Security of Cloud Computing

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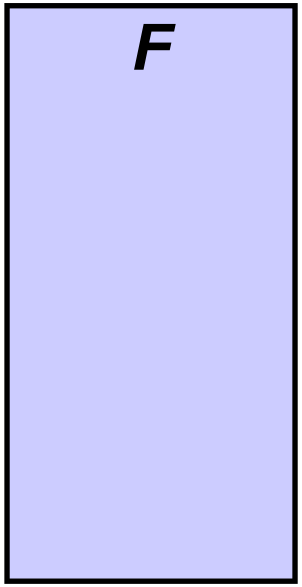
Syllabus

- 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*



- 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

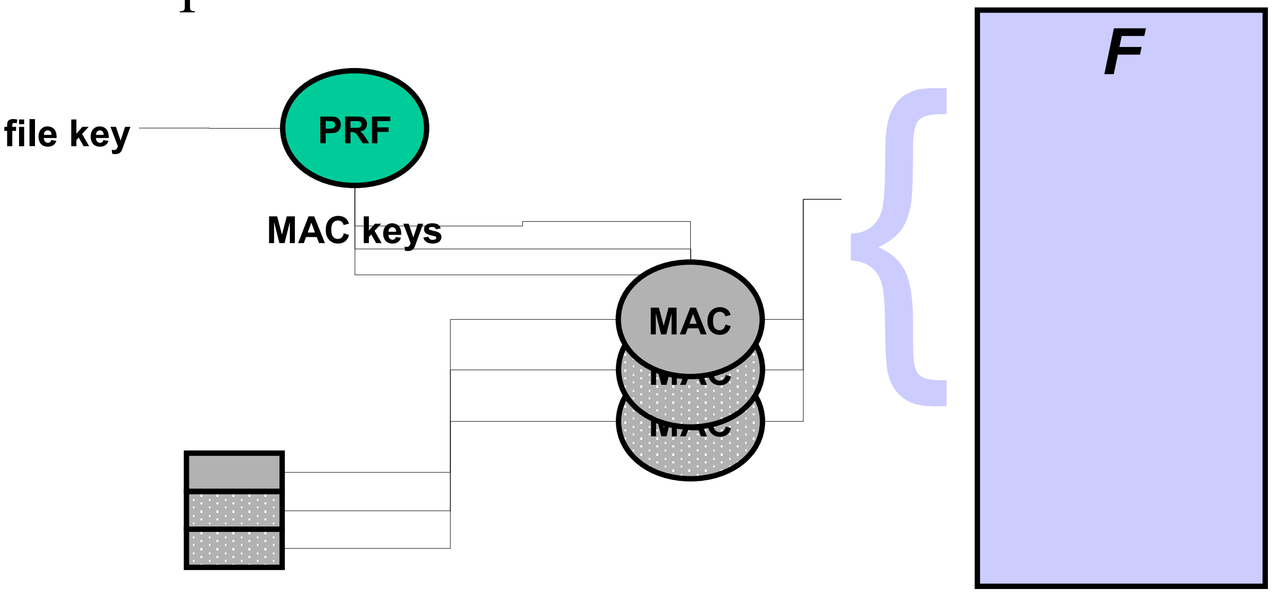
Proofs of Possess - Retrievability

- 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

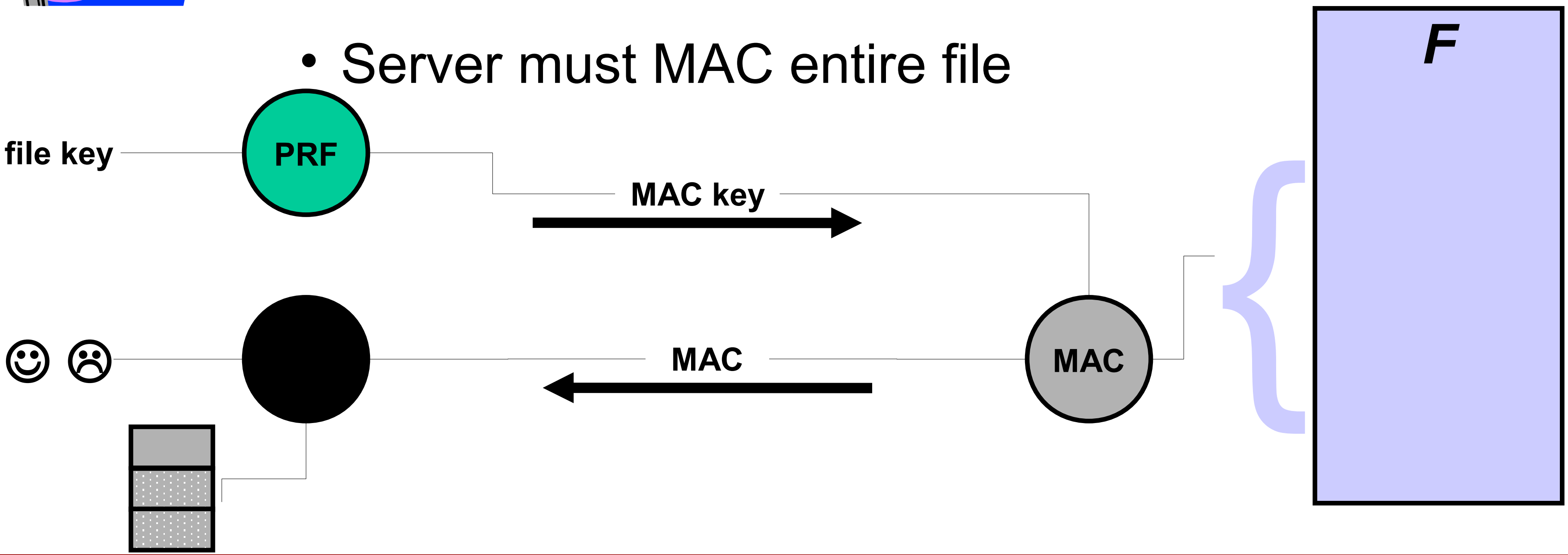
- MAC file with different keys, try one at a time

pseudo random function



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

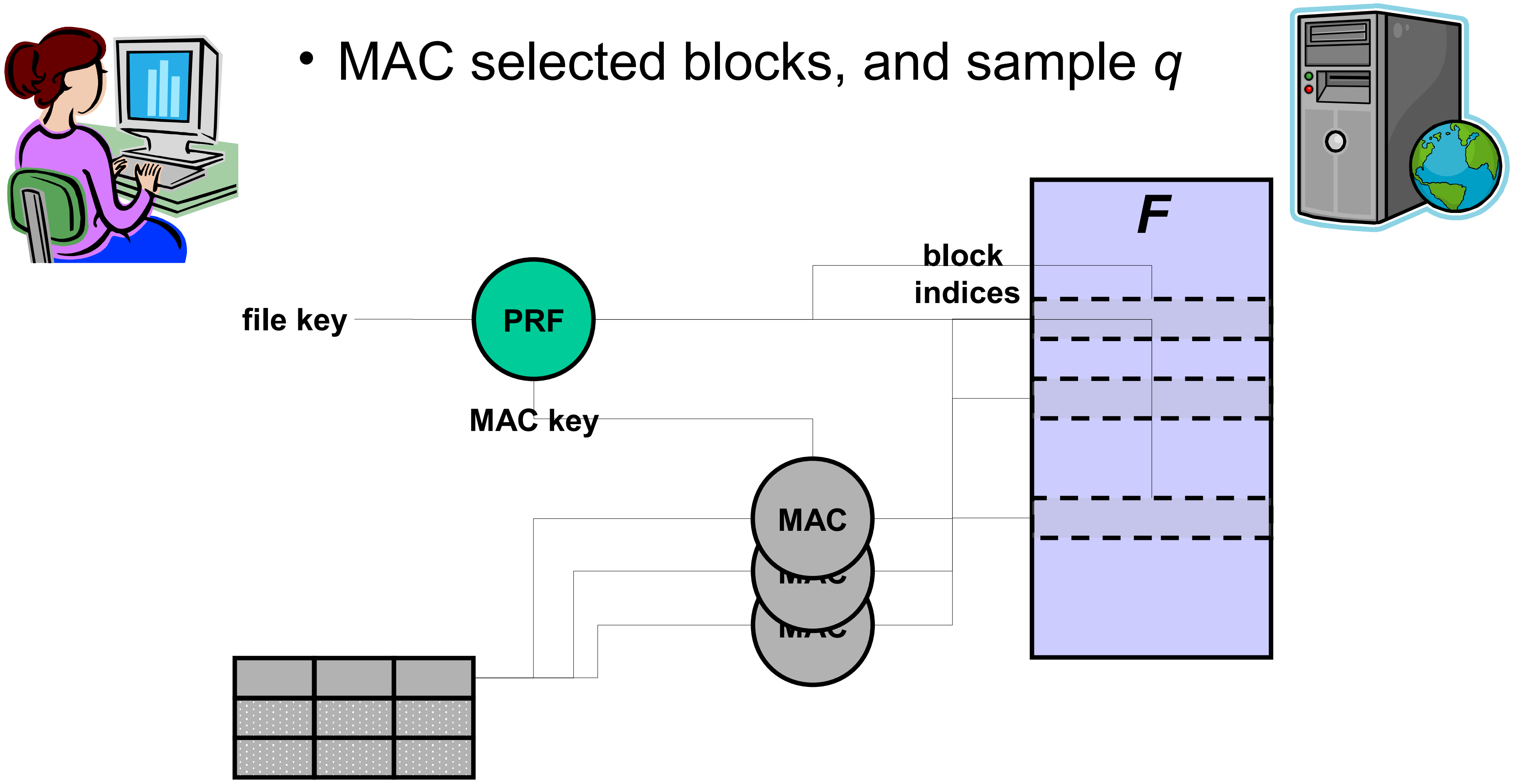
$$P_{esc} = \left(1 - \frac{m}{d}\right)^r$$

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

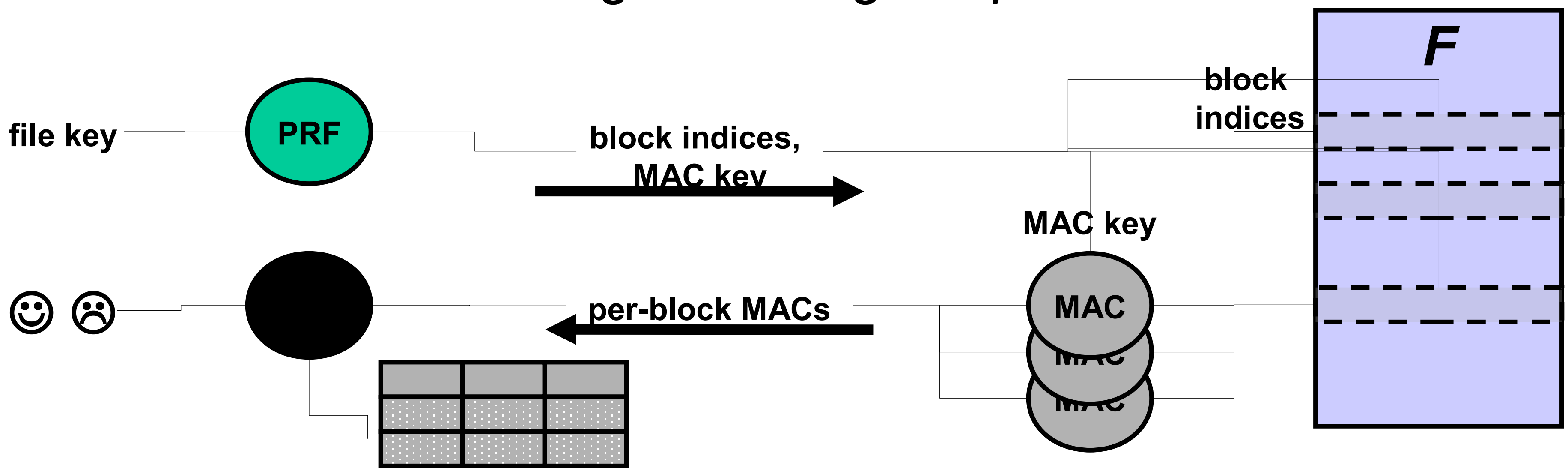
Per-Block MACs

- MAC selected blocks, and sample *q*



Per-Block MACs, cont'd

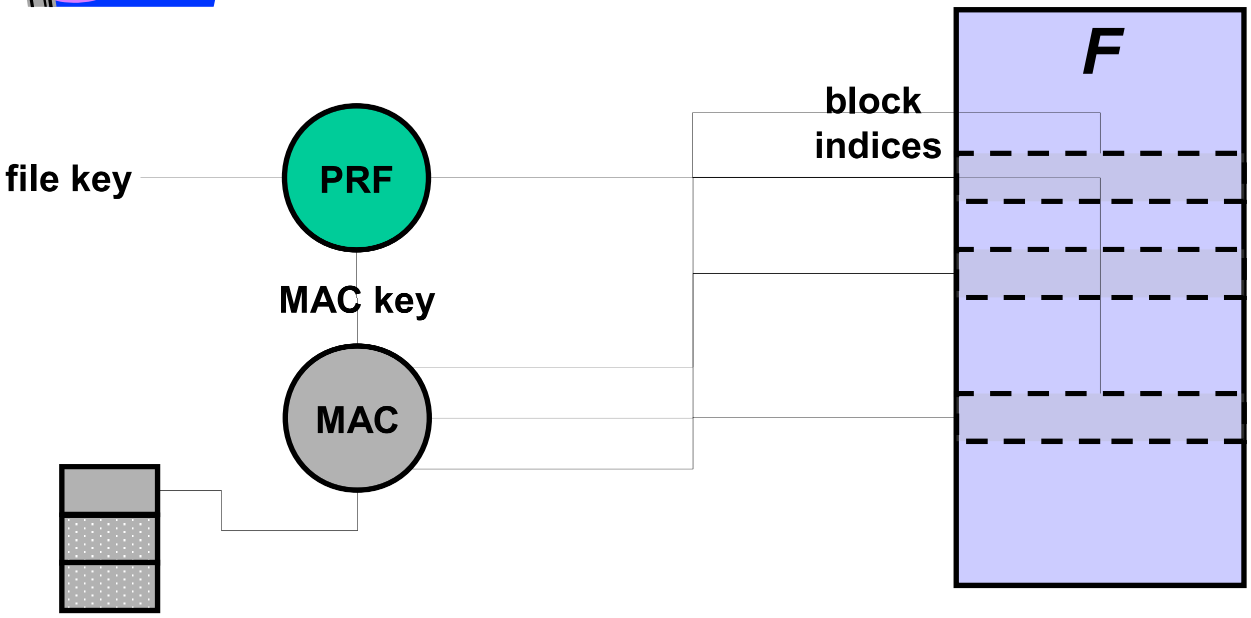
- MAC selected blocks, and sample *q*
- Server work now only *q* MACs / run
- But message exchange ~ *q*



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

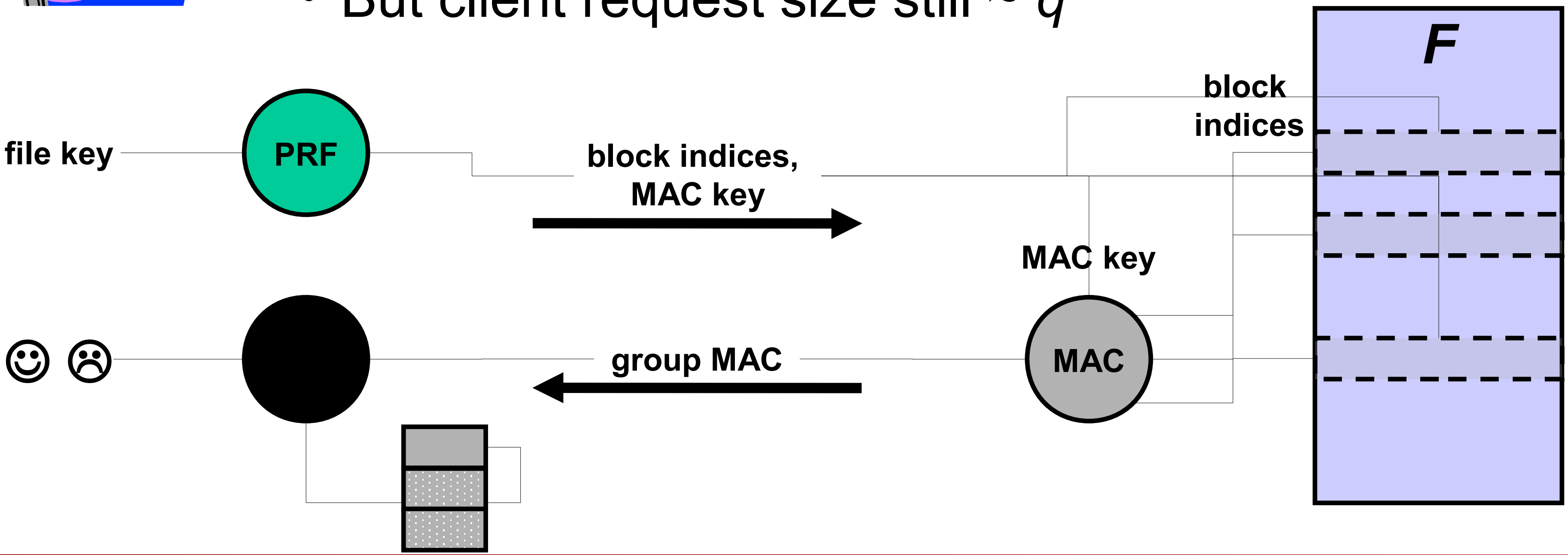
Group MACs

- MAC group of sampled blocks



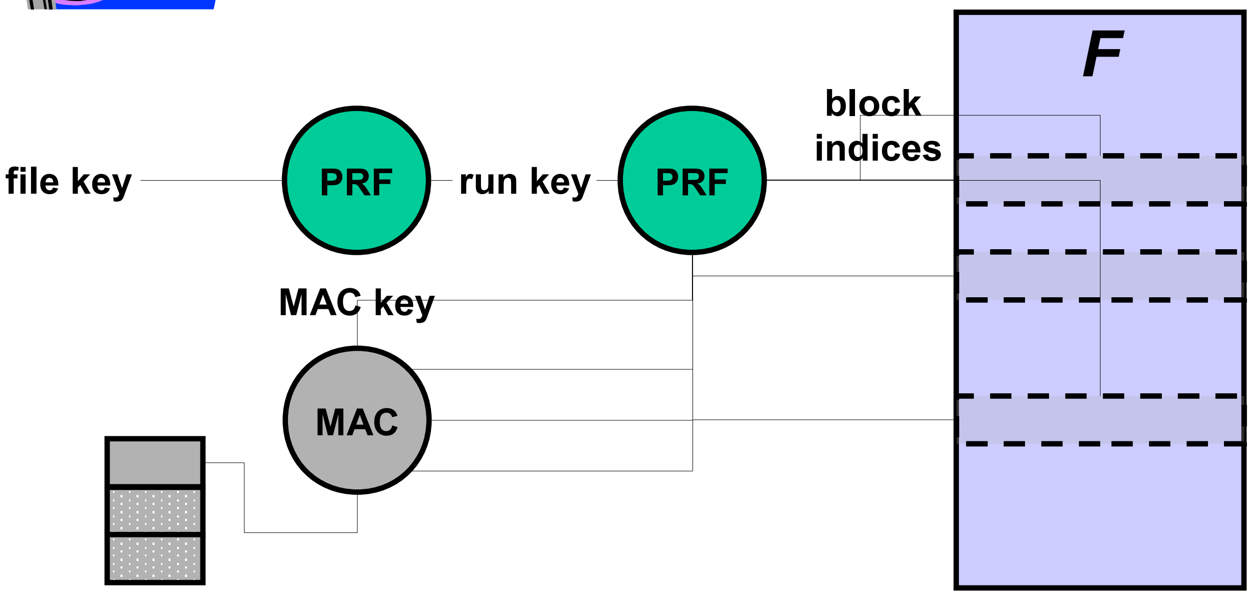
Group MACs, cont'd

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



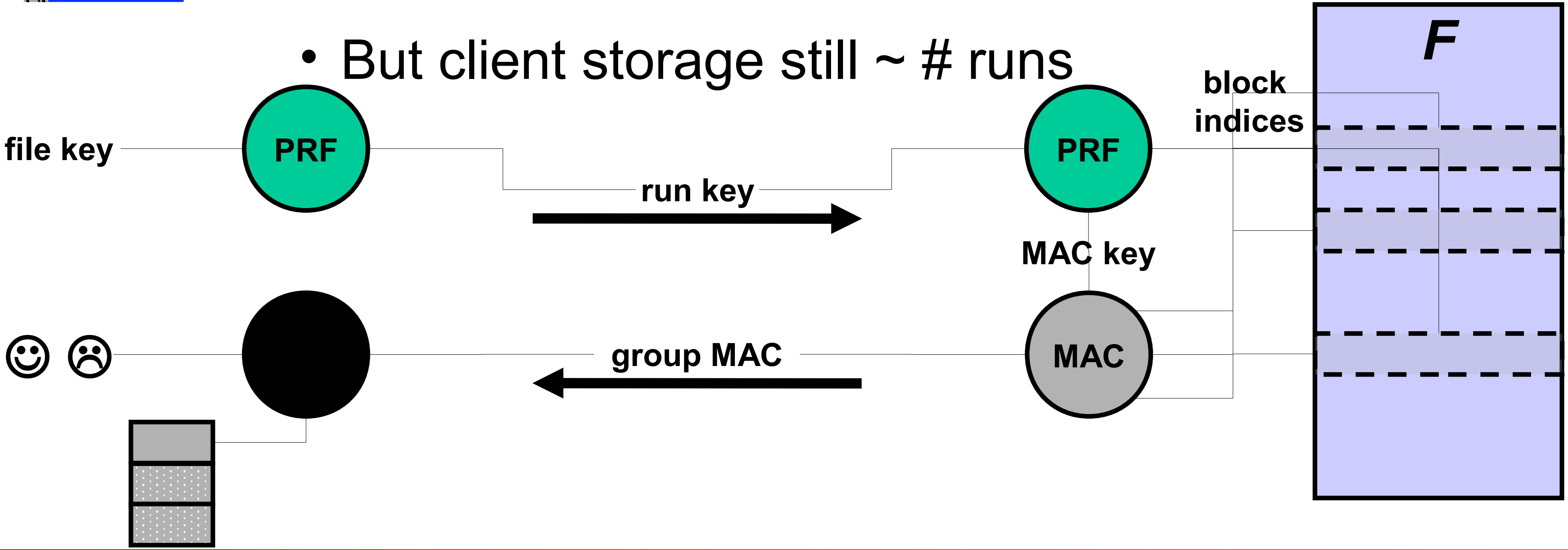
Index Derivation

- Derive block indices from *run key*



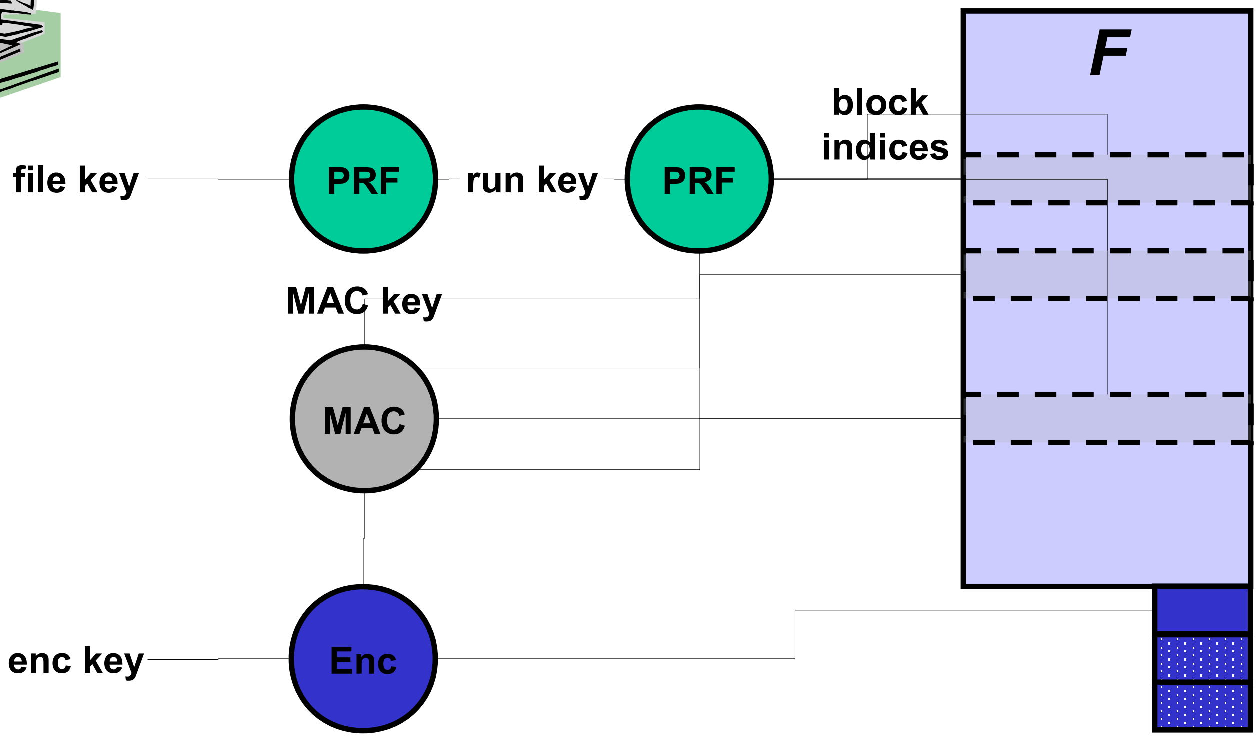
Index Derivation, cont'd

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



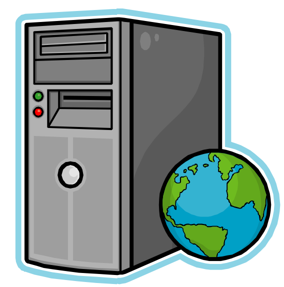
Server Storage of Encrypted MACs

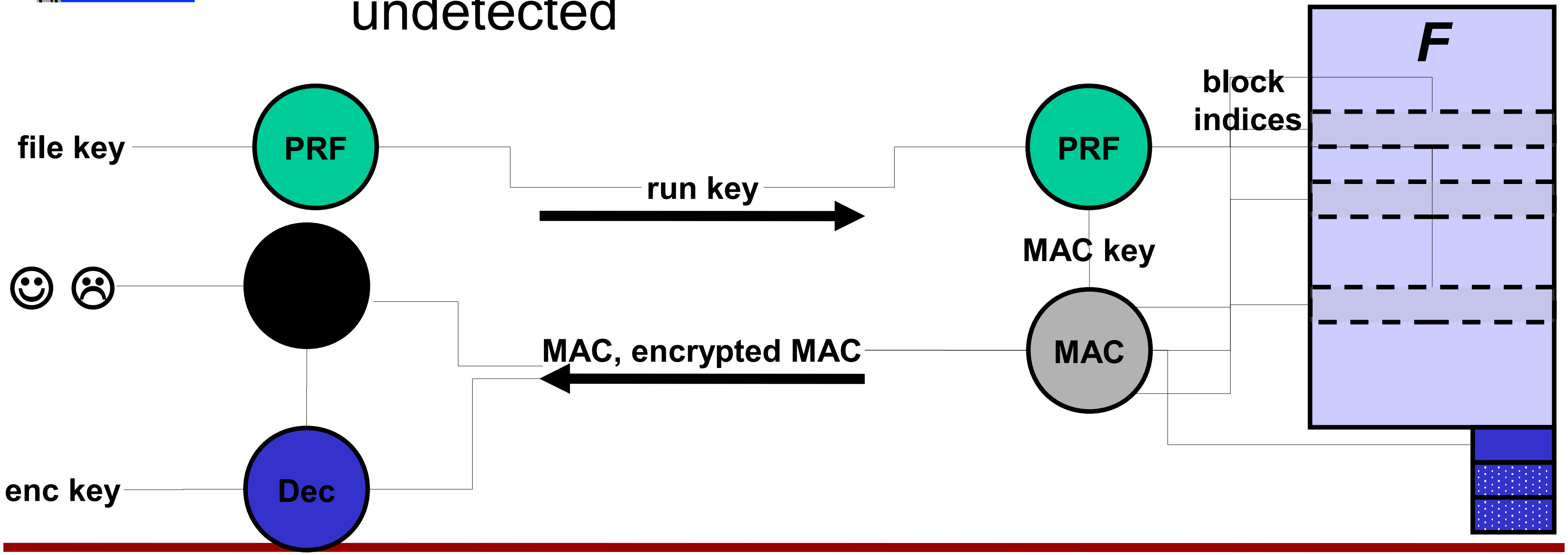
- Encrypt group MACs, store on server



Server Storage of Encrypted MACs, cont'd

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





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

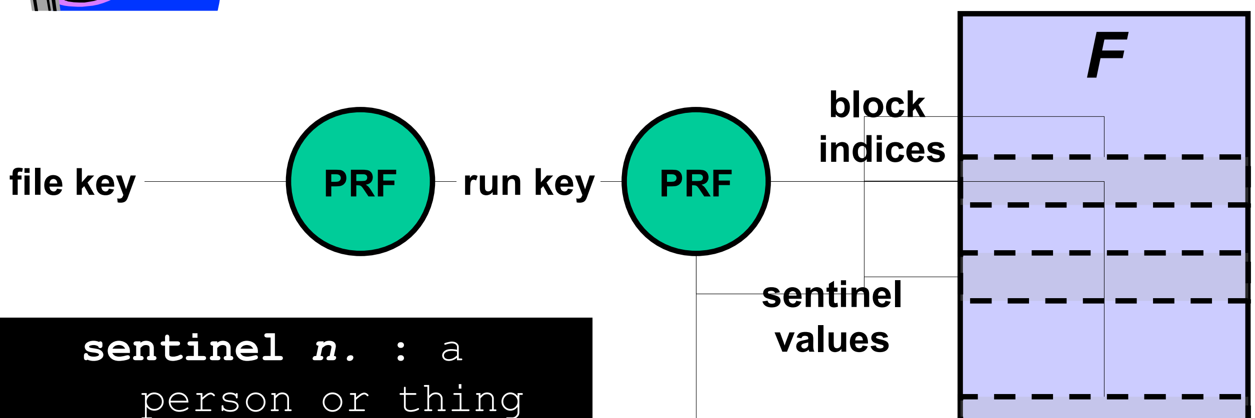
Sentinels – Another Approach

- 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

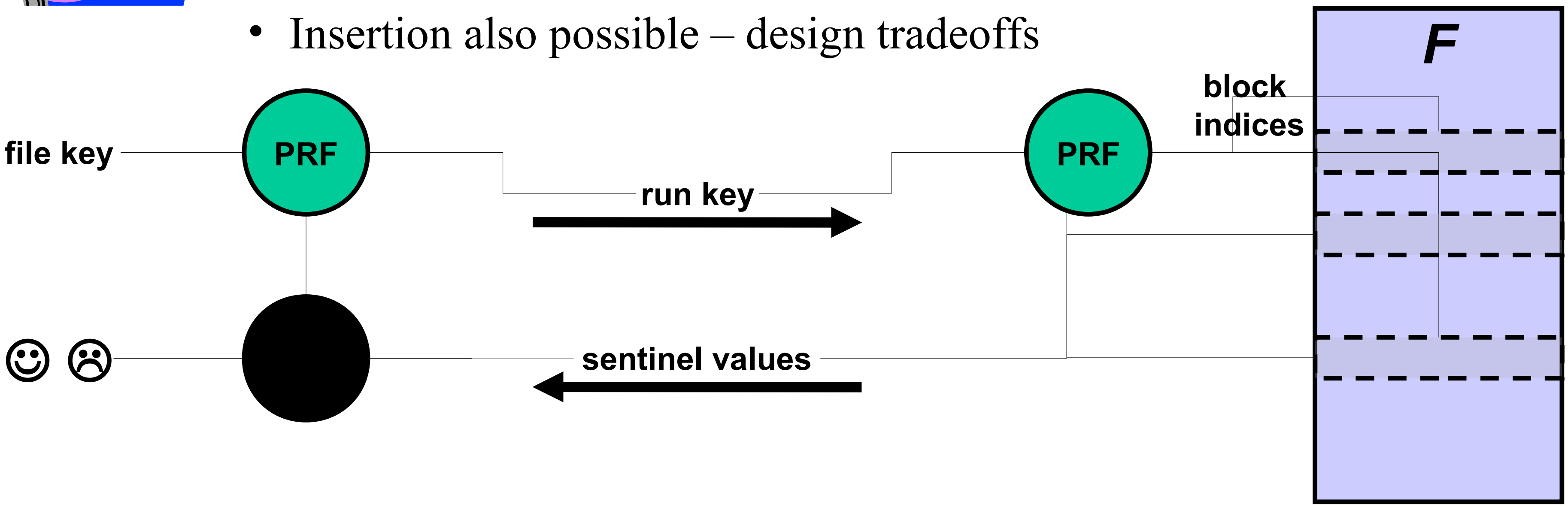


sentinel ***n.*** : a person or thing that watches (dictionary.com)

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 ←→ 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

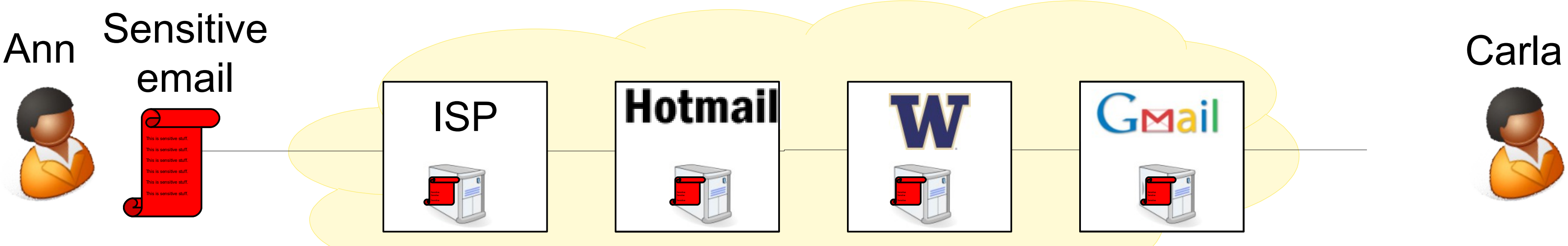
But we also have the inverse problem

- 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 h

She doesn't know where all the copies are

Services may retain data for long after user tries to delete

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.

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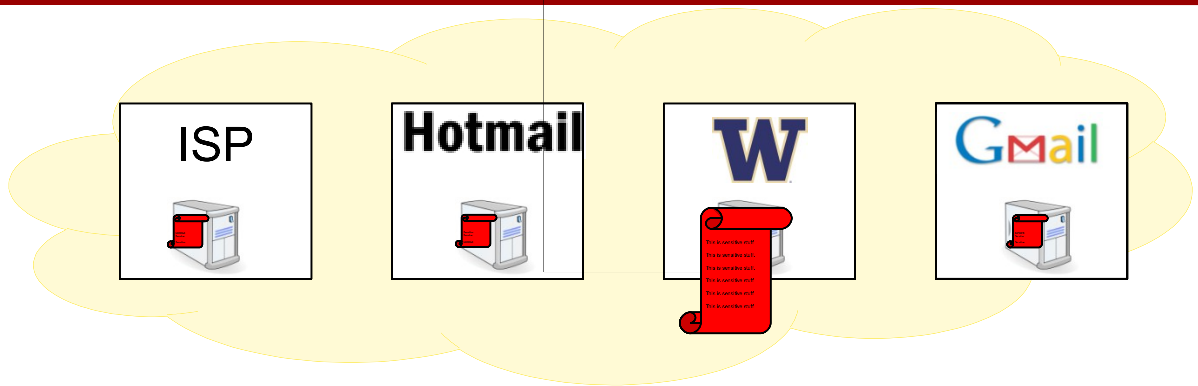
Archived Copies Can Resurface Years Later

Ann

Carla

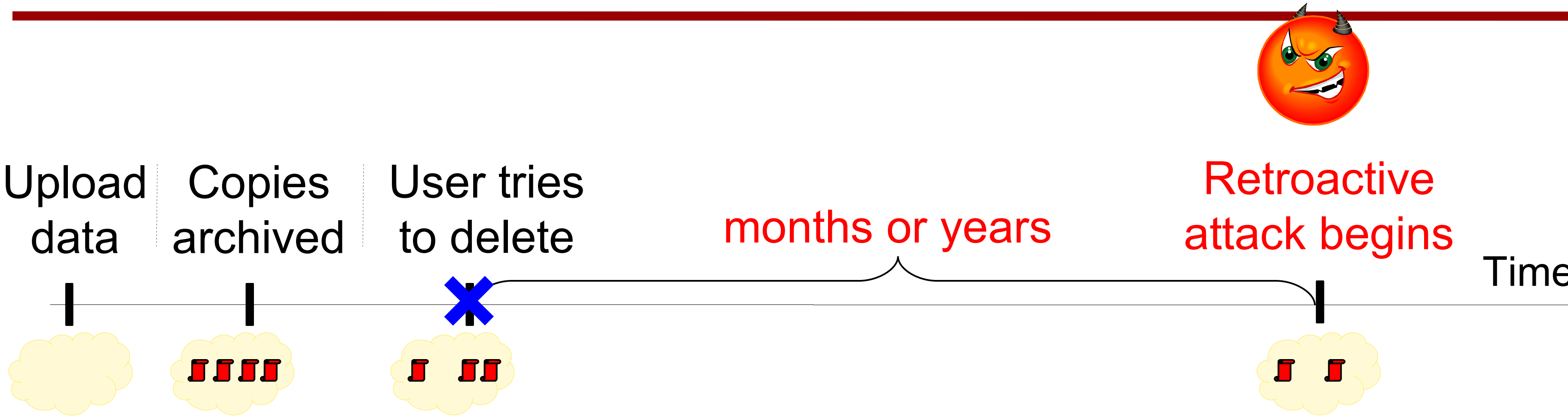


Some time later…

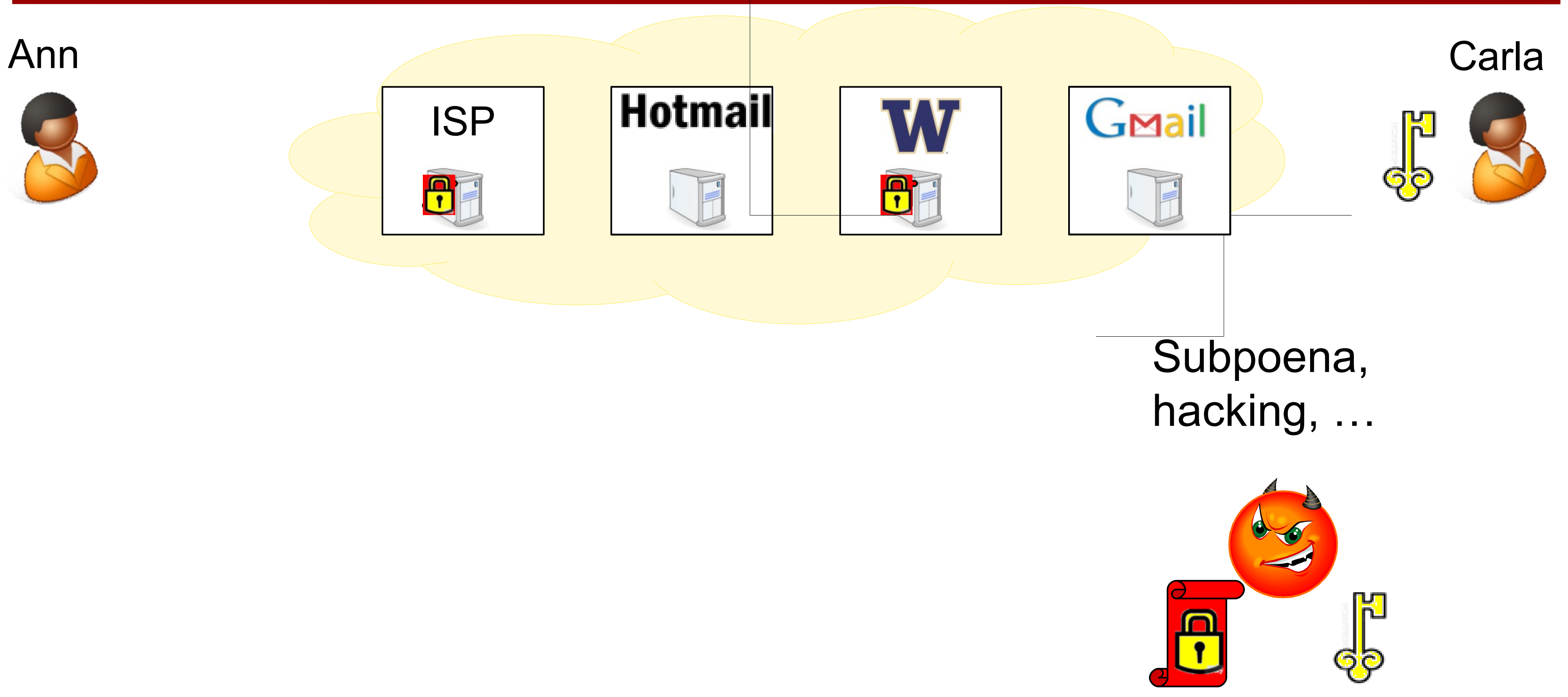
Subpoena, hacking, …

Retroactive attack on archived data

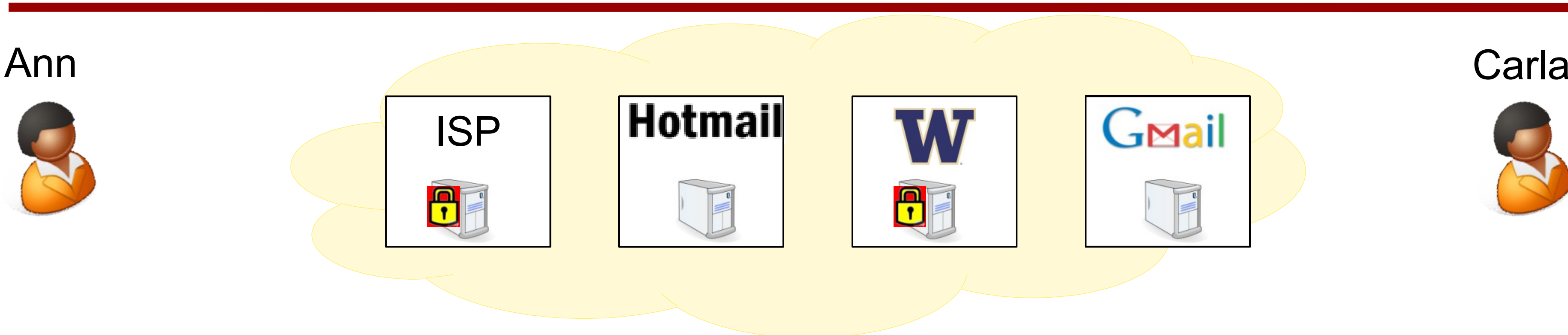
The Retroactive Attack



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



Why Not Use a Centralized Service?



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

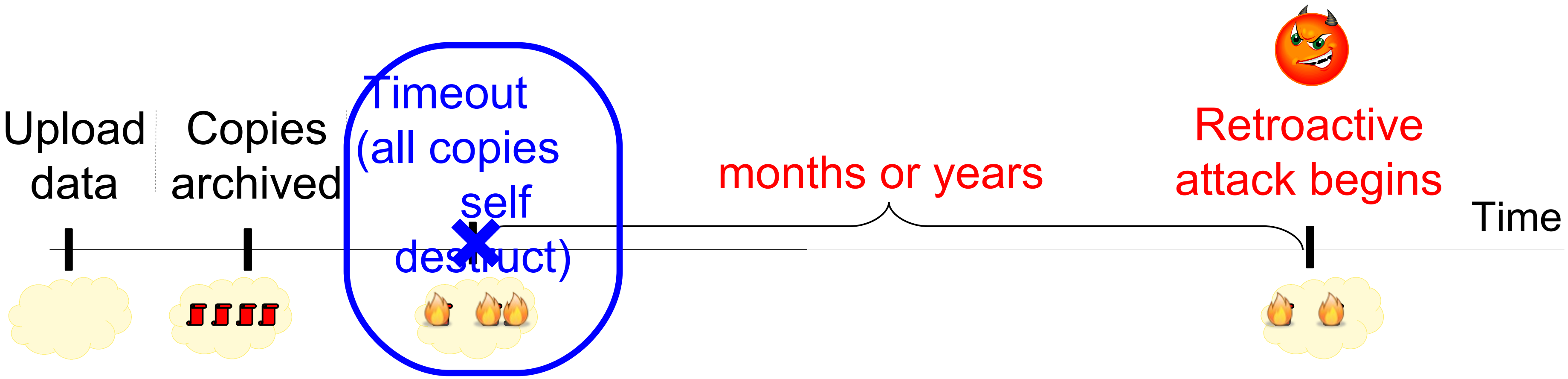
- Hackers
- Misconfigurations
- Legal actions
- Border seizing
- Theft
- Carelessness

Question:

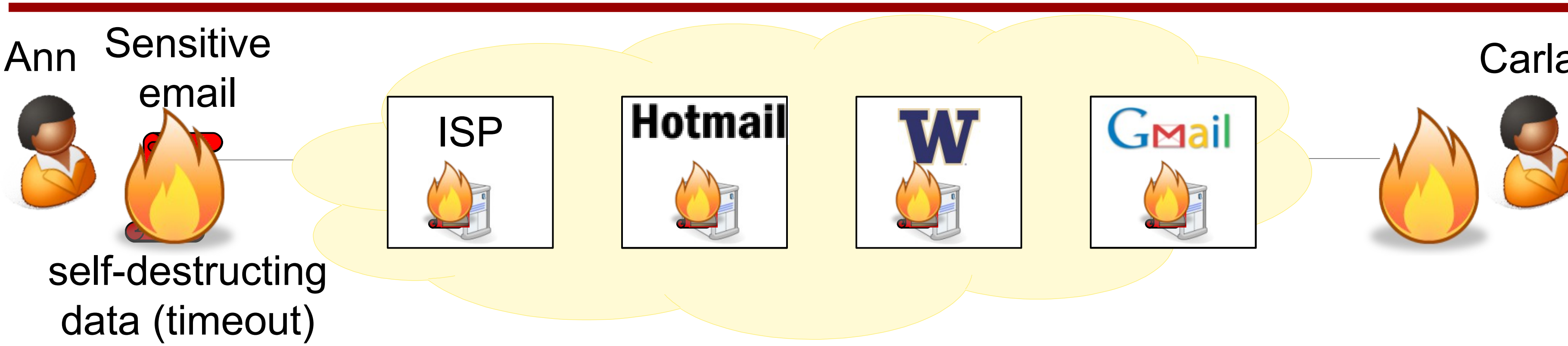
Can we empower users with control of data lifetime?

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

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Vanish: Self-Destructing Data System

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

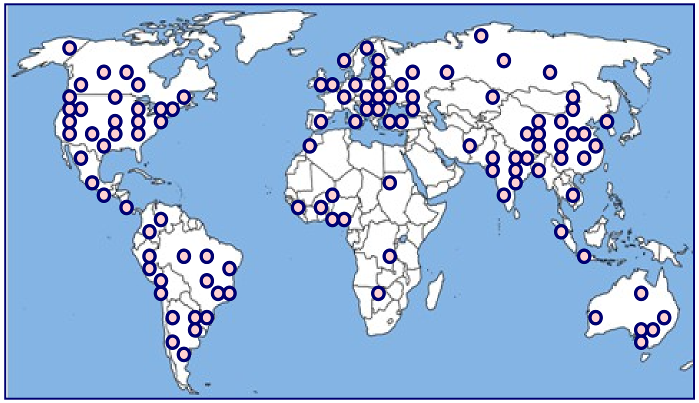
- PGP
- Centralized data management services
- Forward-secure encryption
- …

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

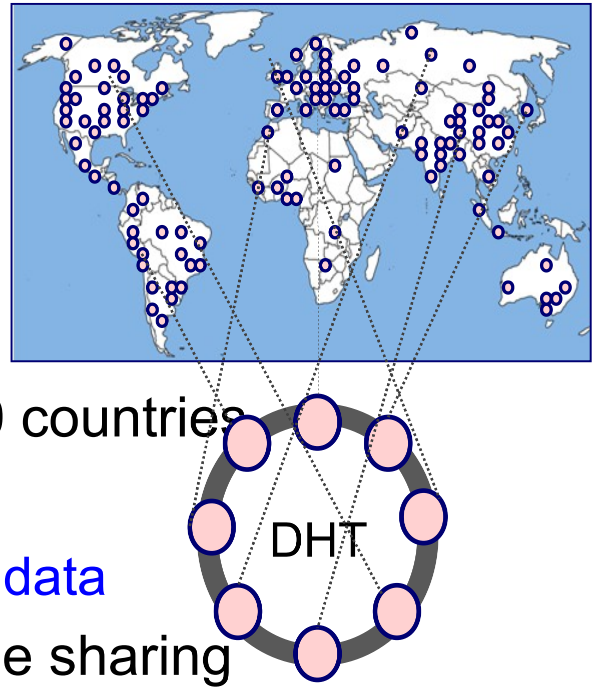
- Get and put (index, value) pairs
- Each node stores part of the index space

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,...,n;

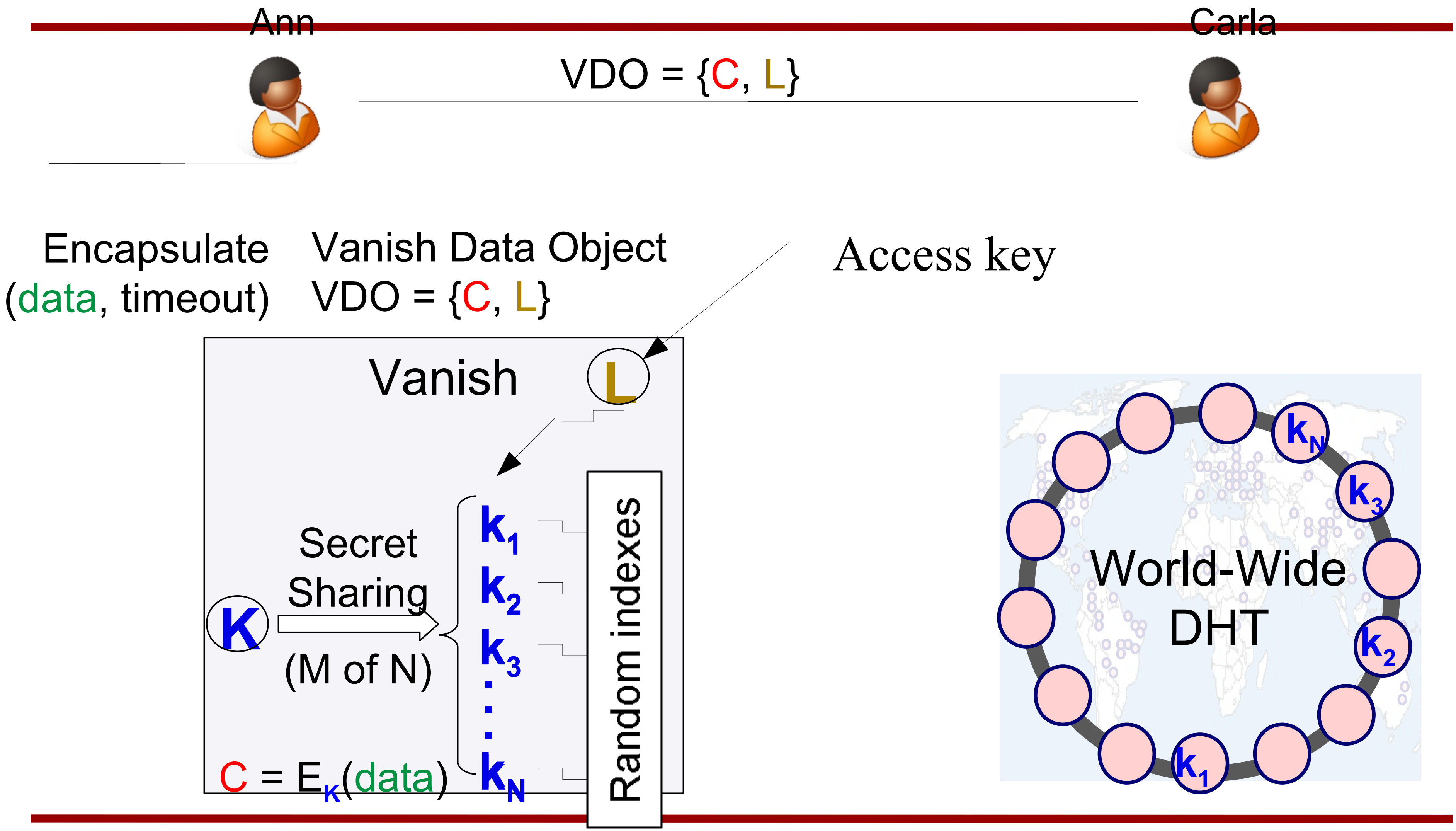
c) generates random $a_i \in Z_p$, i=1, 2,..., t – 1;

d) a_0 = K, the secret;

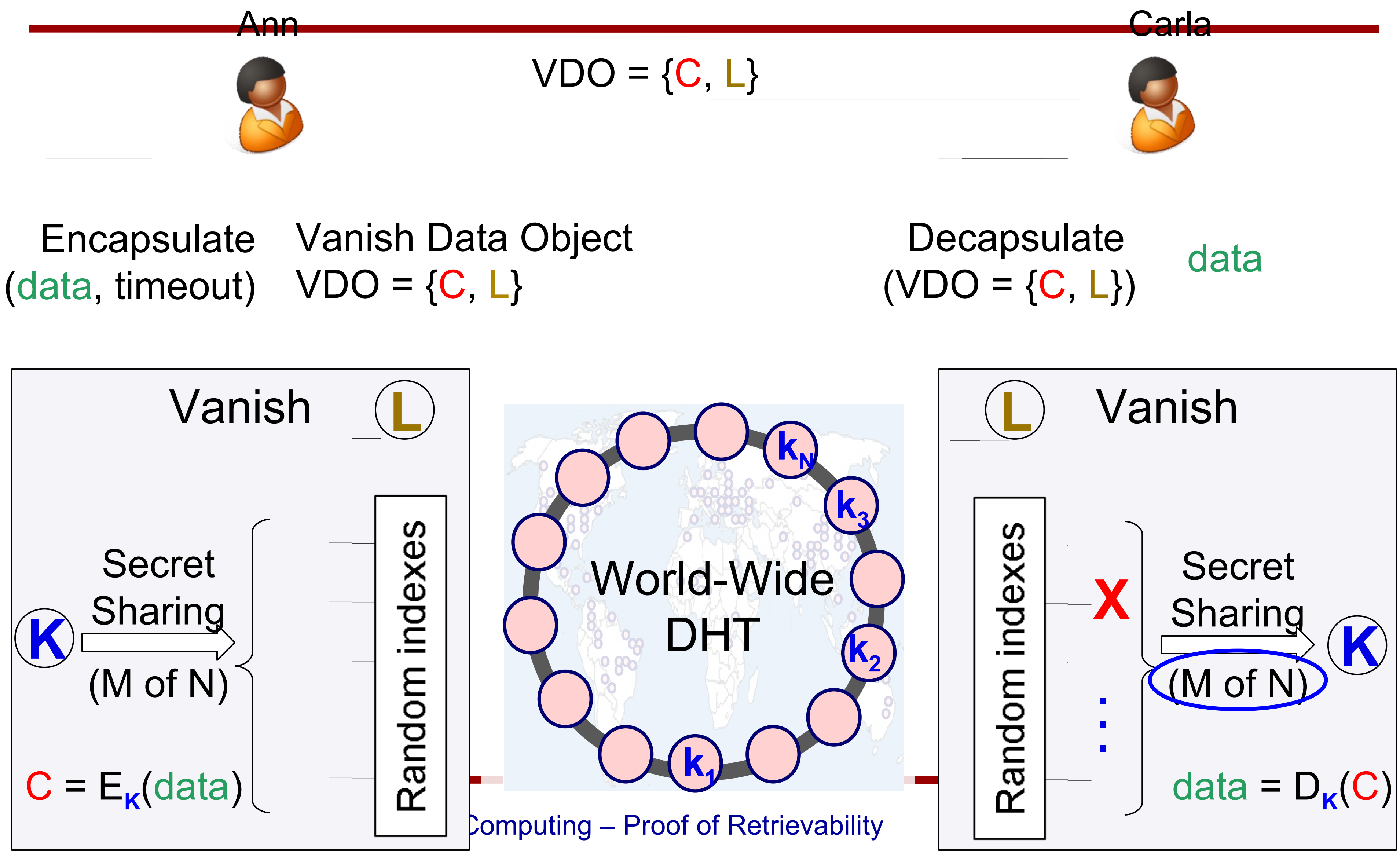
e) $f(x) = \sum_{i=0 \text{ to } t-1} a_i x^i \mod p$;

P_i's share is $(x_i, f(x_i))$.

How Vanish Works: Data Encapsulation



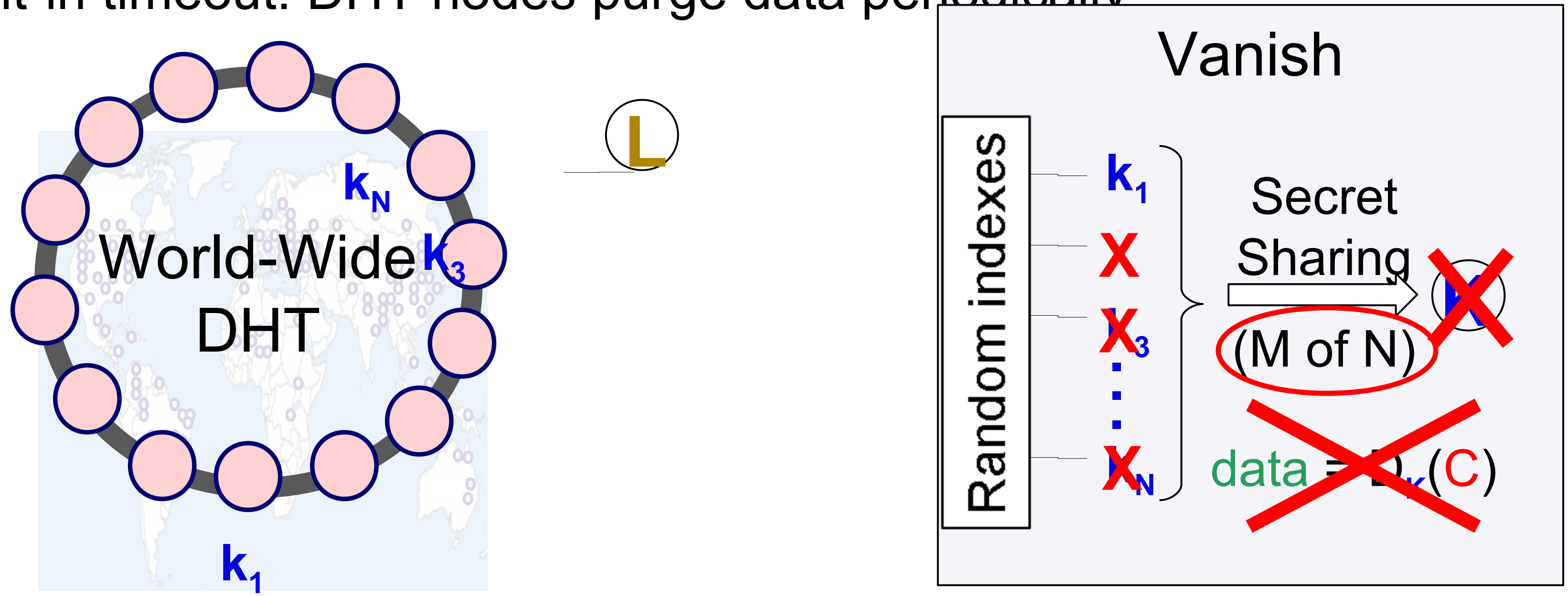
How Vanish Works: Data Decapsulation



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

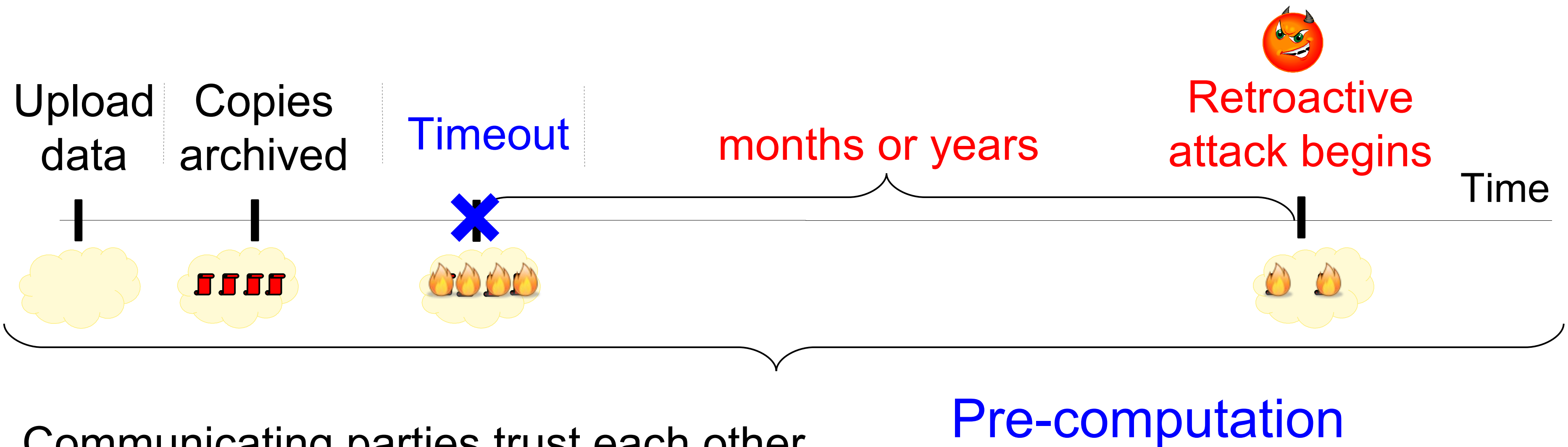


Key loss makes all data copies permanently unreadable

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



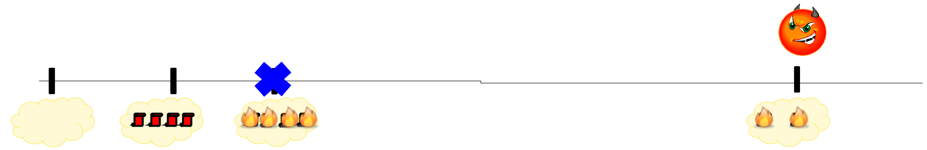
Communicating parties trust each other

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

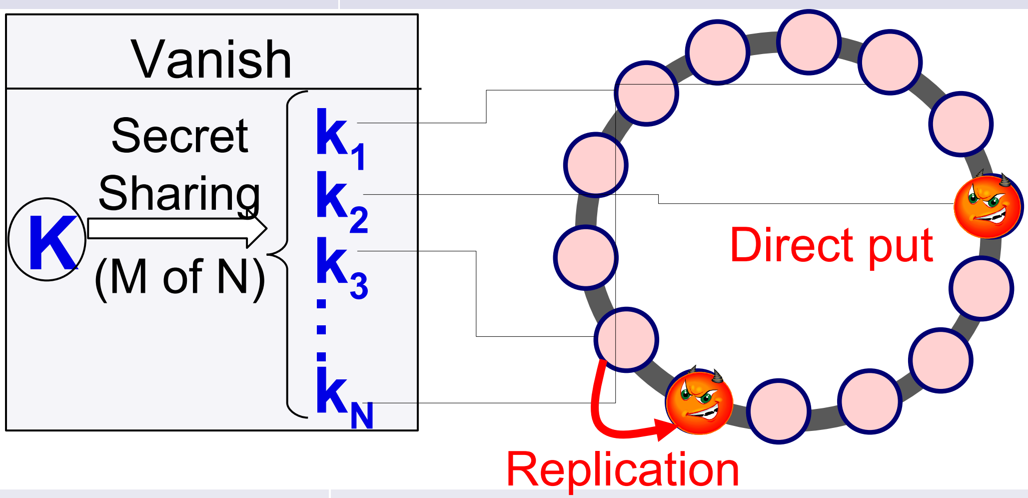
Attack Analysis

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



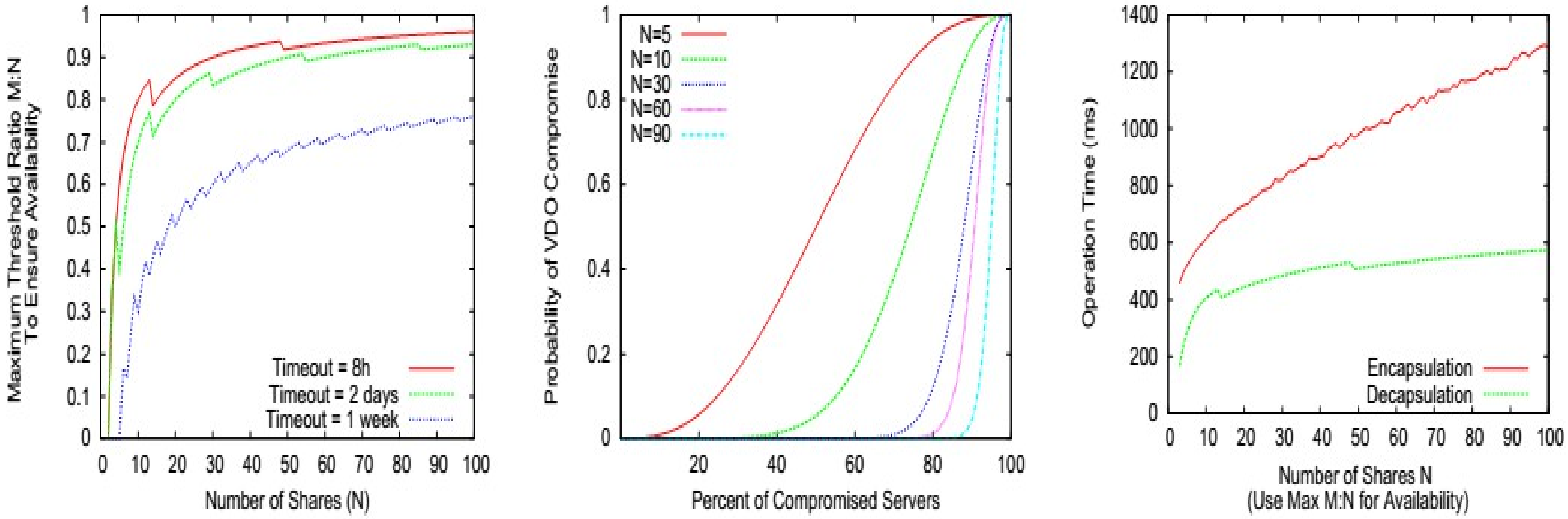
Capture any key pieces from the DHT (pre-computation)	P2P property: huge scale

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.

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 ☺

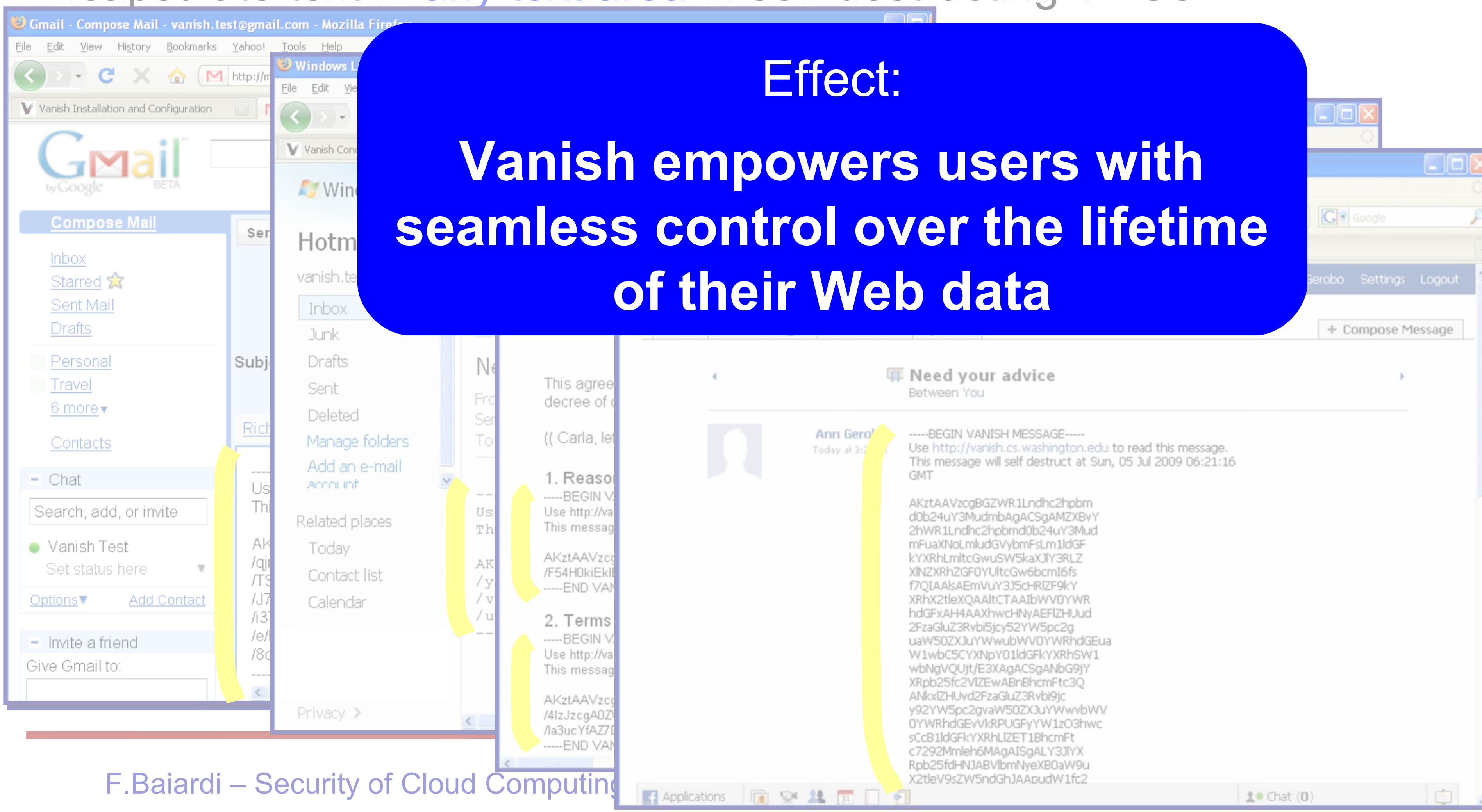
Self-destructing files

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

Conclusions

Two formidable challenges to privacy:

- Data lives forever
- Disclosures of data and keys have become commonplace

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

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]

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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 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.