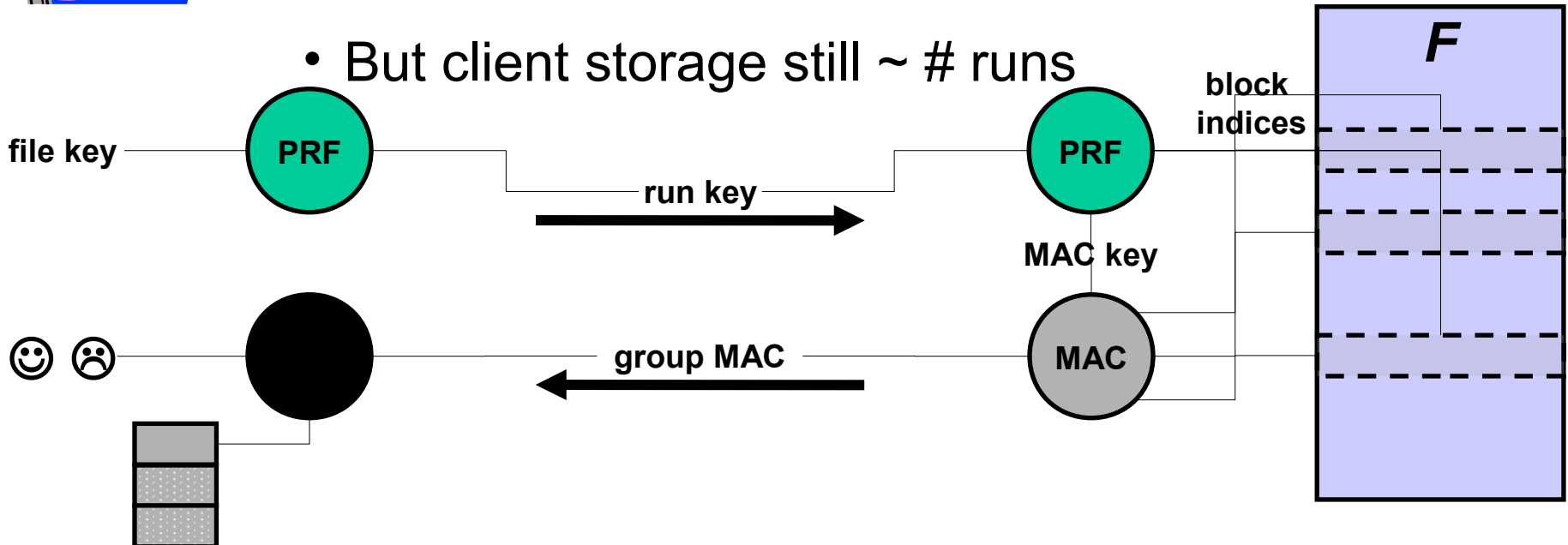
☺ ☹ — ● — **group MAC** ← MAC

Server Storage of Encrypted MACs

- Encrypt group MACs, store on server

Server Storage of Encrypted MACs, cont'd

- Encrypt group MACs, store on server

- Client storage now constant

- But small error rate (< ε) may go undetected

file key — **PRF** → **run key** → **PRF** — **block indices** → *F*

☺ ☹ — ● — **MAC, encrypted MAC** ← **MAC** ← **MAC key**

enc key — **Dec**

Recovering from Errors

MAC sampling detects server error rate ≥ ε with high probability

Smaller error rate (< ε) may go undetected, but can be *corrected*

First solution: Apply error-correcting code to file before storing

But non-trivial: No efficient simple codes known that are robust against arbitrary adversarial errors

Second solution: Encrypt file, apply error-correcting code, then apply *pseudorandom permutation* to block order

Black-Rogaway (CT-RSA 02) define PRP for arbitrary domain

Remaining Challenges …

- There are schemes that support update of the file

- Other scheme based upon homomorphic encryption allow any one to check that the server stores the file

- Number of runs is limited by server storage of encrypted MACs but this is not very compelling

Homorphic encryption = Holy gray of encryption

a) Let R and S be sets and E an encryption $R \rightarrow S$

b) E is

- **Additively homomorphic if** E(a+b)=PLUS(E(a), E(b))

- **Multiplicatively homomorphic if** E(a×b)=MULT(E(a), E(b))

- **Mixed-multiplicatively homomorphic** $E(xy)$=Mixed-mult($E(x),y$)

- *fully homomorphic if* there are no limitations on manipulations

Homomorphic encryption

- Data + Computation at the provider
- Inputs are encrypted by the client
- Outputs are transmitted to the client that decrypt it
- No trivial solution = the provider executes most computations to prevent cases where
  - the data is transmitted to the client,
  - the client decrypts the data, computes the results and encrypts
 - the results are transmitted to the provider

Sentinels – Another Approach

- Sentinels= randomly constructed check values.
- F' = F encryption + embedded sentinels,

  F is encrypted so that sentinels cannot be discovered

- *Verification phase:* V specifies the positions of some sentinels in F' and asks the archive to return the corresponding sentinel values.
- *Security:* Because F is encrypted and the sentinels are randomly valued, the archive cannot feasibly distinguish *a priori* between sentinels and portions of the original file F.
  - If the archive deletes or modifies a substantial, fraction of F', it will with high probability also change a fraction of sentinels.
  - If V requests and verifies enough sentinels, V can detect whether the archive has erased or altered a substantial fraction of F'
- Individual sentinels are, however, only one-time verifiable.

Sentinel Overwriting

- Insert into selected blocks pseudorandom values, and check

file key — **PRF** — **run key** — **PRF** — **block indices**

sentinel values

F
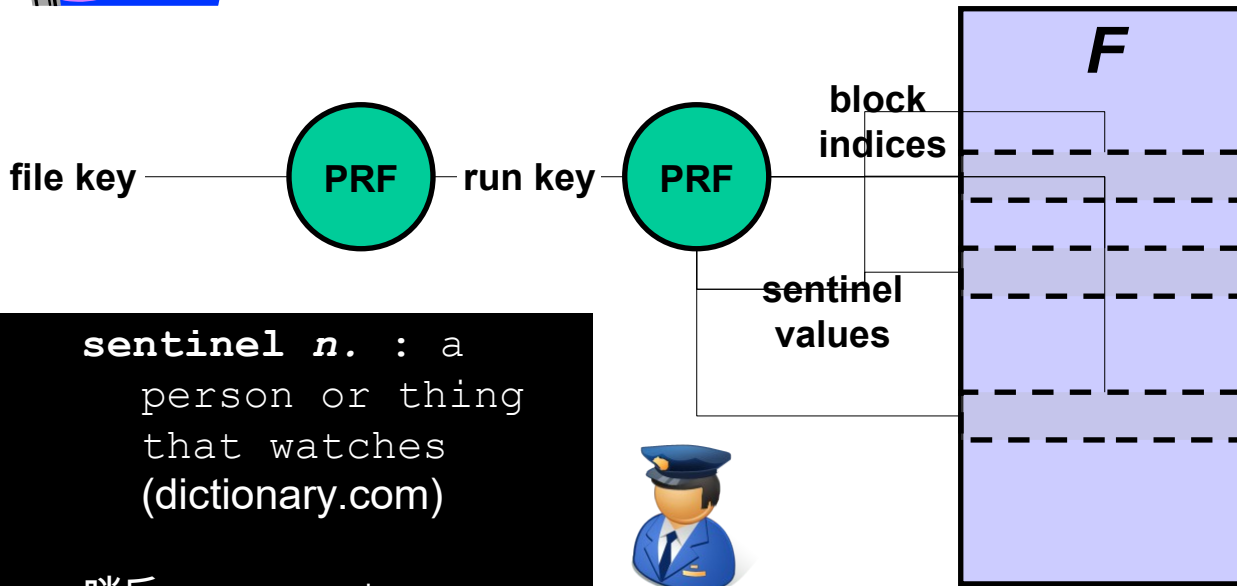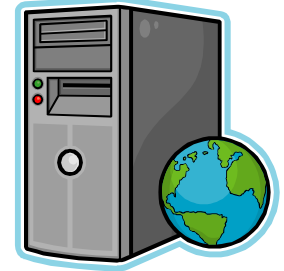
sentinel *n.* : a person or thing that watches (dictionary.com)

哨兵 : security guard, watchman, watcher (babylon.com)

Sentinel Overwriting, cont'd

- Insert pseudorandom values, and check
- Security proof in standard model
- Size limitations … but can optimize
- No special storage at server
- Error correcting code makes up for overwrite
- Insertion also possible – design tradeoffs

file key — **PRF** — **run key** → **PRF** — **block indices** — *F*

☺ ☹ — ● — **sentinel values** ←
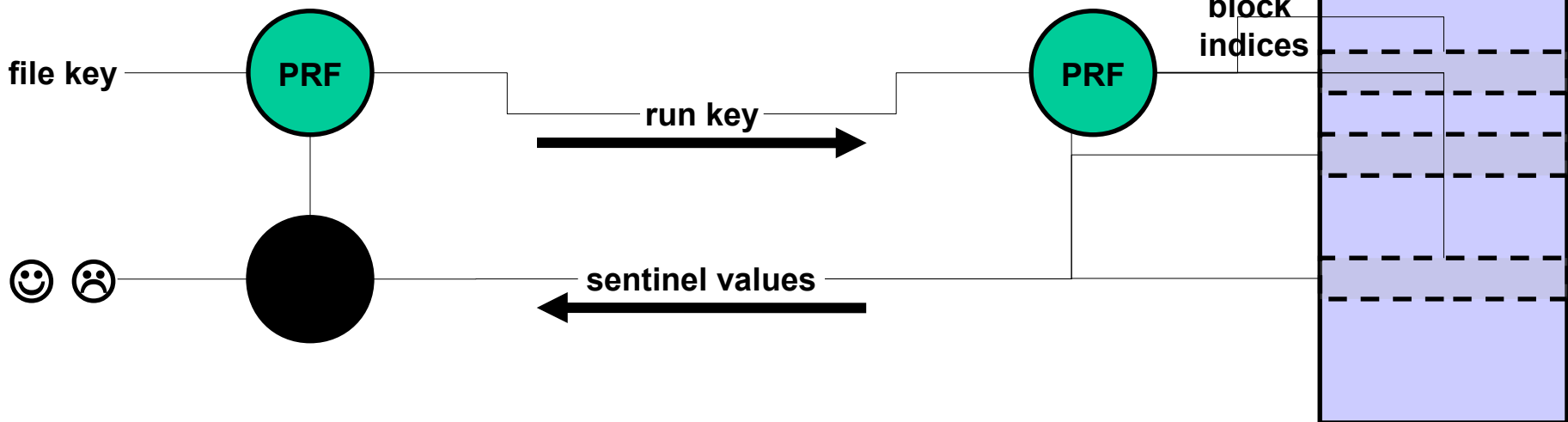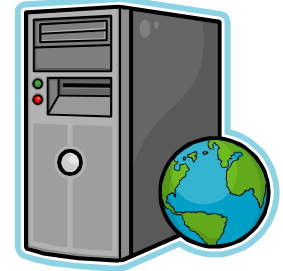
Theoretical Considerations

- Proof of retrievability is a protocol for demonstrating that a party possesses a file

  - Successful verification ←→ Successful retrieval
  - Party's "response" interface is preferred building block for reduction

- Different from *proof of knowledge*, which demonstrates that a party possesses a witness related to a public value

  - e.g., discrete log x of g^x
  - No corresponding public value for file

- The sentinel POR scheme has curious feature that the sentinels and protocol messages are *independent* of the file whose possession is being proved

Conclusions

Proofs of retrievability provide assurance that file stored on server can be retrieved – with only a modest number of operations and overhead

Multiple design steps lead to practical schemes based on MACs, sentinels

   Many variants, optimizations to explore

Next step: Integration with actual file systems for a real test of performance, parameterization

But we also have the inverse problem

- How can you be sure that data in the cloud has been erased?

- In general you cannot be sure if the data has been collected or created on the cloud

- But there are other solutions when data has been created outside and then stored in the cloud

Vanish: Increasing Data Privacy with Self-Destructing Data

R.Geambasu, T. Kohno, A. Levy, H.M. Levy.
Proceedings of the USENIX Security Symposium, Montreal,

Canada, August 2009.

Motivating Problem: Data Lives Forever

Ann — Sensitive email

ISP | Hotmail | W | Gmail

Carla
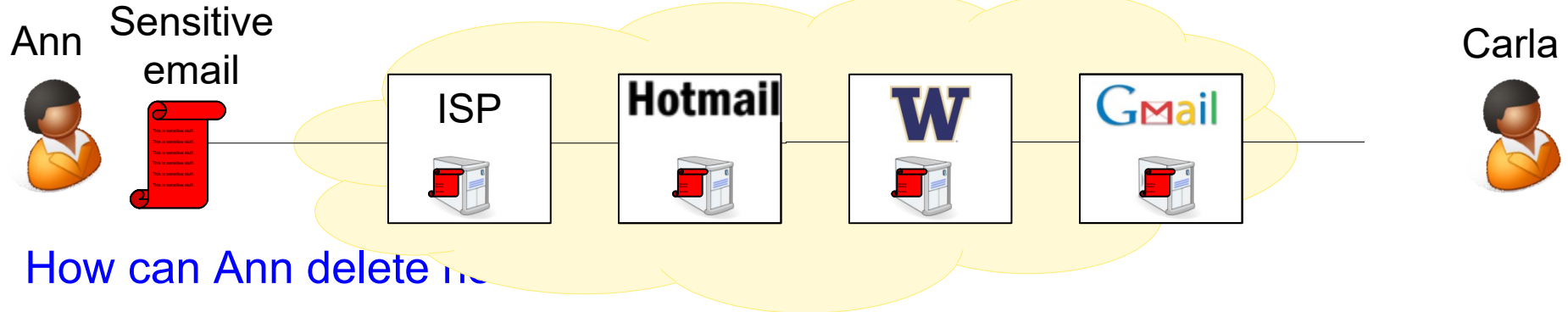
How can Ann delete...

She doesn't know where all the copies are

Services may retain data for long after user tries to delete

ars technica

Last updated July 3, 2009

Are "deleted" photos really gone from Facebook? Not always

When you delete embarrassing photos from sites like MySpace and Facebook, they don't disappear immediately.
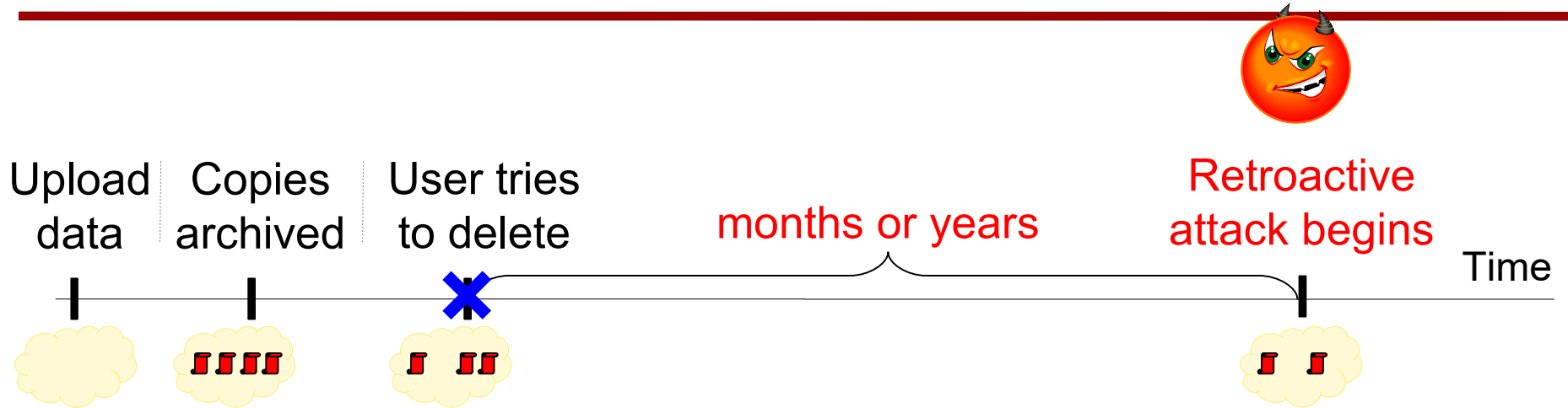
Archived Copies Can Resurface Years Later

Ann

ISP

Hotmail

W

Gmail
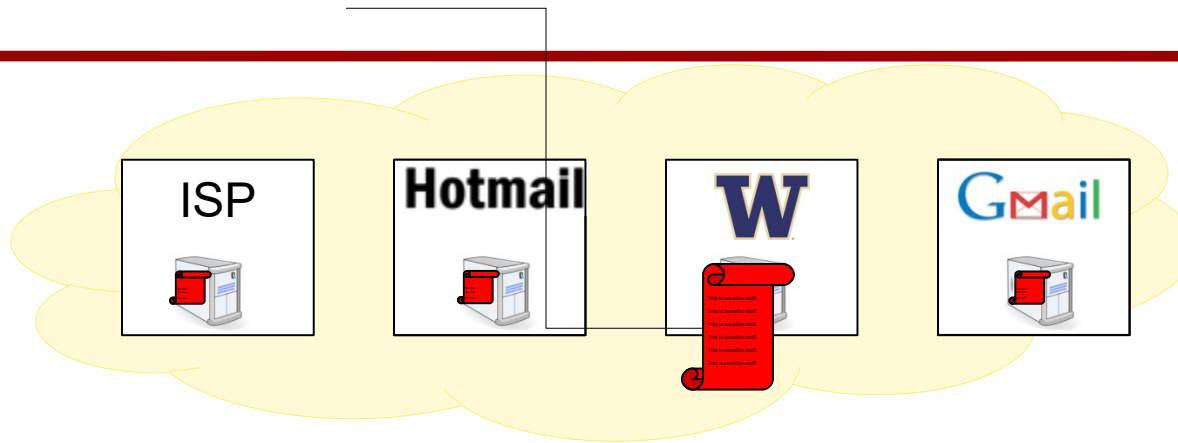
Carla

Some time later…

Subpoena, hacking, …

Retroactive attack on archived data

The Retroactive Attack

Upload data

Copies archived

User tries to delete

months or years

Retroactive attack begins

Time

Why Not Use Encryption (e.g., PGP)?

Ann

Carla

ISP

Hotmail

W

G**mail**
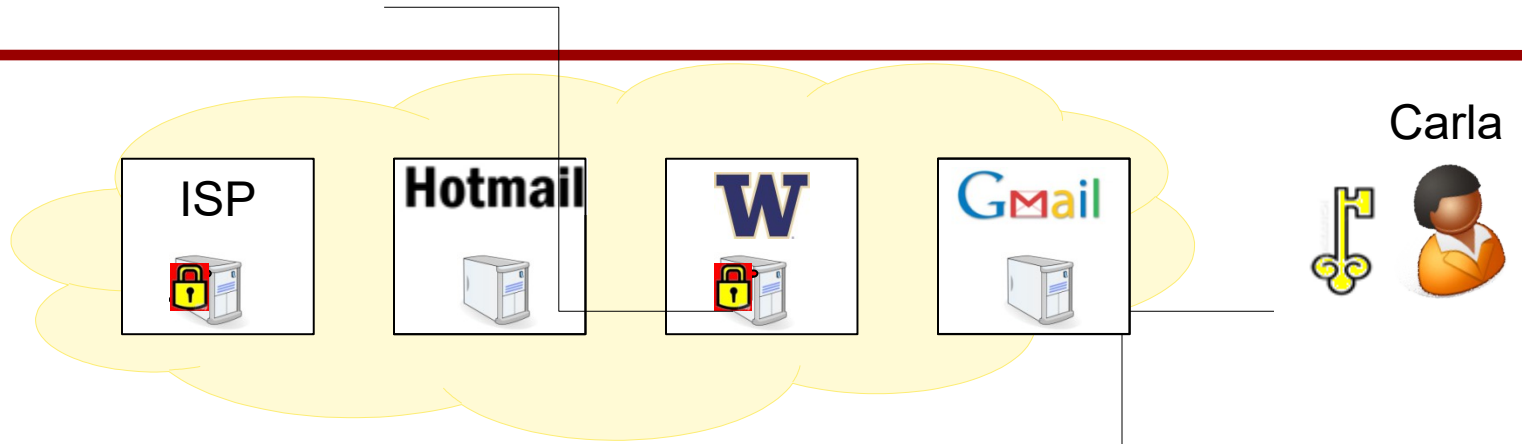
Subpoena, hacking, …
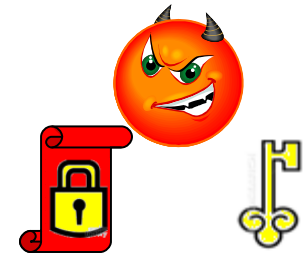
Why Not Use a Centralized Service?

Ann

Carla

ISP

Hotmail

W

Gmail
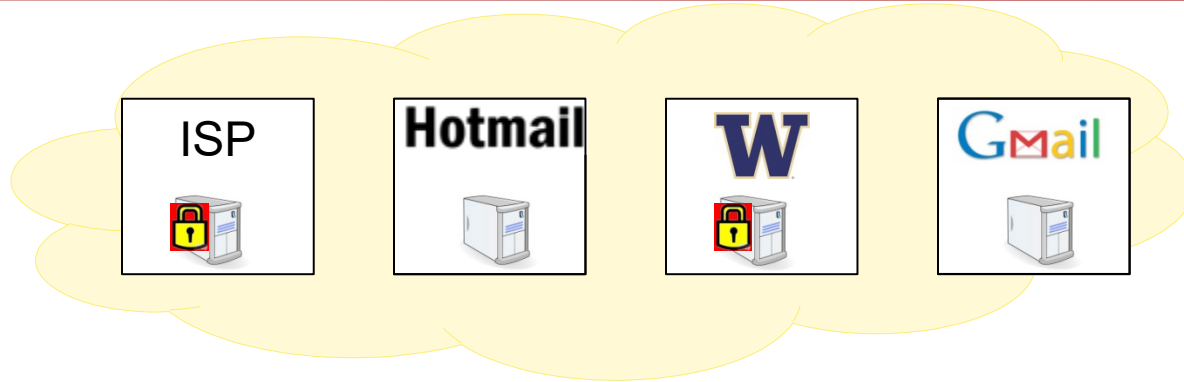
Centralized Service

"Trust us: we'll help you delete your data on time."

Backdoor agreement

The Problem: Two Huge Challenges for Privacy

Data lives forever

On the web: emails, Facebook photos, Google Docs, blogs, …

In the home: disks are cheap, so no need to ever delete data

In your pocket: phones and USB sticks have GBs of storage

Retroactive disclosure of both data and user keys has become commonplace

Hackers

Misconfigurations

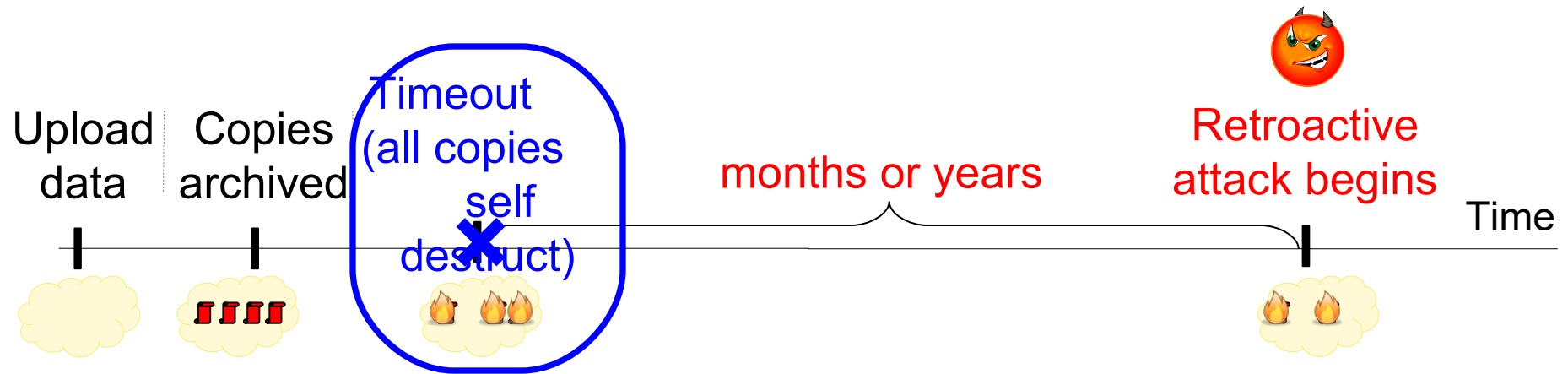Legal actions

Border seizing
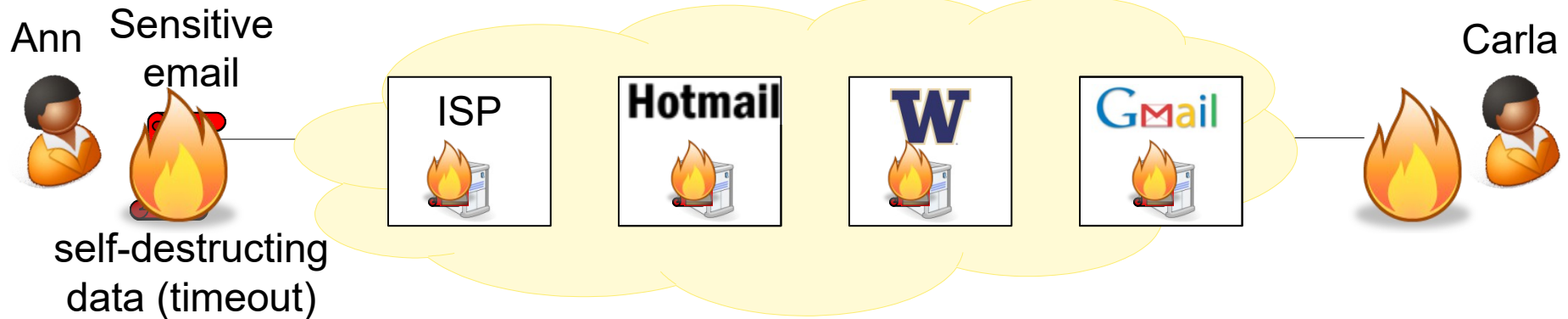
Theft

Carelessness

Question:

Can we empower users with control of data lifetime?

Answer:

Self-destructing data

Upload data — Copies archived — Timeout (all copies self destruct) — months or years — Retroactive attack begins — Time

Self-Destructing Data Model

Ann
Sensitive email

self-destructing data (timeout)

ISP — Hotmail — W — Gmail

Carla

Goals

1. Until timeout, users can read original message
2. After timeout, all copies become permanently unreadable
   2.1. even for attackers who obtain an archived copy & user keys
   2.2. without requiring explicit delete action by user/services
   2.3. without having to trust any centralized services

Vanish: Self-Destructing Data System

Traditional solutions are not sufficient for self-destructing data goals:

PGP

Centralized data management services

Forward-secure encryption

…

Let's try something completely new!

Idea:
Leverage P2P systems

P2P 101: Intro to Peer-To-Peer Systems

- A system of individually-owned computers that make a portion of their resources available directly to their peers without intermediary managed hosts or servers. [~wikipedia]
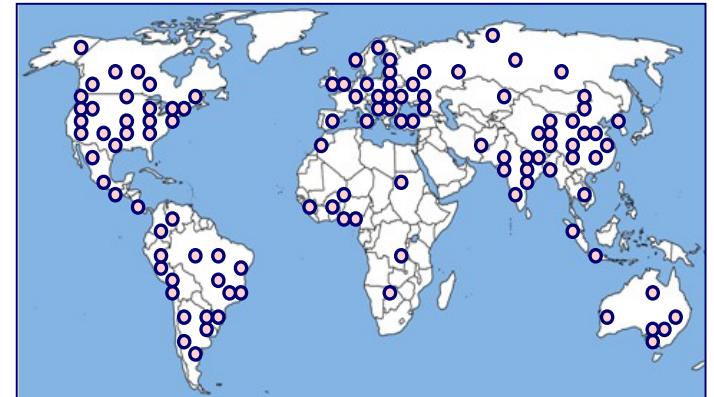
- Important properties (for Vanish):
- Huge scale – millions of nodes
- Geographic distribution – hundreds of countries
- Decentralization – individually-owned, no single point of trust
- Constant evolution – nodes constantly join and leave

Distributed Hashtables (DHTs)

Hashtable data structure implemented on a P2P network

    Get and put (index, value) pairs

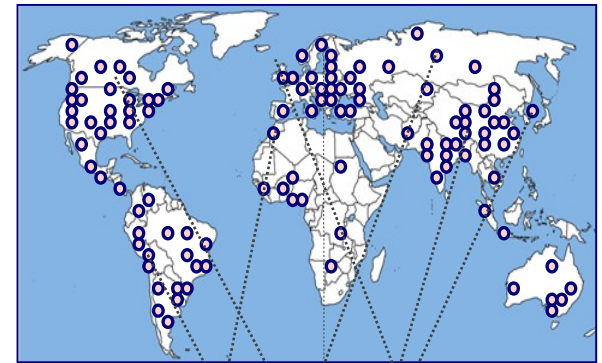   Each node stores part of the index space

DHTs are part of many file sharing systems:

    Vuze, Mainline, KAD

    Vuze has ~1.5M simultaneous nodes in ~190 countries

Vanish leverages DHTs to provide self-destructing data

    One of few applications of DHTs outside of file sharing

DHT
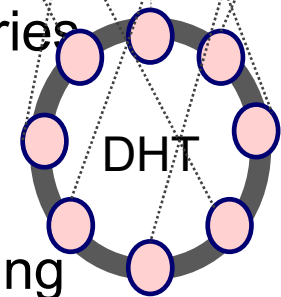
Logical structure

Shamir's (t, n)-threshold scheme:

a) D chooses prime p such that $p \leq n+1$, K in Z_p the group generated by p;

b) generates distinct, random, non-zero x_i in Z_p, $i=1,...,n$;

c) generates random $a_i \in Z_p$, $i=1, 2,..., t-1$;

d) $a_0 = K$, the secret;

e) $f(x) = \sum_{i=0 \text{ to } t-1} a_i x^i$ mod p;

P_i's share is $(x_i, f(x_i))$.
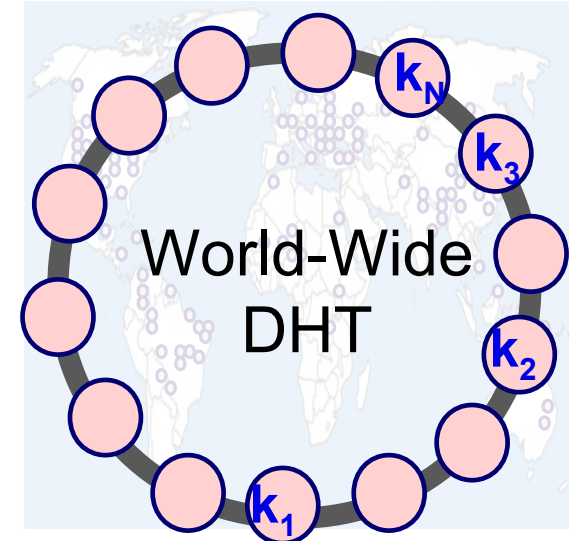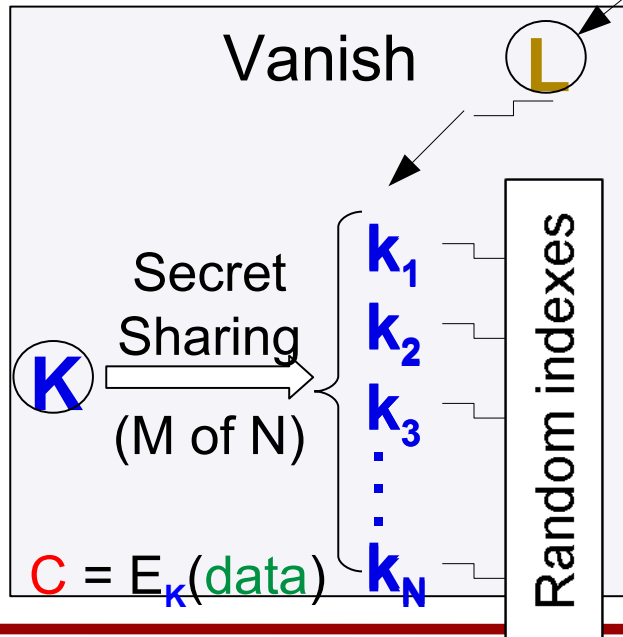
How Vanish Works: Data Encapsulation

Ann   Carla

VDO = {C, L}

Encapsulate   Vanish Data Object   Access key
(data, timeout) VDO = {C, L}

Vanish   L

Secret
Sharing k_1
                k_2 Random indexes
K k_3
(M of N)   ⋮
                k_N

$C = E_K(data)$

World-Wide
DHT

k_N
k_3
k_2
k_1

How Vanish Works: Data Decapsulation

Ann — VDO = {C, L} — Carla
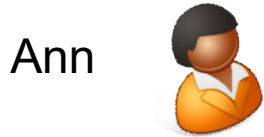
Encapsulate
(data, timeout)

Vanish Data Object
VDO = {C, L}

Decapsulate
(VDO = {C, L})

data

Vanish L

Secret Sharing

K

(M of N)

$C = E_K(data)$

Random indexes

World-Wide DHT

k_N
k_3
k_2
k_1

L Vanish

Random indexes

X

Secret Sharing

(M of N)

K

$data = D_K(C)$

Computing – Proof of Retrievability
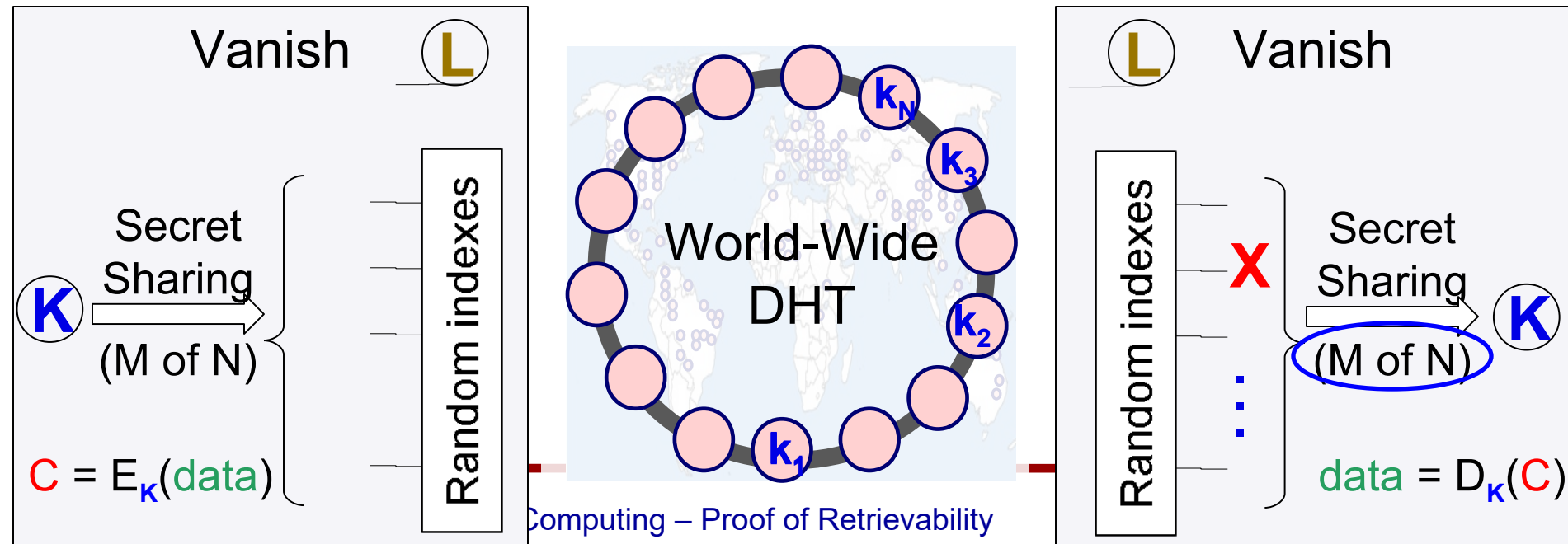
How Vanish Works: Data Timeout

The DHT loses key pieces over time

    Natural churn: nodes crash or leave the DHT
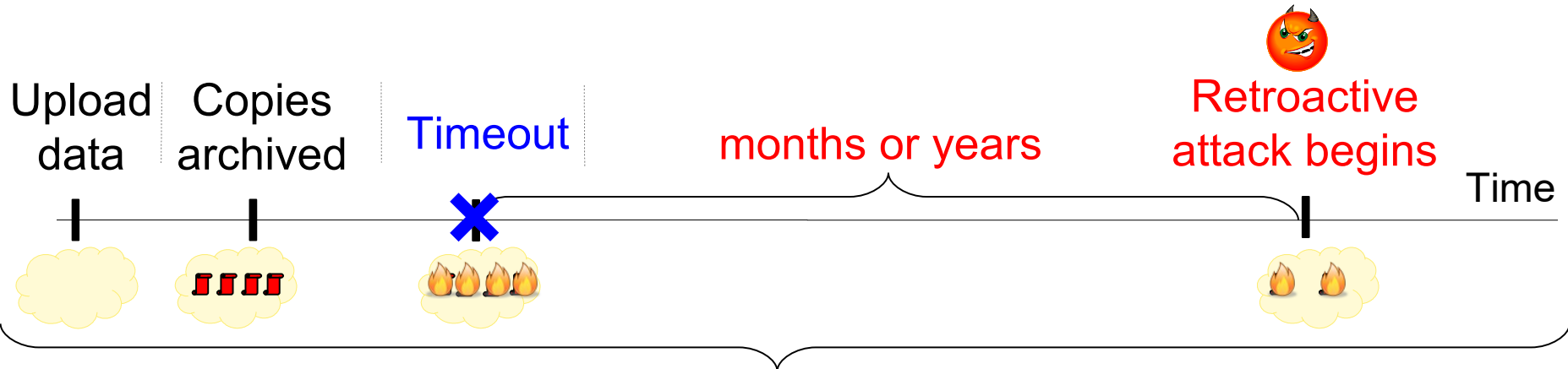
    Built-in timeout: DHT nodes purge data periodically
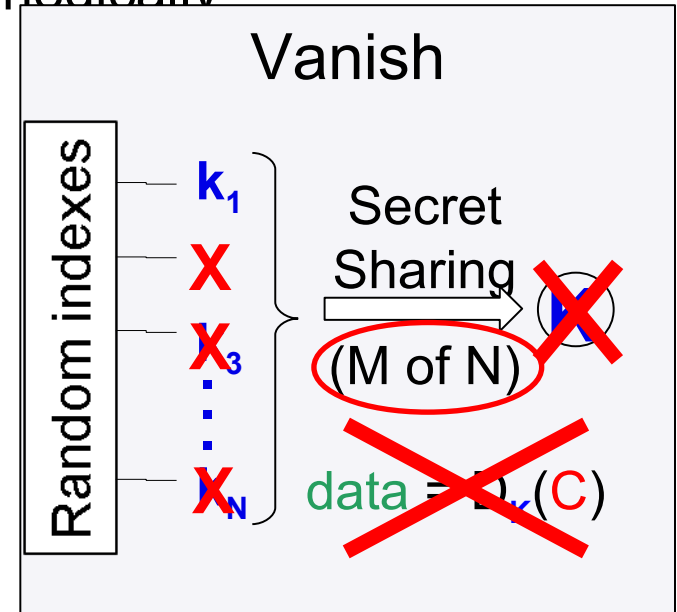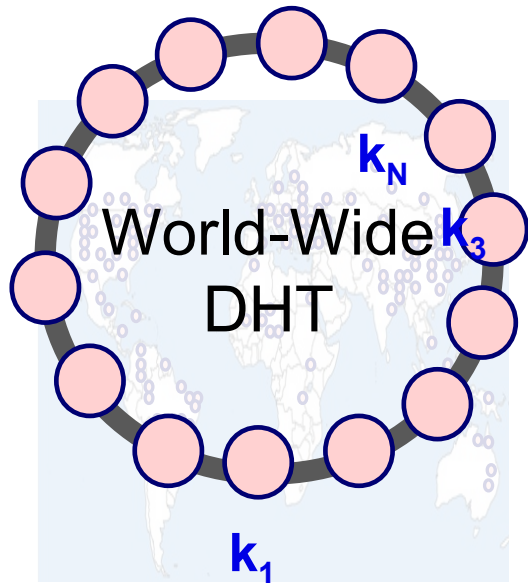
Key loss makes all data copies permanently unreadable

Threat Model

Goal: protect against retroactive attacks on old copies

    Attackers don't know their target until after timeout

    Attackers may do non-targeted "pre-computations" at any time

Communicating parties trust each other

   E.g., Ann trusts Carla not to keep a plain-text copy

Attack Analysis

Retroactive Attack	Defense
Obtain data by legal means (e.g., subpoenas)	P2P properties: constant evolution, geographic distribution, decentralization
Gmail decapsulates all Vanish Data Object emails	Compose with traditional encryption (e.g., PGP)
ISP sniffs traffic	Anonymity systems (e.g., Tor)
DHT eclipse, routing attack	Defenses in DHT literature (e.g., constraints on routing table)
DHT Sybil attack	Defenses in DHT literature; Vuze offers some basic protection
Intercept DHT "get" requests & save results	Vanish obfuscates key share lookups
Capture key pieces from the DHT (pre-computation)	P2P property: huge scale
More (see paper)	

Retroactive Attacks
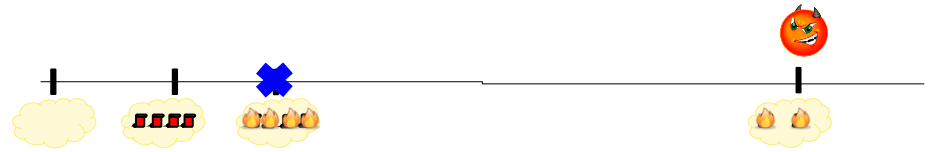
Attack	Defense
Obtain data by legal means (e.g., subpoenas)	P2P properties: constant evolution, geographic distribution, decentralization
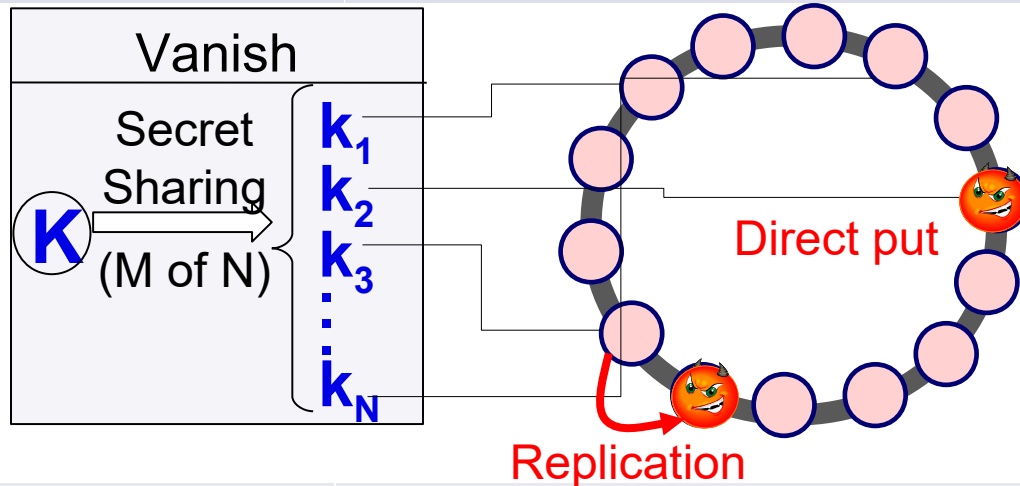
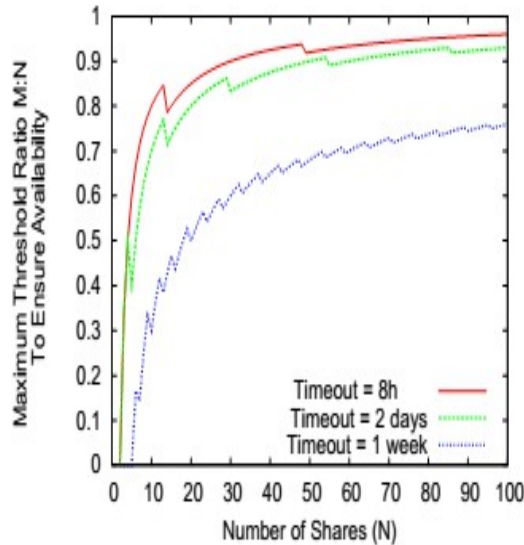| Capture any key pieces from the DHT (pre-computation) | P2P property: huge scale |

Given the huge DHT scale, how many nodes does the attacker need to be effective?
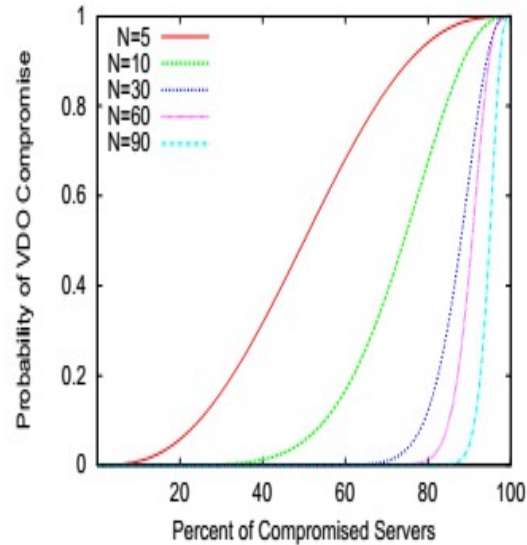
Current estimate: Attacker must join with ~8% of DHT size, for 25% capture
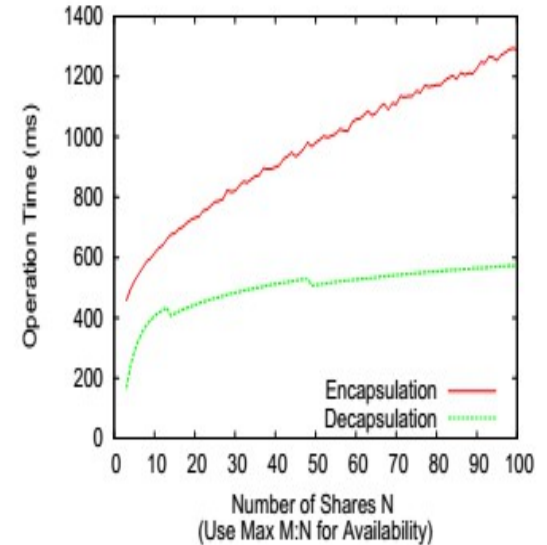
There may be other attacks (and defenses)

Performances

(a) Availability.

(b) Security.

(c) Performance.

F.Baiardi – Security of Cloud Computing – Proof of Retrievability

Vanish Applications

Self-destructing data & Vanish support many applications

Example applications:

Firefox plugin

Included in our release of Vanish

Thunderbird plugin

Developed by the community two weeks after release ☺

Self-destructing files

Self-destructing trash-bin

…

Firefox Plugin For Vanishing Web Data

Encapsulate text in any text area in self-destructing VDOs

Conclusions

Two formidable challenges to privacy:

http://vanish.cs.washington.edu/

Data lives forever

Disclosures of data and keys have become commonplace

Self-destructing data empowers users with lifetime control

Vanish:

Combines global-scale DHTs with secret sharing to provide self-destructing data

Firefox plugin allows users to set timeouts on text data anywhere on the web

Vanish ≠ Vuze-based Vanish

Customized DHTs, hybrid approach, other P2P systems

Further extensions for security in the paper

Attacking Vanish

Defeating Vanish with Low-Cost Sybil Attacks Against Large DHTs

Scott Wolchok[1], Owen S. Hofmann[2], Nadia Heninger[3], Edward W. Felten[3],
J. Alex Halderman[1], Christopher J. Rossbach[2], Brent Waters[2], and Emmett Witchel[2]

[1]The University of Michigan
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[2]The University of Texas at Austin
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[3]Princeton University
{nadiah,felten}@cs.princeton.edu

September 18, 2009

The Sybil attack

One entity presents multiple identities for malicious intent.

Disrupt geographic and multi-path routing protocols by "being in more than one place at once" and reducing diversity.

Relevant in many context:

- P2P network
- Ad hoc networks
- Wireless sensor networks

Existing Work:
Is Preventing Sybil Attacks Possible?

John Douceur, Microsoft Research

"The Sybil Attack", IPTPS '01 (First International Workshop on Peer-to-Peer Systems (revised paper 2002))

named and introduced problem

strong negative theoretical results for networks without a centralized authority

Validation

Goal: accept all legitimate identities, but no counterfeits.

Verify identities:

- – Direct validation
- – Indirect validation

Direct validation

Validate the distinctness of two entities by asking them to perform task that one entity can not do:

If the communication resource is restricted, the verifier broadcasts a request for identities and then only accepts replies that occur within a given time interval.

If the storage resource is restricted, the verifier can challenges each identity to store large amount of unique data. The verifier verifies by keeping small excerpts of the data (sentinel).

If the computation resource is restricted, the verifier challenges each identity to solve a unique computational problem.

Direct validation

Assumption:

- all entities have identical resource constraints.
- all involved entities are verified simultaneously.

Extreme and unrealistic!

Indirect validation

Accept identities that have been validated by a sufficient count of other identities that it has already accepted.

Danger: a group of faulty entities can vouch for counterfeit identities.

Pluto Mail

- it enables users to

    – unsend, edit, and auto-expire sent emails to view when their emails are opene

    – use their existing email client and address

- it helps users reduce their online footprint, avoid email disasters

- it requires no downloads or plugins for either the sender or recipient.