



Security of Cloud Computing

Fabrizio Baiardi
f.baiardi@unipi.it



Syllabus

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

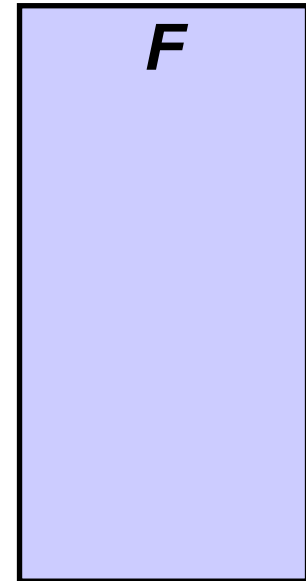
Introduction



- 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



- 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



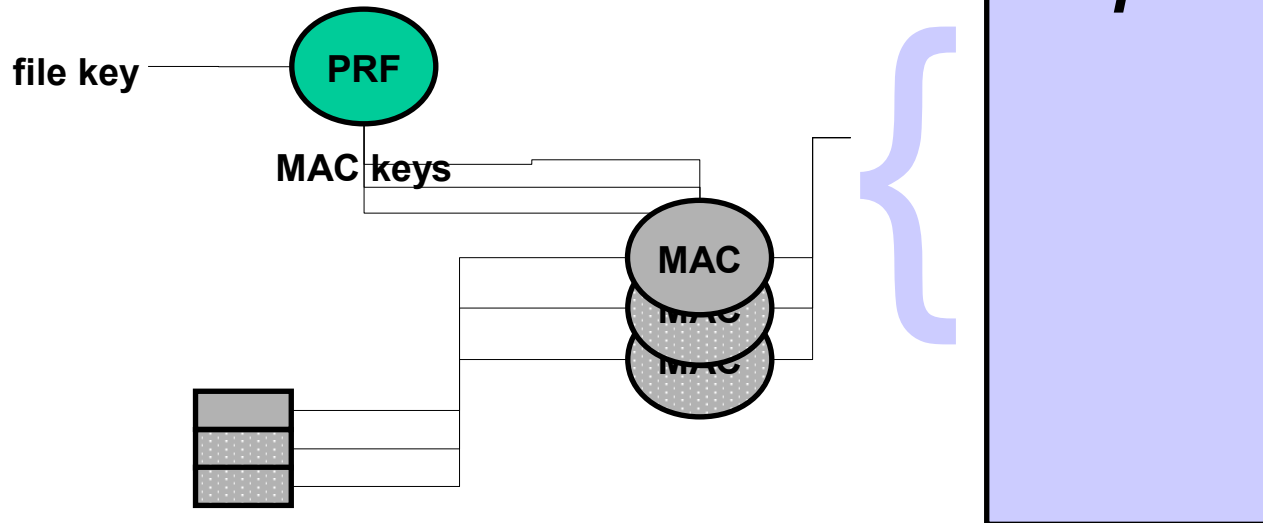
Proofs of Posses Retrievability

- 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



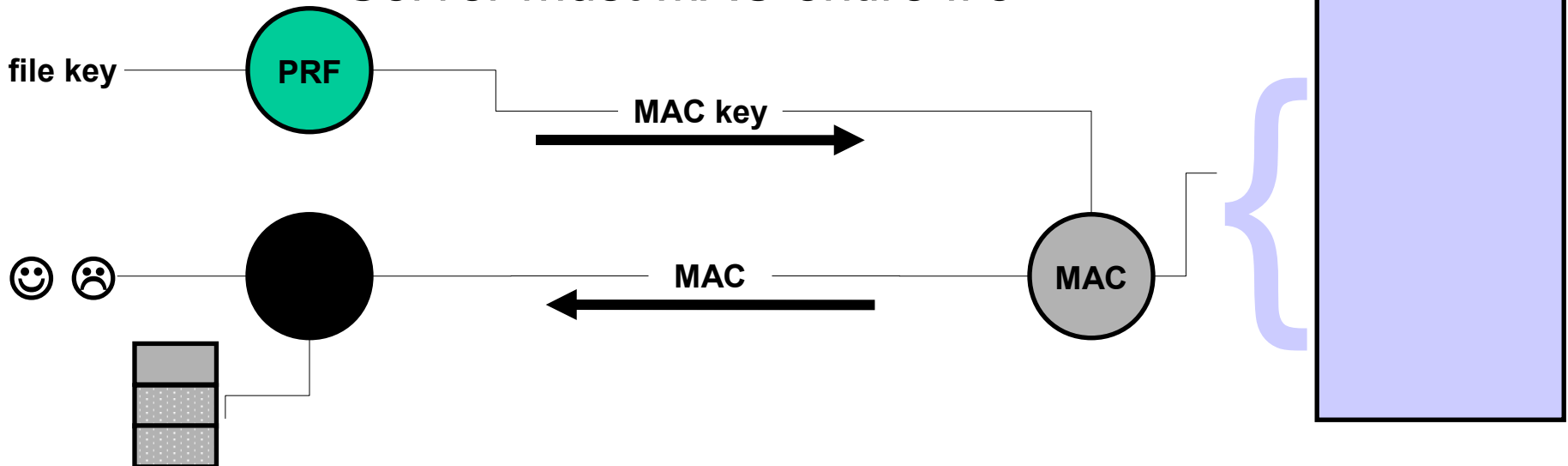
- MAC file with different keys, try one at a time



Simple Approach, cont'd



- MAC file with different keys, try one at a time
- # runs limited by client storage
- Server must MAC entire file



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

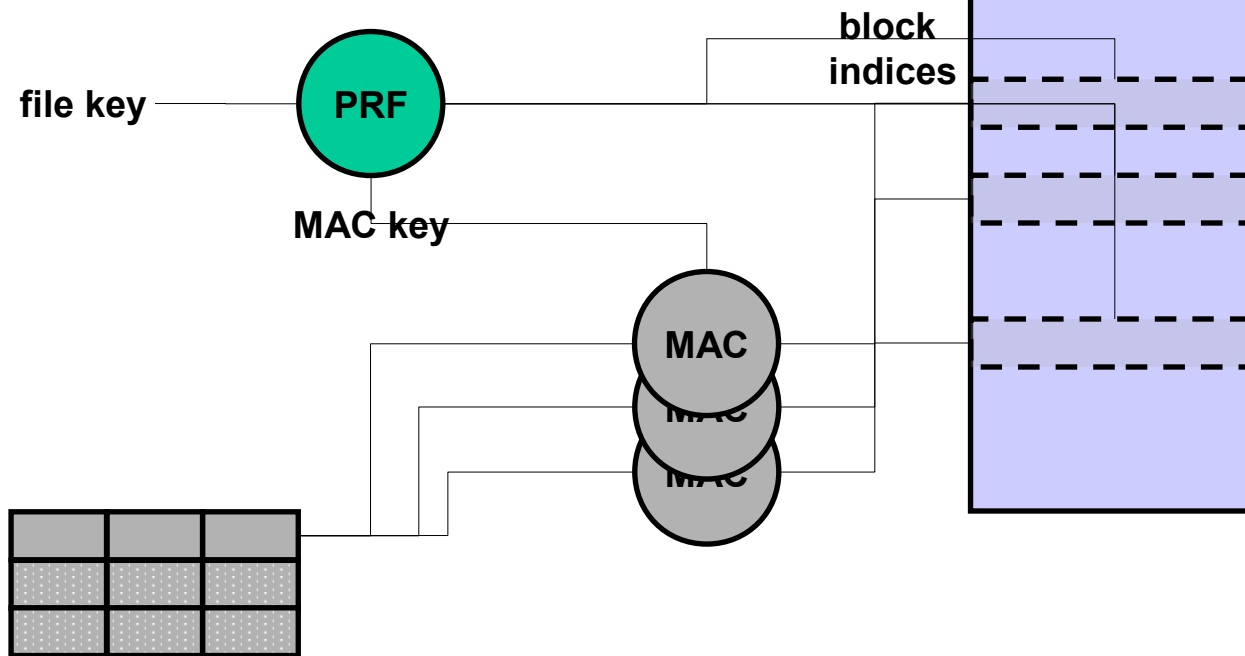
$$P_{esc} = \left(1 - \frac{m}{d}\right)^r$$

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

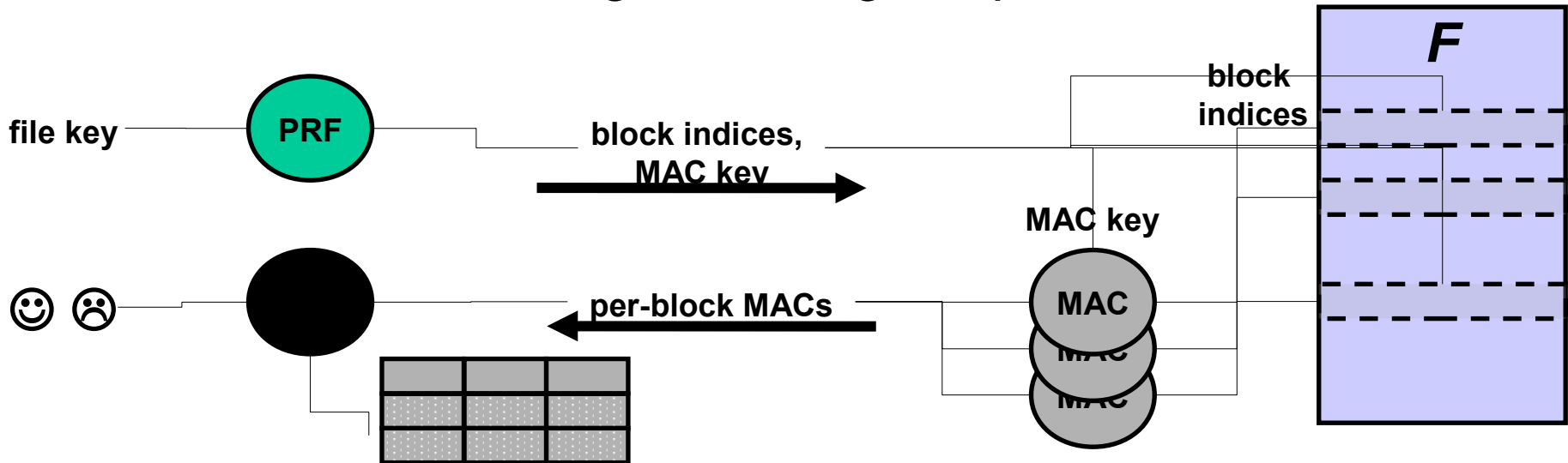
- MAC selected blocks, and sample q



Per-Block MACs, cont'd



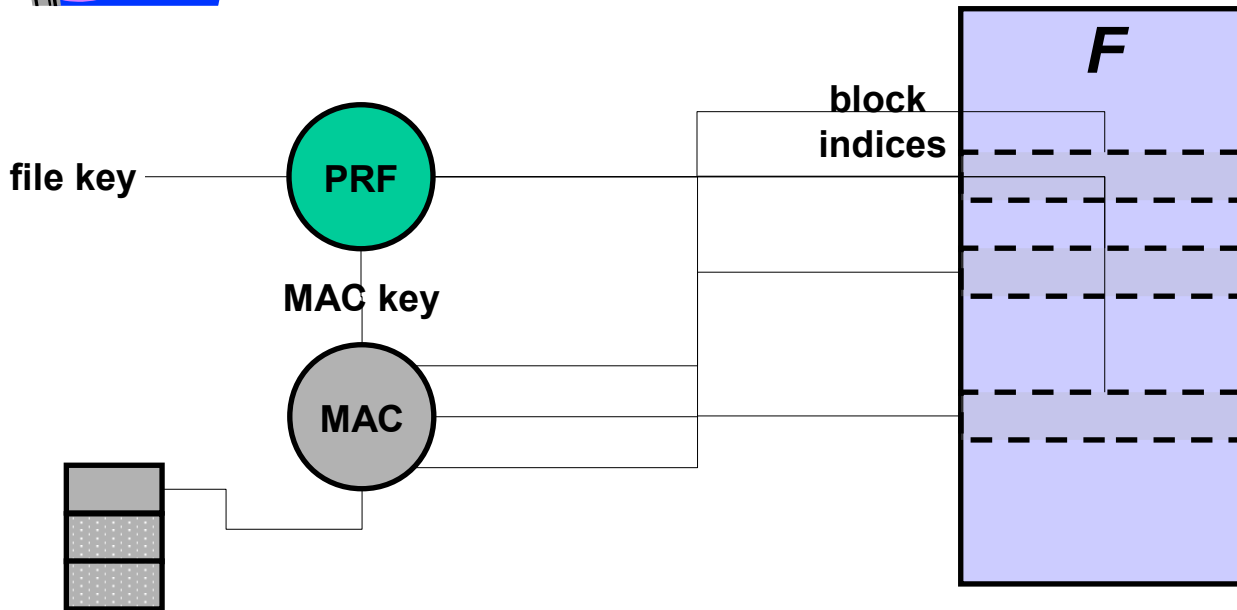
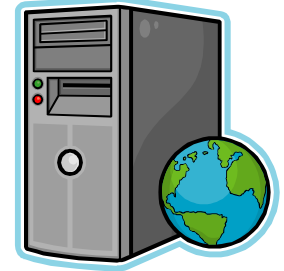
- MAC selected blocks, and sample q
- Server work now only q MACs / run
- But message exchange $\sim q$



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

Group MACs

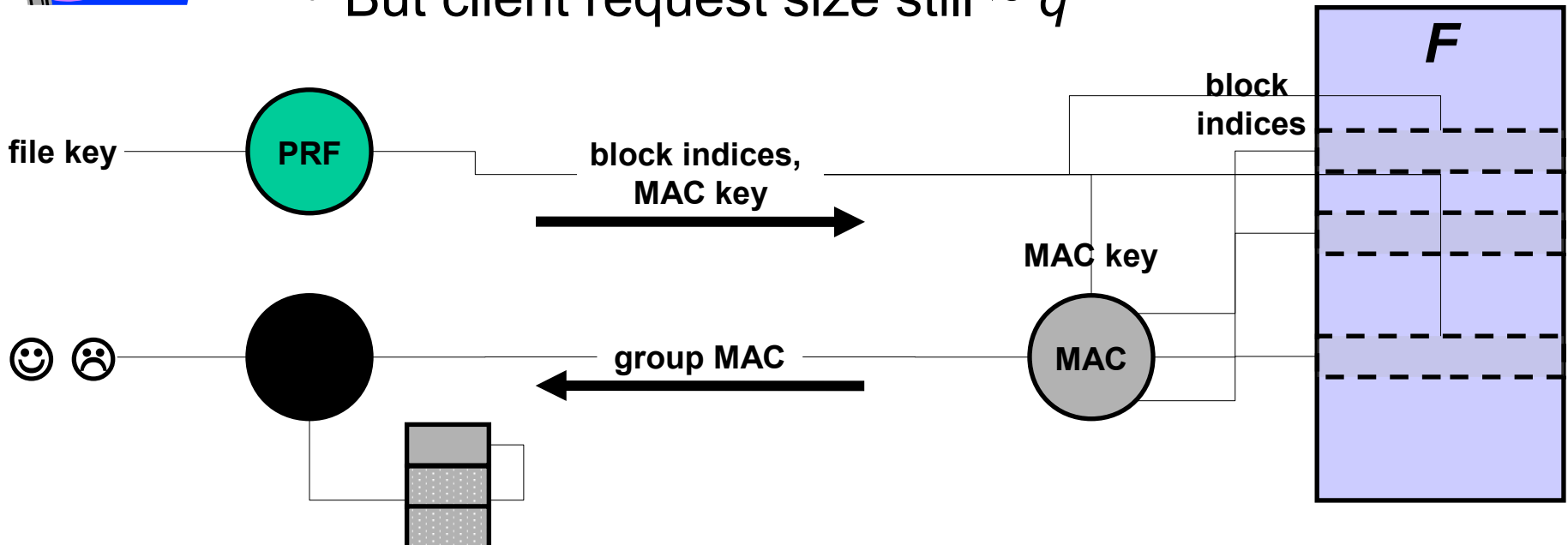
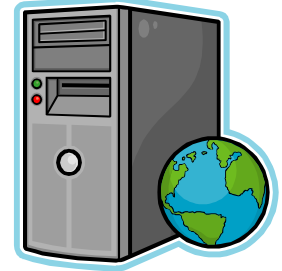
- MAC group of sampled blocks



Group MACs, cont'd

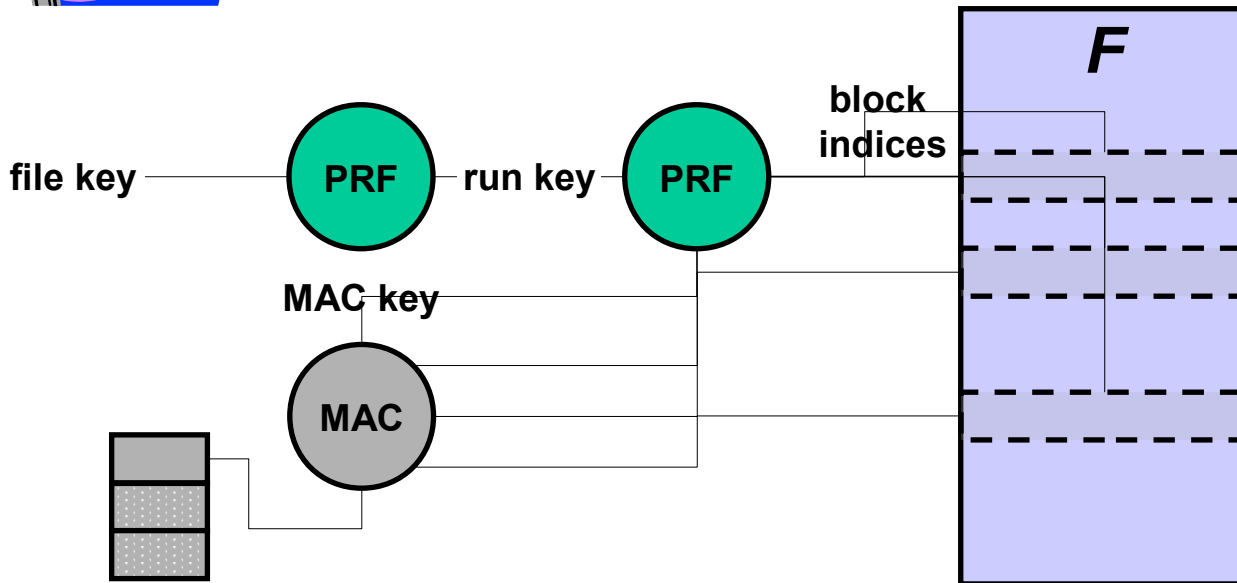
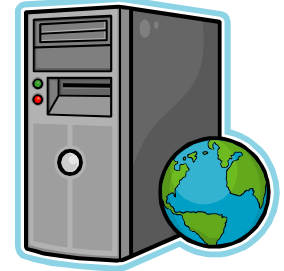


- MAC group of sampled blocks
- Server response now constant size
- But client request size still $\sim q$



Index Derivation

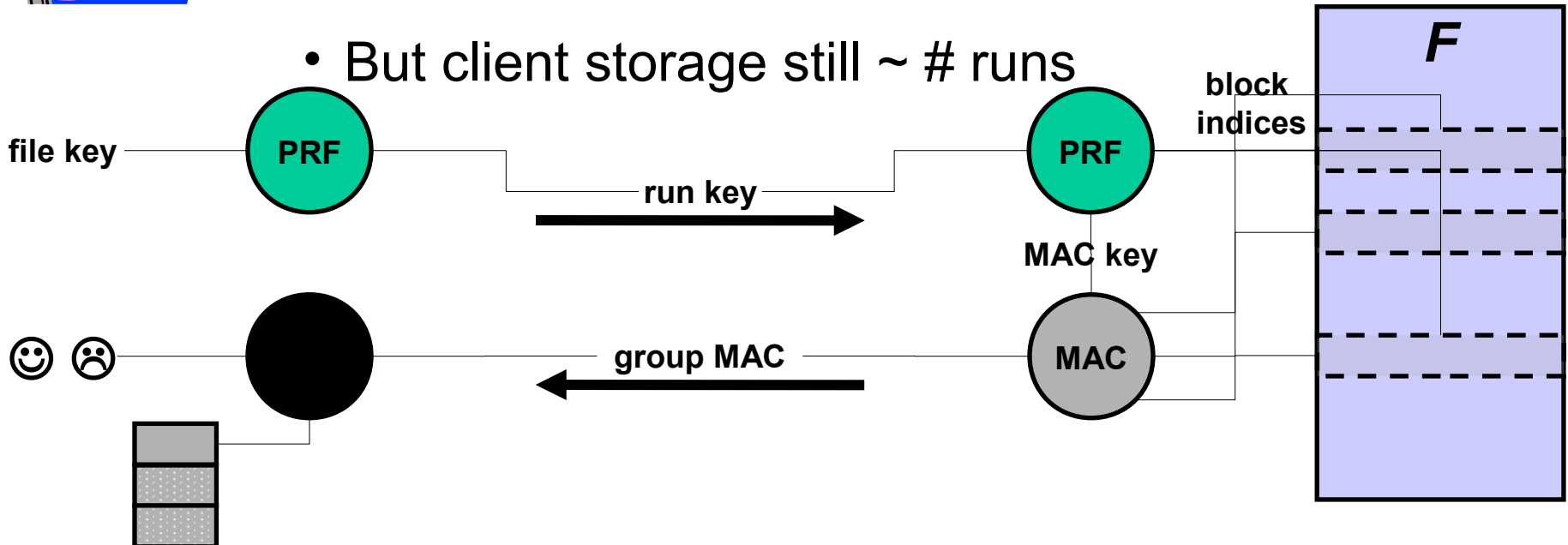
- Derive block indices from *run key*



Index Derivation, cont'd

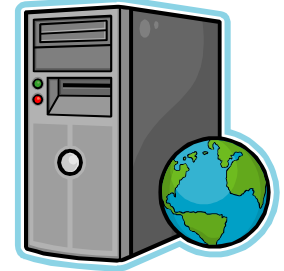
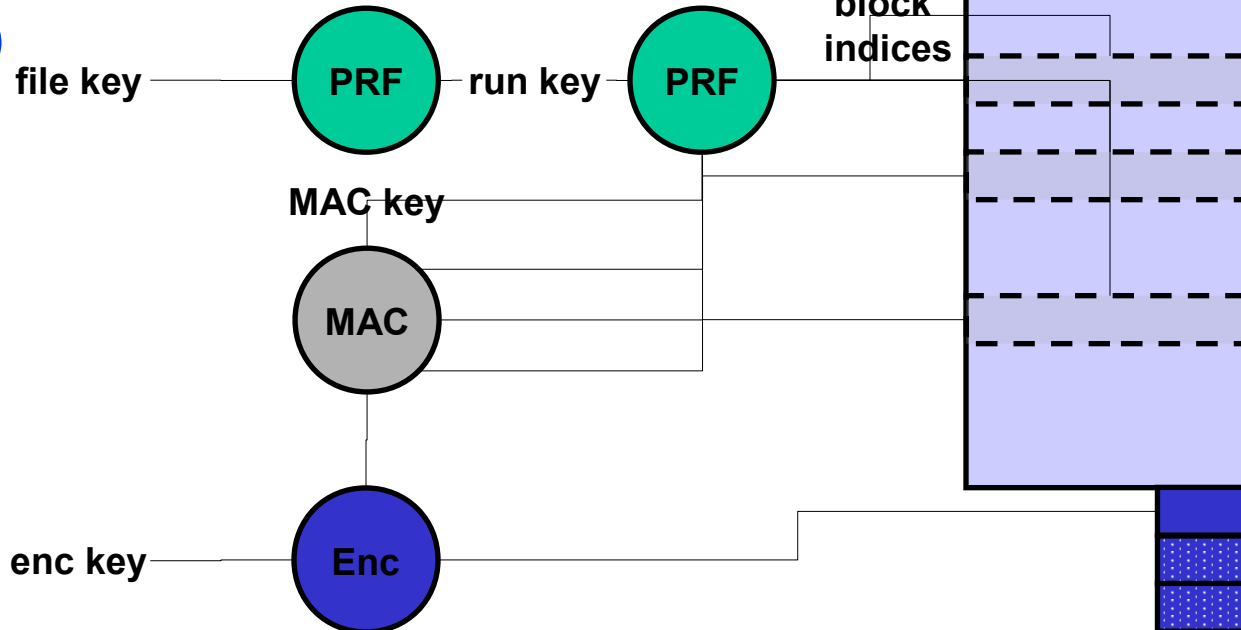


- Derive block indices from run key
- Both message exchanges now constant size
- But client storage still $\sim \#$ runs



Server Storage of Encrypted MACs

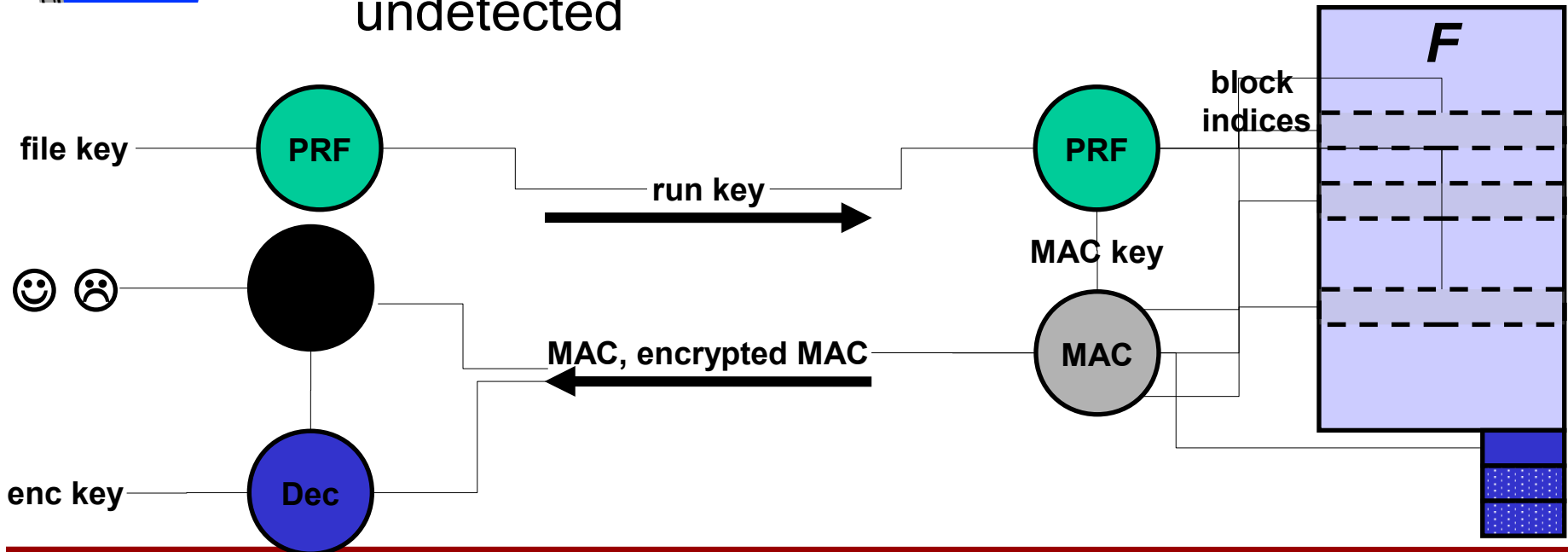
- Encrypt group MACs, store on server



Server Storage of Encrypted MACs, cont'd



- Encrypt group MACs, store on server
- Client storage now constant
- But small error rate ($< \epsilon$) may go undetected





Recovering from Errors

MAC sampling detects server error rate $\geq \varepsilon$ with high probability

Smaller error rate ($< \varepsilon$) 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



Homomorphic encryption = Holy grail of encryption

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

b) E is

– **Additively homomorphic if**

$$E(a+b) = \text{PLUS}(E(a), E(b))$$

– **Multiplicatively homomorphic if**

$$E(a \times b) = \text{MULT}(E(a), E(b))$$

– **Mixed-multiplicatively homomorphic**

$$E(xy) = \text{Mixed-mult}(E(x), y)$$

– *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



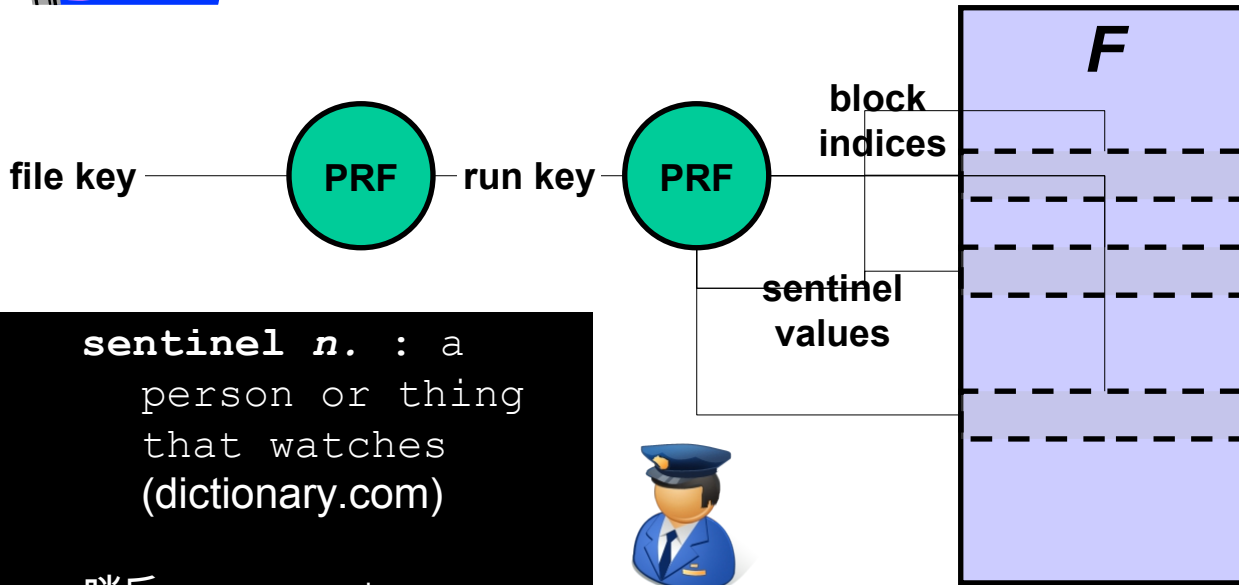
Sentinels – Another Approach

- 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



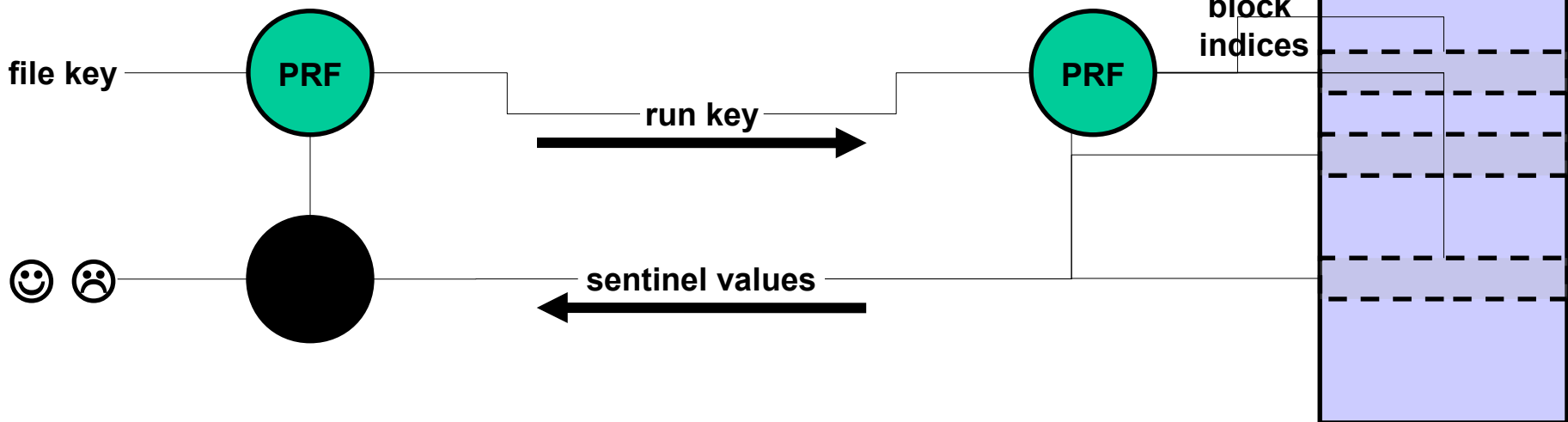
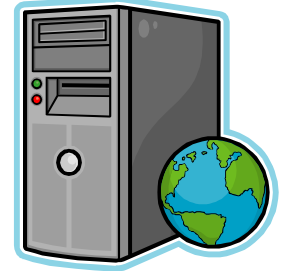
sentinel *n.* : a person or thing that watches (dictionary.com)

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





Theoretical Considerations

- Proof of retrievability is a protocol for demonstrating that a party possesses a file
 - Successful verification \leftrightarrow 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

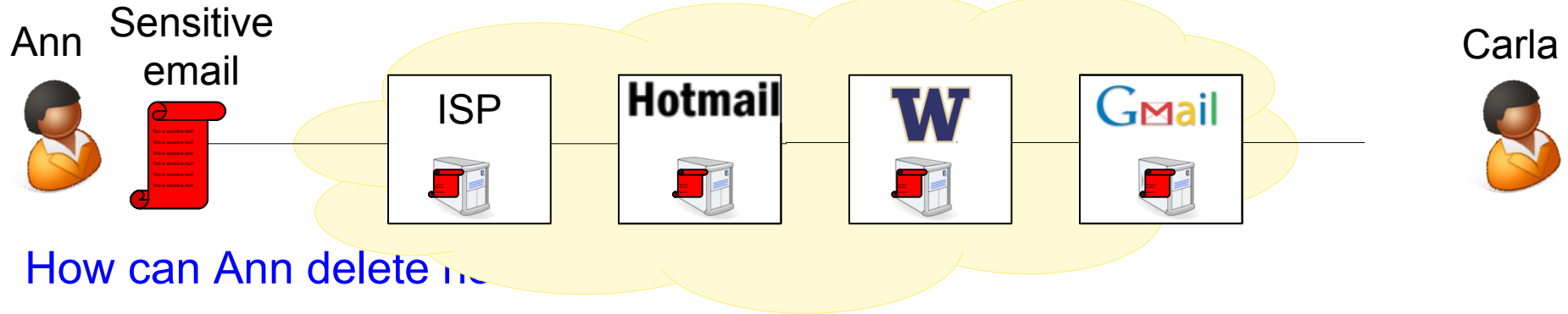
- How can you be sure that data in the cloud has been erased?
- In general you cannot be sure if the data has been collected or created on the cloud
- But there are other solutions when data has been created outside and then stored in the cloud

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



How can Ann delete it?

She doesn't know where all the copies are

Services may retain data for long after user tries to delete

ars
ars technica

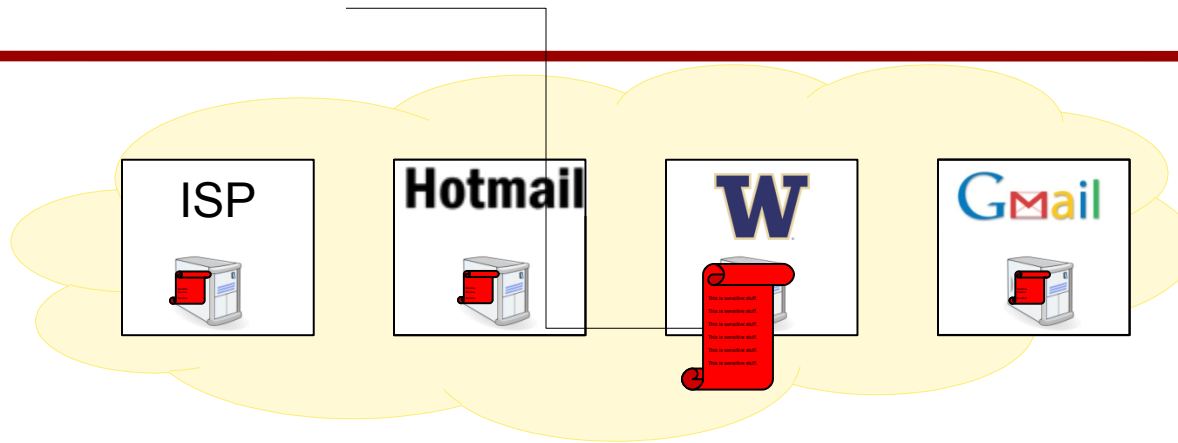
Last updated July 3, 2009

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



Carla



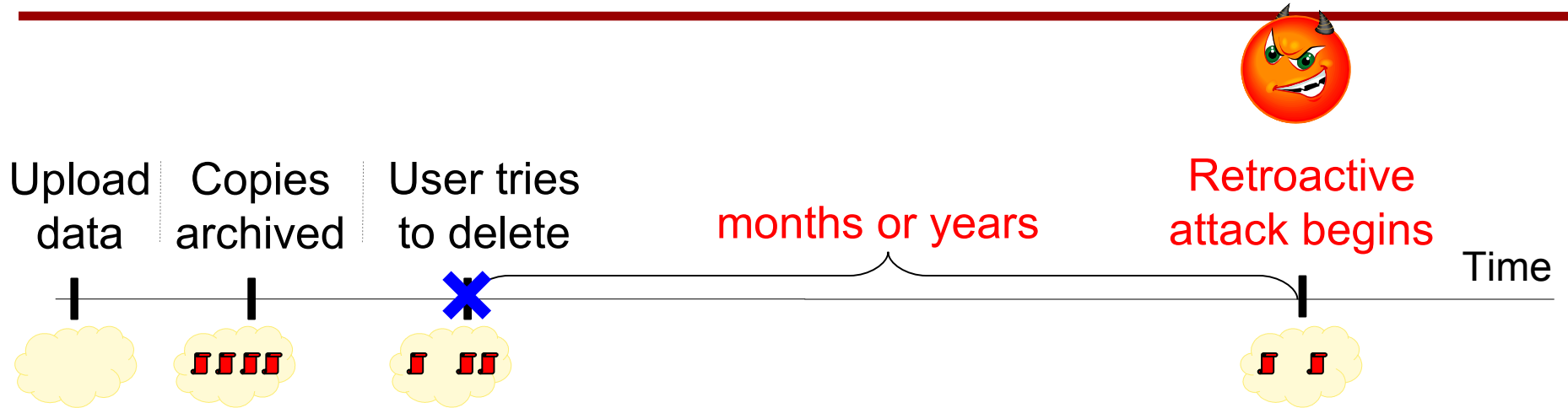
Some time later...

Subpoena,
hacking, ...

**Retroactive attack
on archived data**

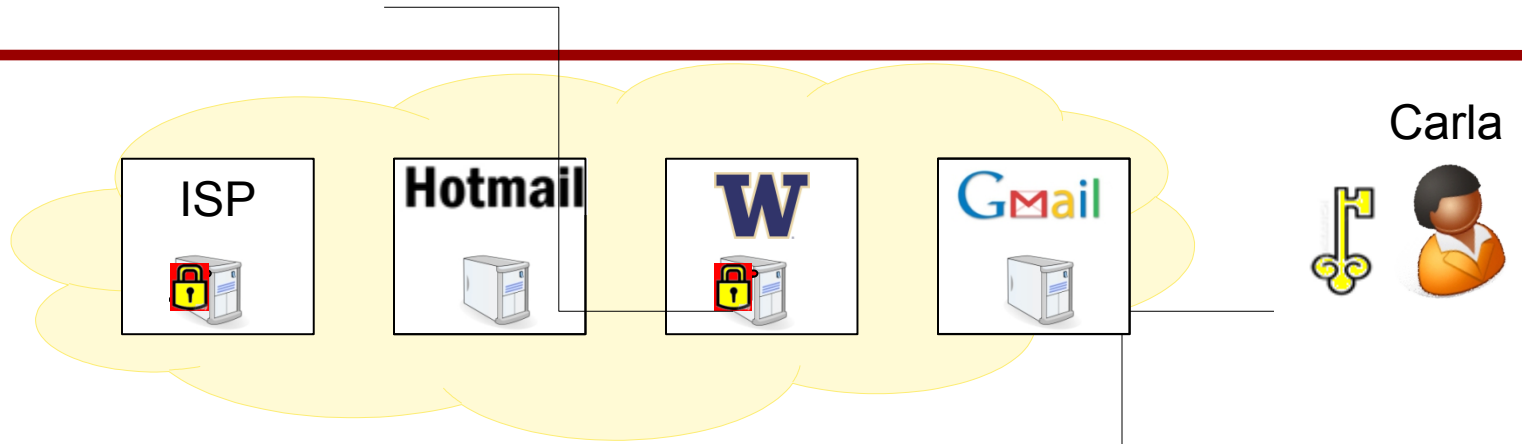


The Retroactive Attack



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

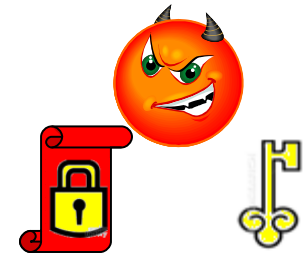
Ann



Carla

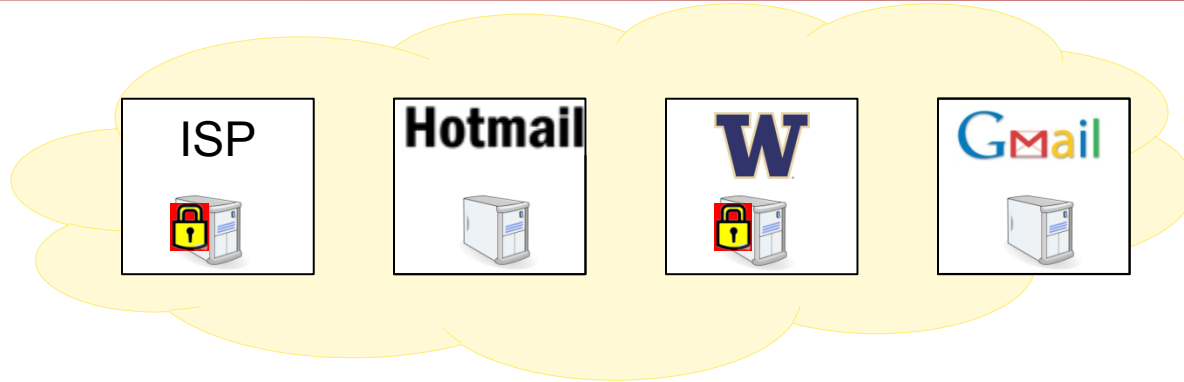


Subpoena,
hacking, ...



Why Not Use a Centralized Service?

Ann



Carla



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

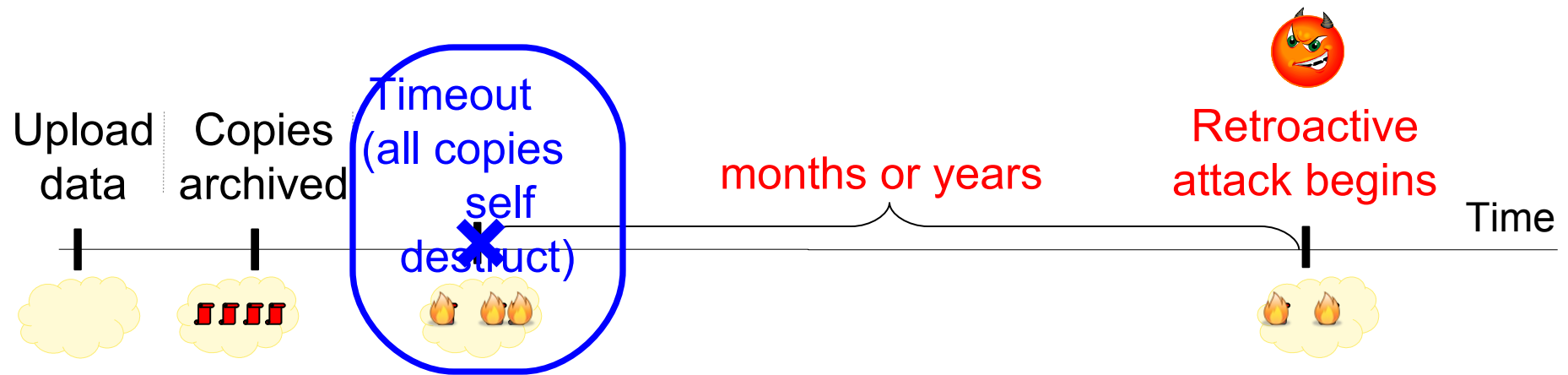
Carelessness

Question:

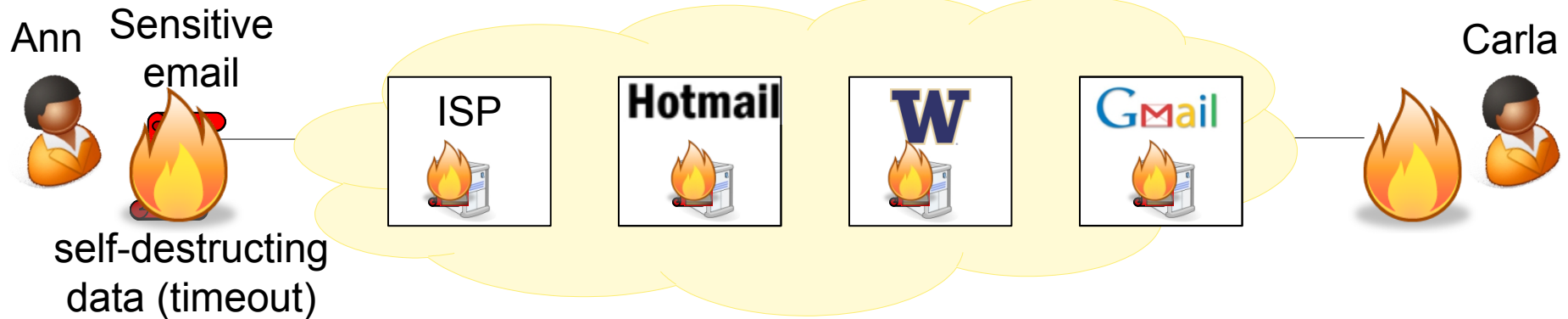
Can we empower users with control of data lifetime?

Answer:

Self-destructing data



Self-Destructing Data Model



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

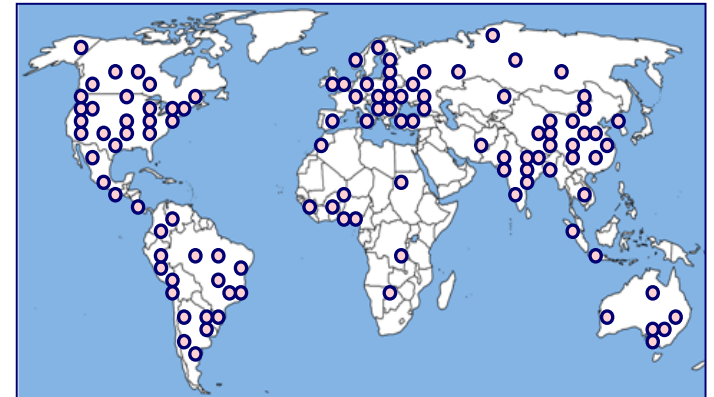
...

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

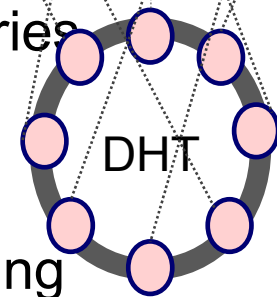
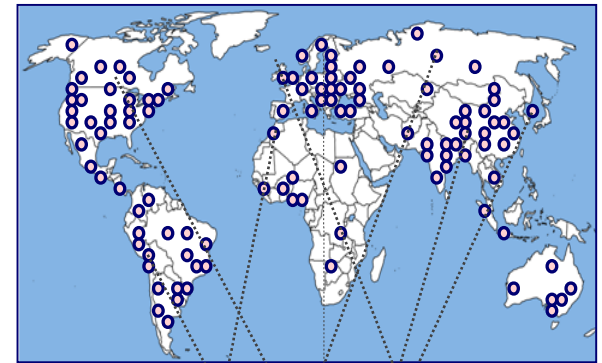
DHTs are part of many file sharing systems:

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



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 , $i=1, \dots, n$;
 - c) generates random $a_i \in Z_p$, $i=1, 2, \dots, t-1$;
 - d) $a_0 = K$, the secret;
 - e) $f(x) = \sum_{i=0}^{t-1} a_i x^i \pmod p$;
 P_i 's share is $(x_i, f(x_i))$.
-

How Vanish Works: Data Encapsulation

Ann



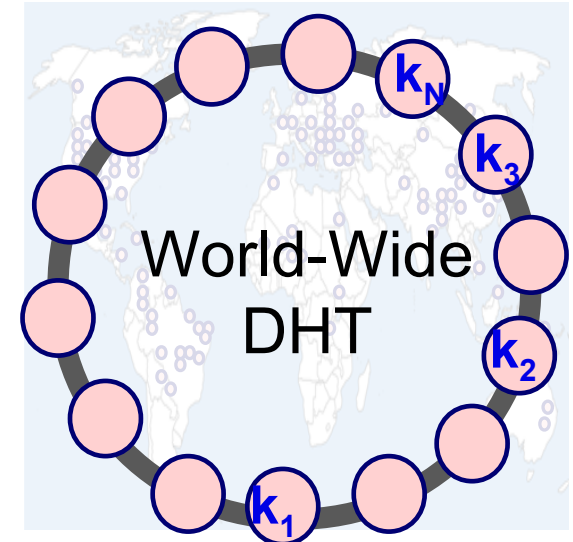
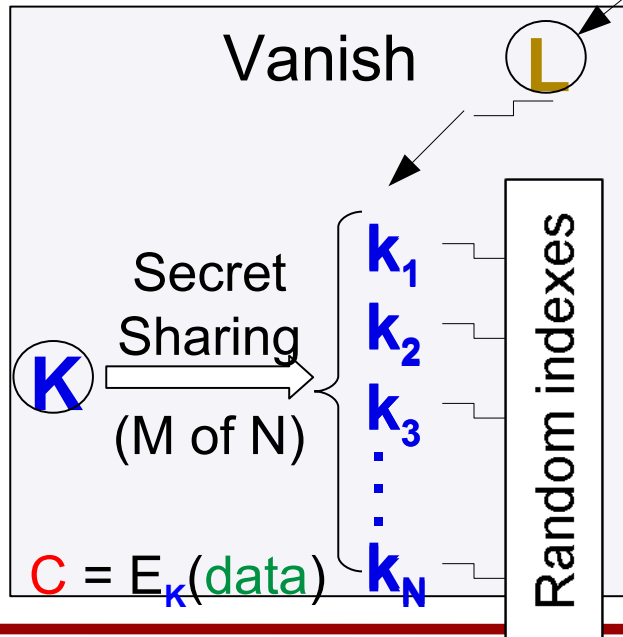
$$\text{VDO} = \{C, L\}$$

Carla



Encapsulate Vanish Data Object
(data, timeout) $\text{VDO} = \{C, L\}$

Access key



How Vanish Works: Data Decapsulation

Ann



$$\text{VDO} = \{C, L\}$$

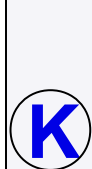
Carla



Encapsulate (data, timeout) Vanish Data Object
 $\text{VDO} = \{C, L\}$

Decapsulate (VDO = {C, L}) data

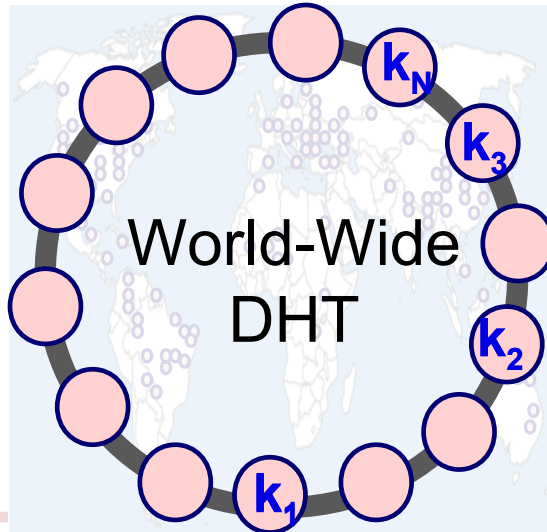
Vanish



Secret Sharing
 (M of N)

$$C = E_K(\text{data})$$

Random indexes



Computing – Proof of Retrievability



Vanish

Random indexes

X
 ...

Secret Sharing
 (M of N)



$$\text{data} = D_K(C)$$

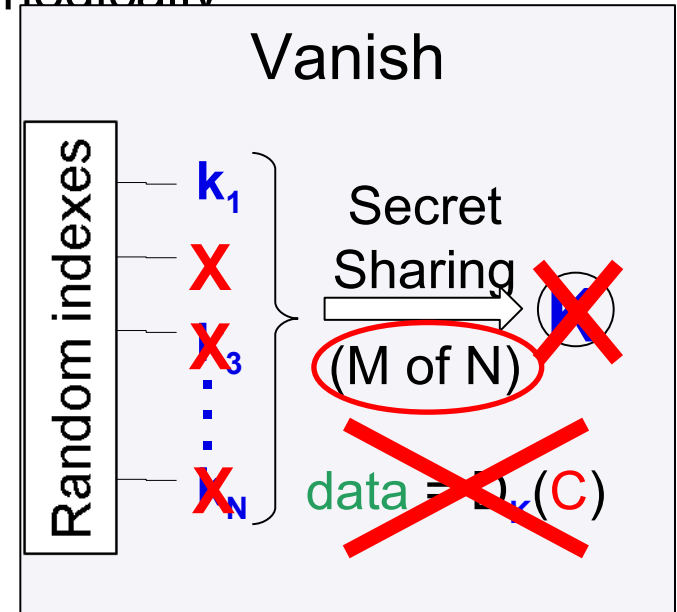
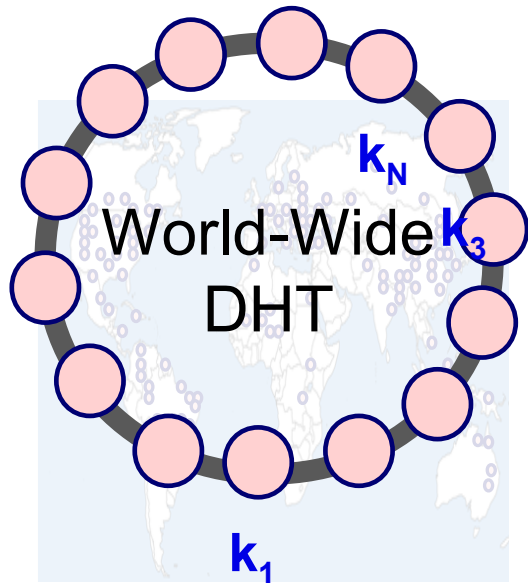


How Vanish Works: Data Timeout

The DHT loses key pieces over time

Natural churn: nodes crash or leave the DHT

Built-in timeout: DHT nodes purge data periodically



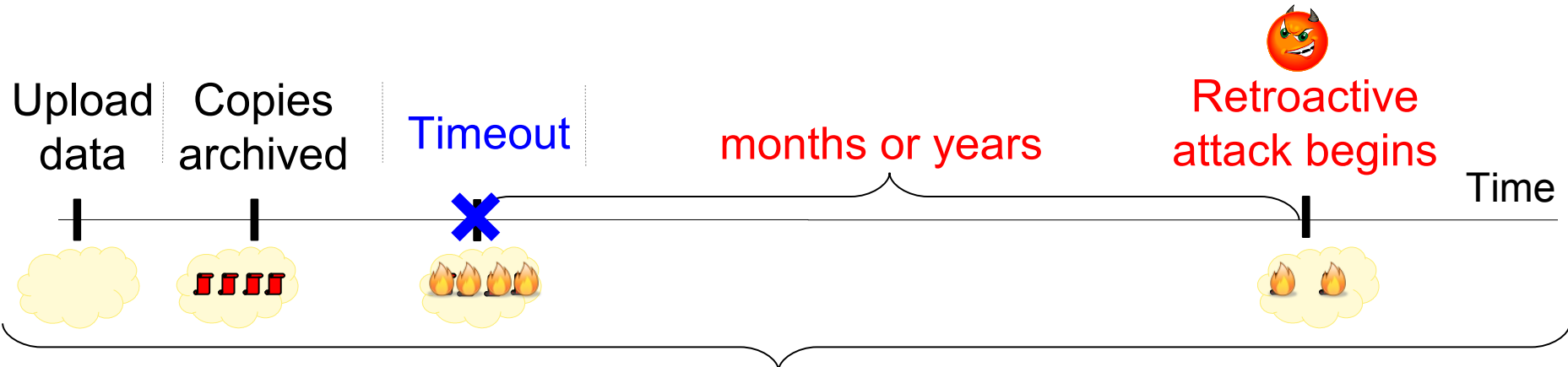
Key loss makes all data copies permanently unreadable

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

Pre-computation

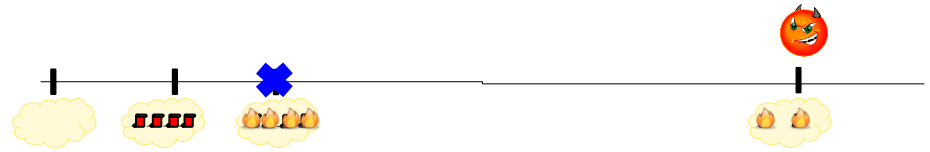


Attack Analysis

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

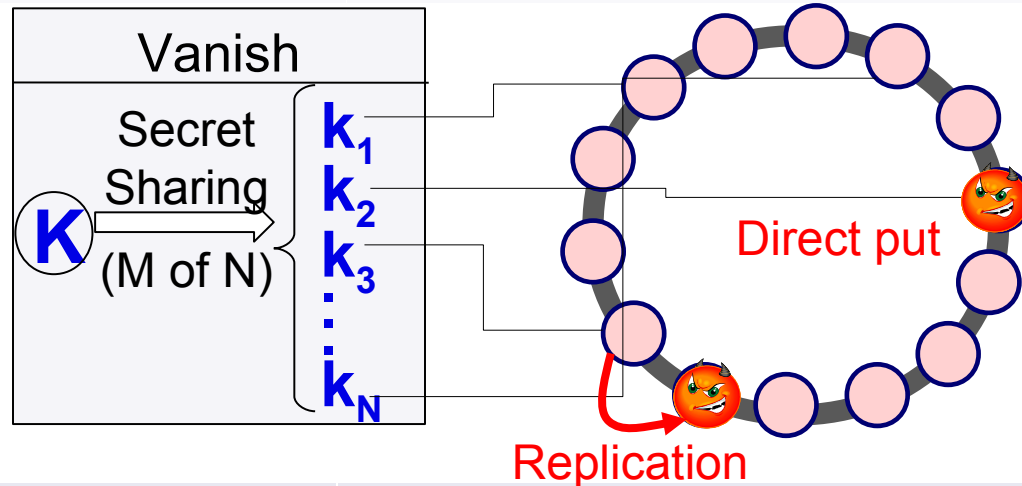


Attack

Obtain data by legal means (e.g., subpoenas)

Defense

P2P properties: constant evolution, geographic distribution, decentralization



Capture any key pieces from the DHT (pre-computation)

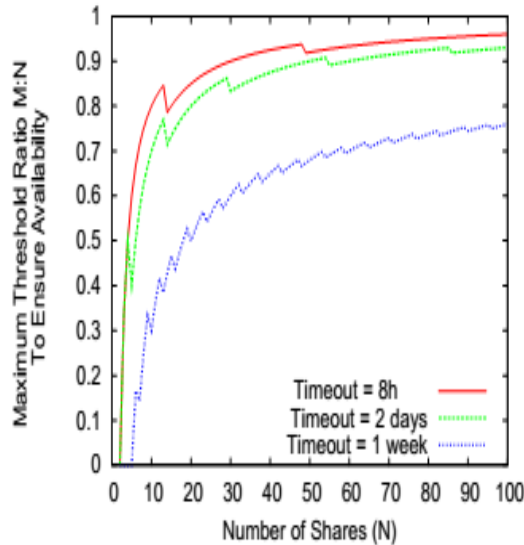
P2P property: huge scale

Given the huge DHT scale, how many nodes does the attacker need to be effective?

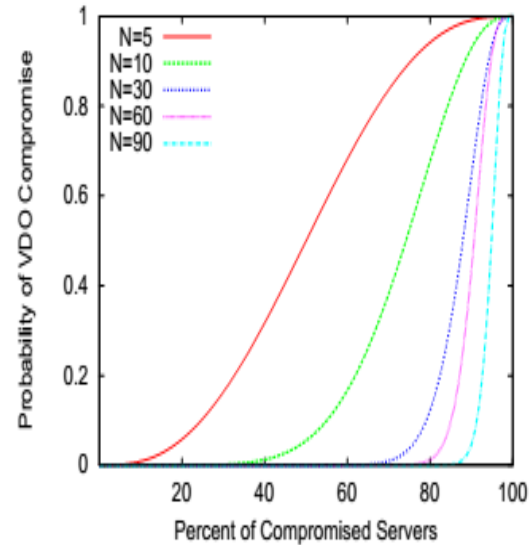
Current estimate: Attacker must join with ~8% of DHT size, for 25% capture

There may be other attacks (and defenses)

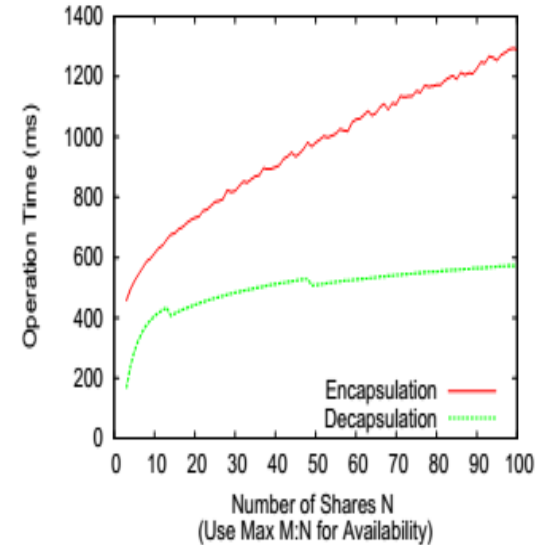
Performances



(a) Availability.



(b) Security.



(c) Performance.



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

Effect:

Vanish empowers users with seamless control over the lifetime of their Web data

The screenshot shows a Gmail 'Compose Mail' window in Mozilla Firefox. The 'Vanish Test' status is set to 'Set status here'. The message content includes a 'Need your advice' header, a sender 'Ann Gerol', and a self-destructing VDO. The VDO text is as follows:

```
-----BEGIN VANISH MESSAGE-----
Use http://vanish.cs.washington.edu to read this message.
This message will self destruct at Sun, 05 Jul 2009 06:21:18
GMT

AKztAAVzcgBGZWR1Lndhc2hpblm
d0b24uY3MudmbAgACsgAMZXBvY
2hWR1Lndhc2hpblmd0b24uY3Mud
mFuaXNoLmludGVybmFsLm1ldGF
kYXRhLmltcGwusW5kaXJlY3RlZ
XNlZXRhZGF0YUltcGw6b24uY3M
f7Q1AAsAEmVuY3J3cHRlZl9kY
XRhX2tleXQAAltCTAAIbWV0YWR
hdGFxAH4AAxhwCHNyAEFhZHUud
2FzaGluz3Rvbi5jcy52YW5pc2g
uaW50ZXJ0eWwubWV0YWRhdGEua
W1wbC5CYXNpY01ldGFKYXRhSW1
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XRpb25fc2VlZEwABnBhcmFtc3Q
ANl0ZlJld2FzaGluz3Rvbi9jc
y92YW5pc2gvaW50ZXJ0eWwvbWV
0YWRhdGEvVkrPUGFyYW1z03hwc
sCcB1ldGFKYXRhLlZET1BhcmFt
c7292Mmle6MAGAlSgALY3JlYX
Rpb25fdHJABVlbnNyeXB0aW9u
X2tleV9sZW5ndGhJAaodW1f2
```




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 \neq 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 Wolchok¹, Owen S. Hofmann², Nadia Heninger³, Edward W. Felten³,
J. Alex Halderman¹, Christopher J. Rossbach², Brent Waters², and Emmett Witchel²

¹The University of Michigan
{wolchok,halderman}@umich.edu

²The University of Texas at Austin
{rossbach,bwaters,witchel}@cs.utexas.edu

³Princeton 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.



Vanishing mail

Pluto Mail

- it enables users to
 - unsend, edit, and auto-expire sent emails to view when their emails are opened
 - 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.