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SESSION ID: BR-W01

Provable Security for End-to-End Encrypted Cloud Storage

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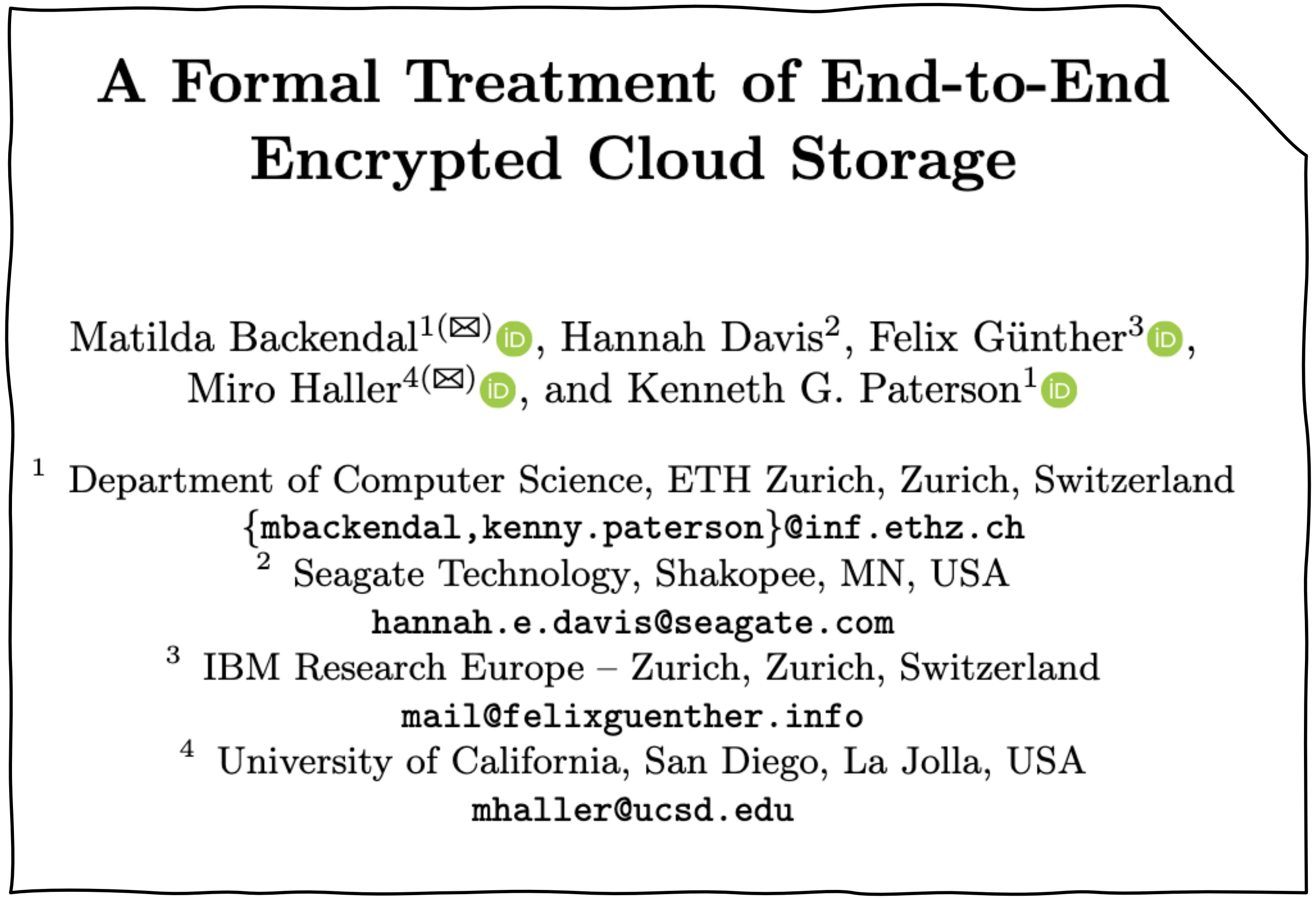
Provable Security for E2EE Cloud Storage



A Formal Treatment of End-to-End Encrypted Cloud Storage

Matilda Backendal[1](✉), Hannah Davis[2], Felix Günther[3], Miro Haller[4](✉), and Kenneth G. Paterson[1]

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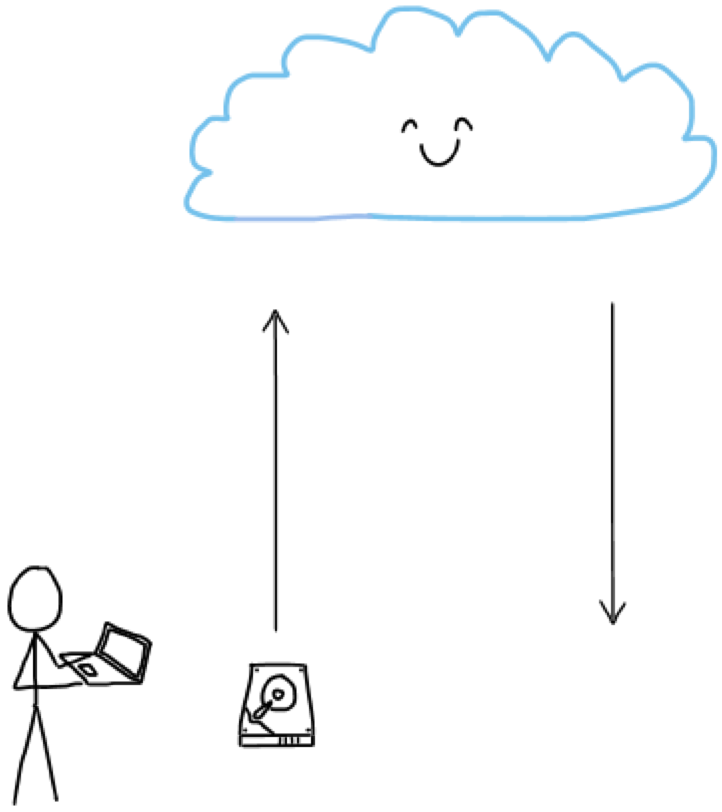
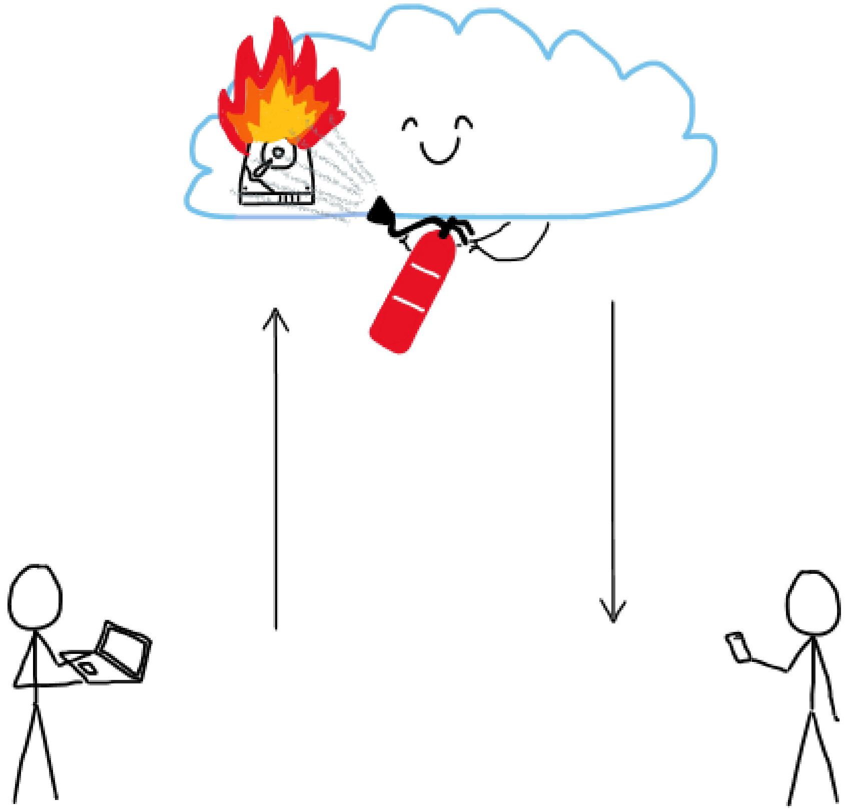
Cloud Storage

- Benefits:
  - + Availability



Cloud Storage

- Benefits:
  - Availability
  - Redundancy

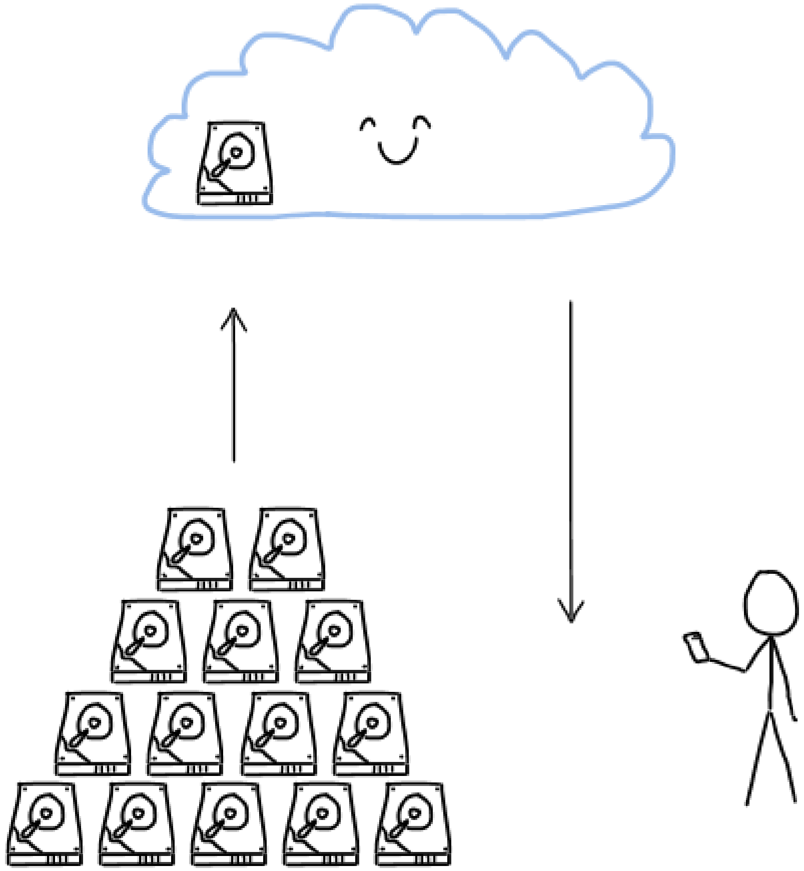


Cloud Storage

- Benefits:
  - + Availability
  - + Redundancy
  - + Scalability

STORING 50% OF ALL DATA BY 2025 [1]

Google Cloud Amazon S3



[1] https://cybersecurityventures.com/the-world-will-store-200-zettabytes-of-data-by-2025/ (Sausalito, Calif., Feb. 1, 2024)

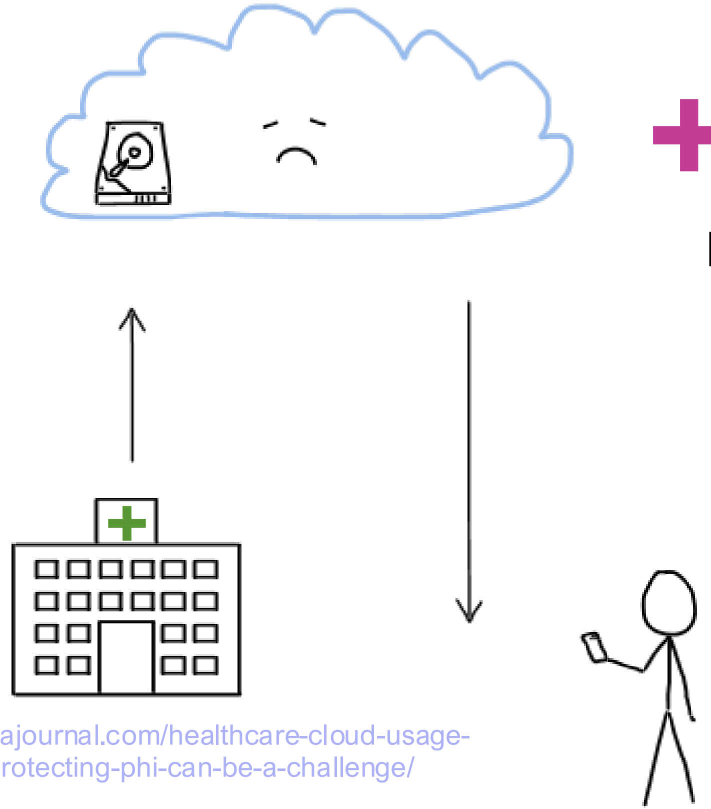
Cloud Storage

Google Cloud Amazon S3

- Benefits:
  - + Availability
  - + Redundancy
  - + Scalability
- Concerns:
  - - Data leaks

4 of 5

Americans had private information exposed at least once [2]



https://www.hipaajournal.com/healthcare-cloud-usage-grows-but-protecting-phi-can-be-a-challenge/

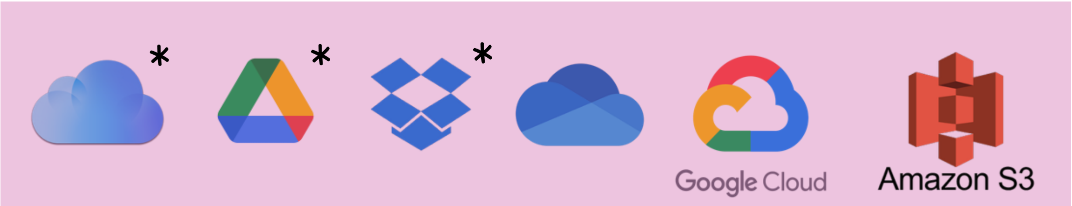
+381%

Data breaches [2]

[2] https://www.apple.com/newsroom/pdfs/The-Rising-Threat-to-Consumer-Data-in-the-Cloud.pdf (December 2022)

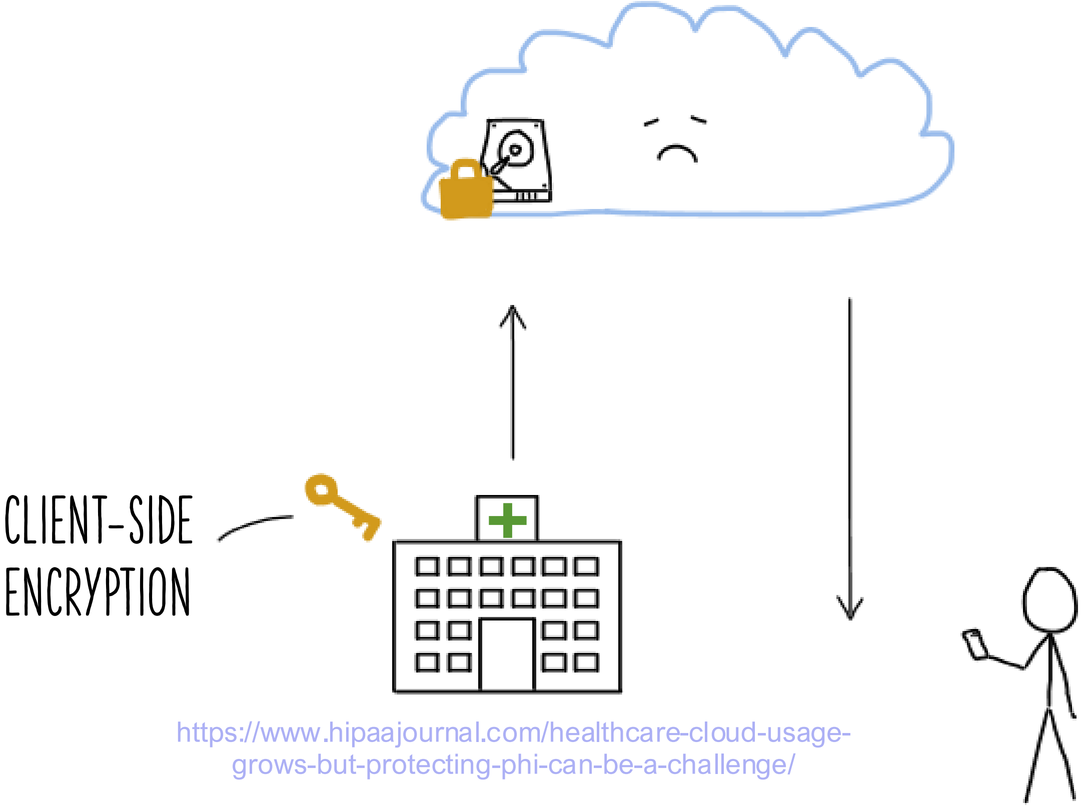
Cloud Storage

- Benefits:
  - + Availability
  - + Redundancy
  - + Scalability
- Concerns:
  - - Data leaks



no E2EE by default

*OPTIONAL AND LIMITED E2EE



https://www.hipaajournal.com/healthcare-cloud-usage-grows-but-protecting-phi-can-be-a-challenge/

E2EE Cloud Storage Providers

"WITH **MEGA**, YOU CONTROL THE ENCRYPTION"

300 MILLION USERS

MEGA

INSECURE!

[BHP23]
[AHMP23]

AMNESTY INTERNATIONAL, GERMAN GOVERNMENT

"ULTIMATE SECURITY"

Nextcloud

INSECURE!

[ABCP23]

"EXCEPTIONALLY PRIVATE CLOUD"

sync.com

"EUROPE'S MOST SECURE CLOUD STORAGE"

pCloud

INSECURE!

icedrive

"THE STRONGEST ENCRYPTED CLOUD STORAGE IN THE WORLD"

Seafile

"SUPPORTS CLIENT-SIDE END-TO-END ENCRYPTION"

[HT24]

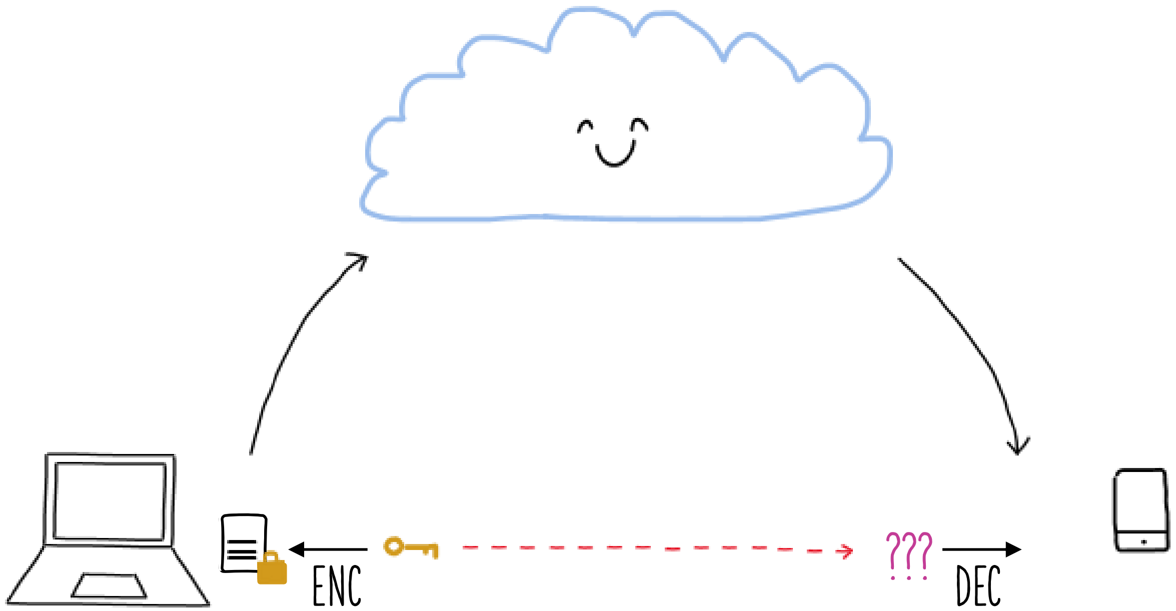
"FREE, ENCRYPTED, AND SECURE CLOUD STORAGE. YOUR PRIVACY, SECURED BY MATH"

Proton Drive

NOT PROVABLY SECURE [M24]

Why Is It Hard?

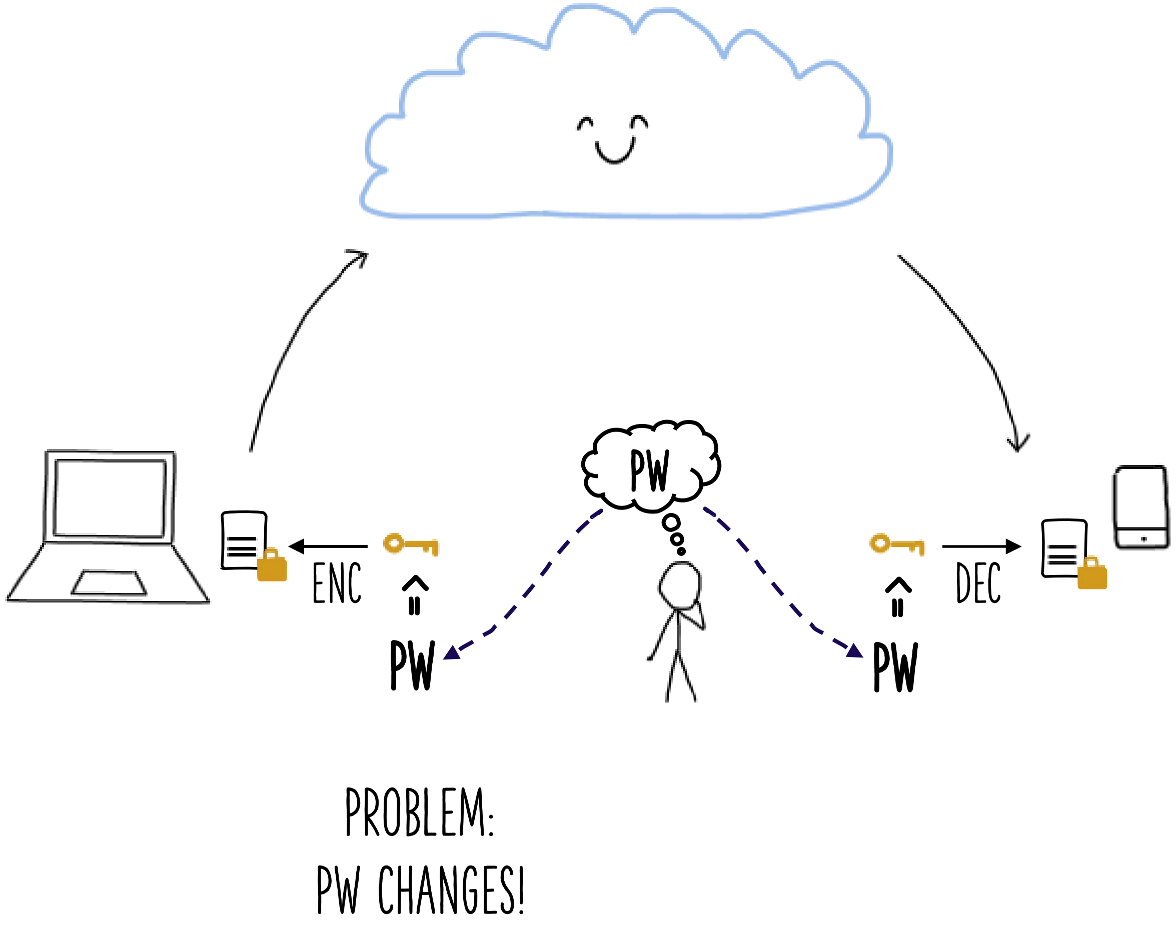
1 key distribution



Why Is It Hard?

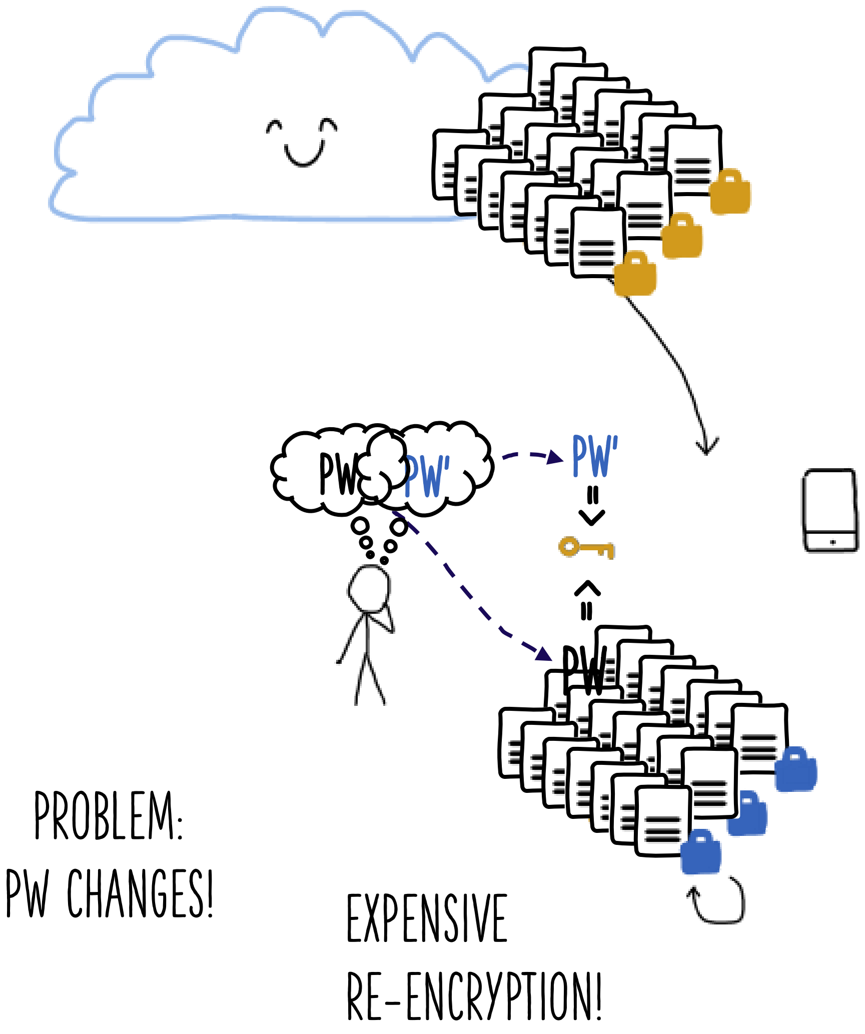
1 key distribution

2 password-based security



Why Is It Hard?

1. key distribution
2. password-based security

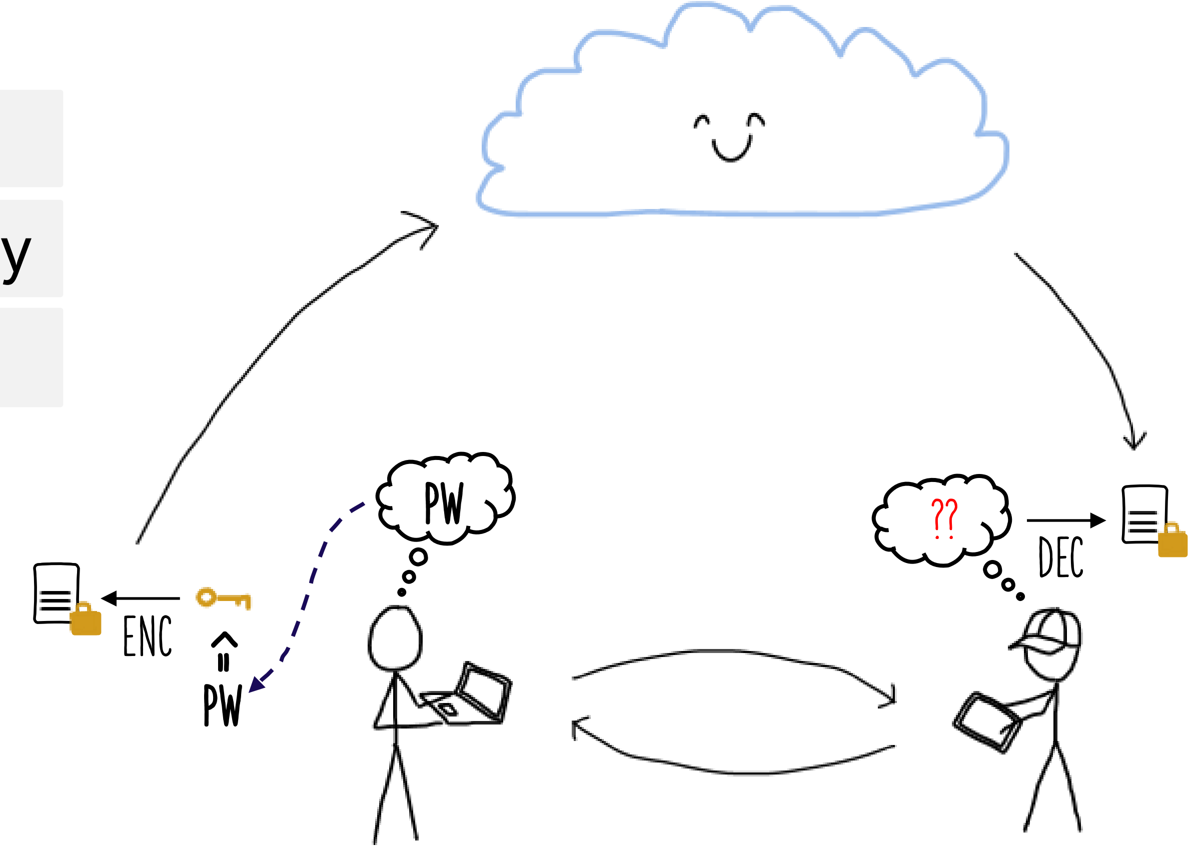


PROBLEM:
PW CHANGES!

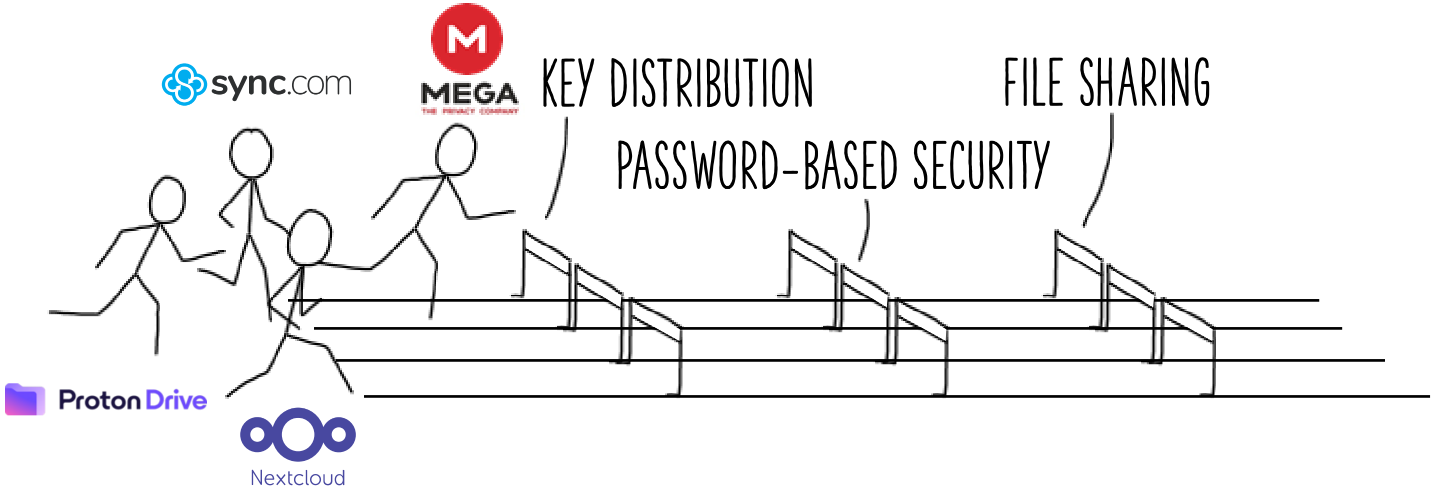
EXPENSIVE
RE-ENCRYPTION!

Why Is It Hard?

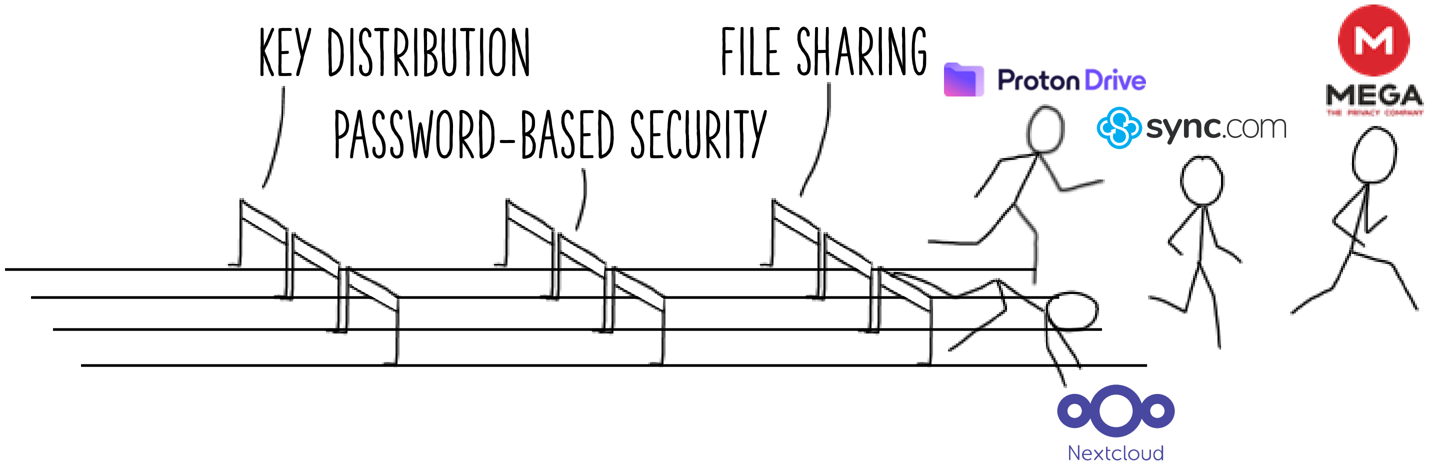
1	key distribution
2	password-based security
3	file sharing



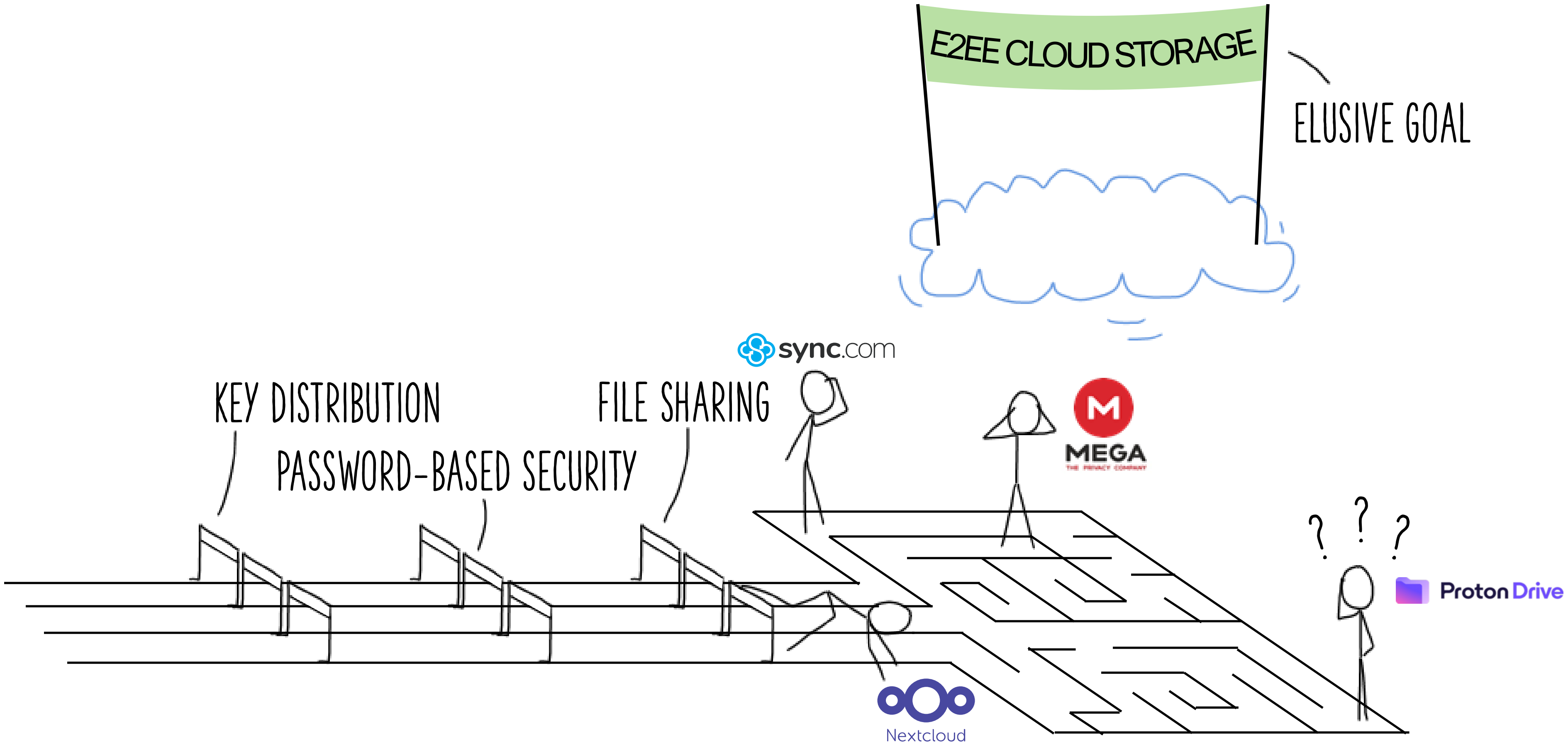
Why Is It *Actually* Hard?



Why Is It *Actually* Hard?



Why Is It *Actually* Hard?

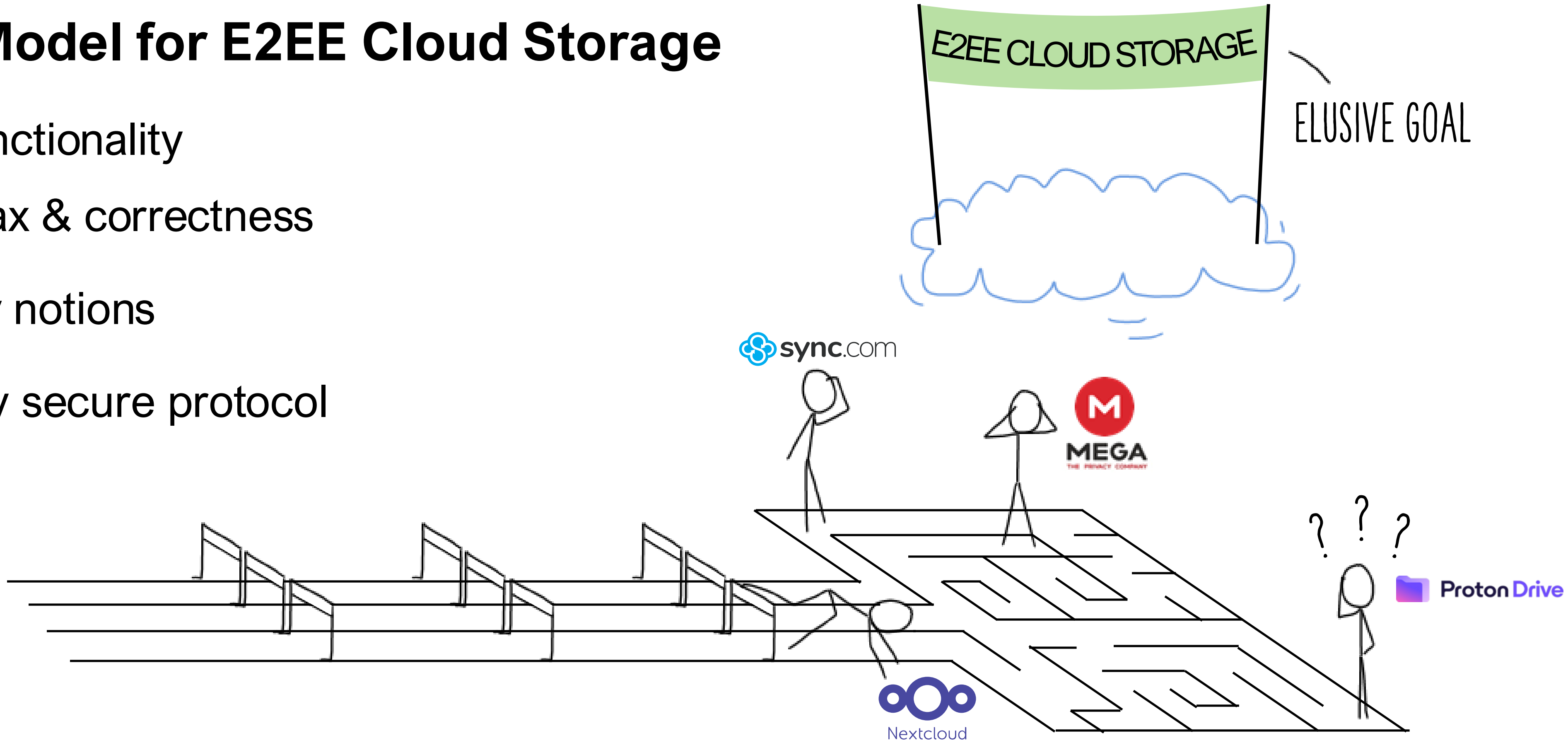


Our Work

Formal Model for E2EE Cloud Storage

- Core functionality

  → Syntax & correctness
- Security notions
- Provably secure protocol



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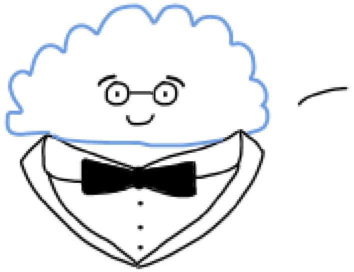
Formalizing E2EE Cloud Storage

Syntax and Security

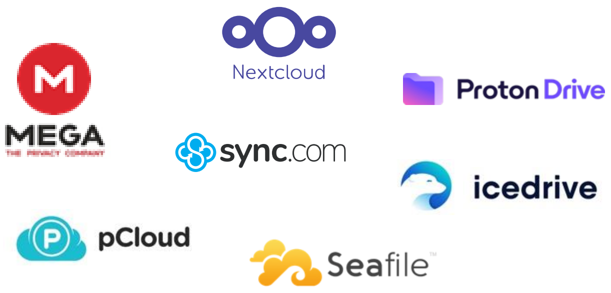
Many Voices.
One Community.

Formalizing E2EE Cloud Storage

Model Goals



ALL MODELS ARE WRONG, BUT SOME ARE USEFUL!

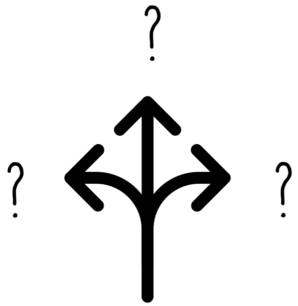


Capture existing systems

1	Expressive

Capture *real-world* systems

2	Faithful



Capture future systems

3	Generic

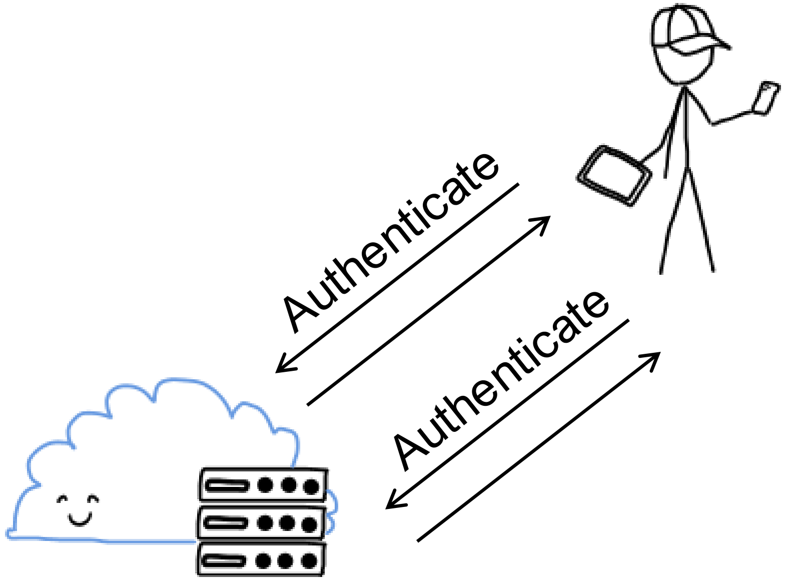
Syntax "WHAT MAKES A CLOUD STORAGE A CLOUD STORAGE?"

Core Functionality

1 EXPRESSIVE

- Register (create account)
- Authenticate (log in)
- Put (upload a file)
- Update (modify content)
- Get (download)
- Share
- Accept (receive share)

INTERACTIVE PROTOCOLS

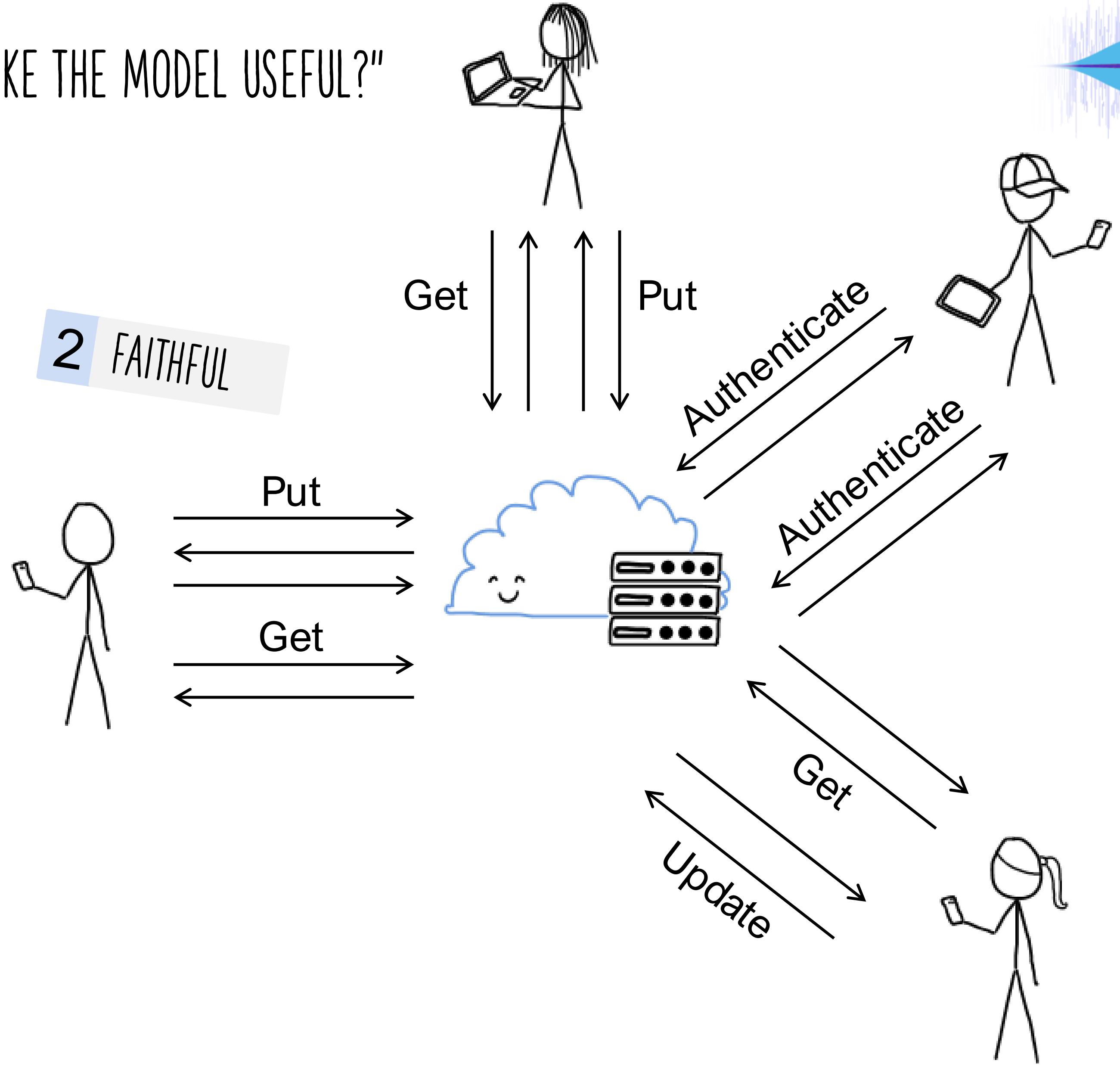


Syntax "HOW DO WE MAKE THE MODEL USEFUL?"

Model Choices

- Arbitrary interleaving

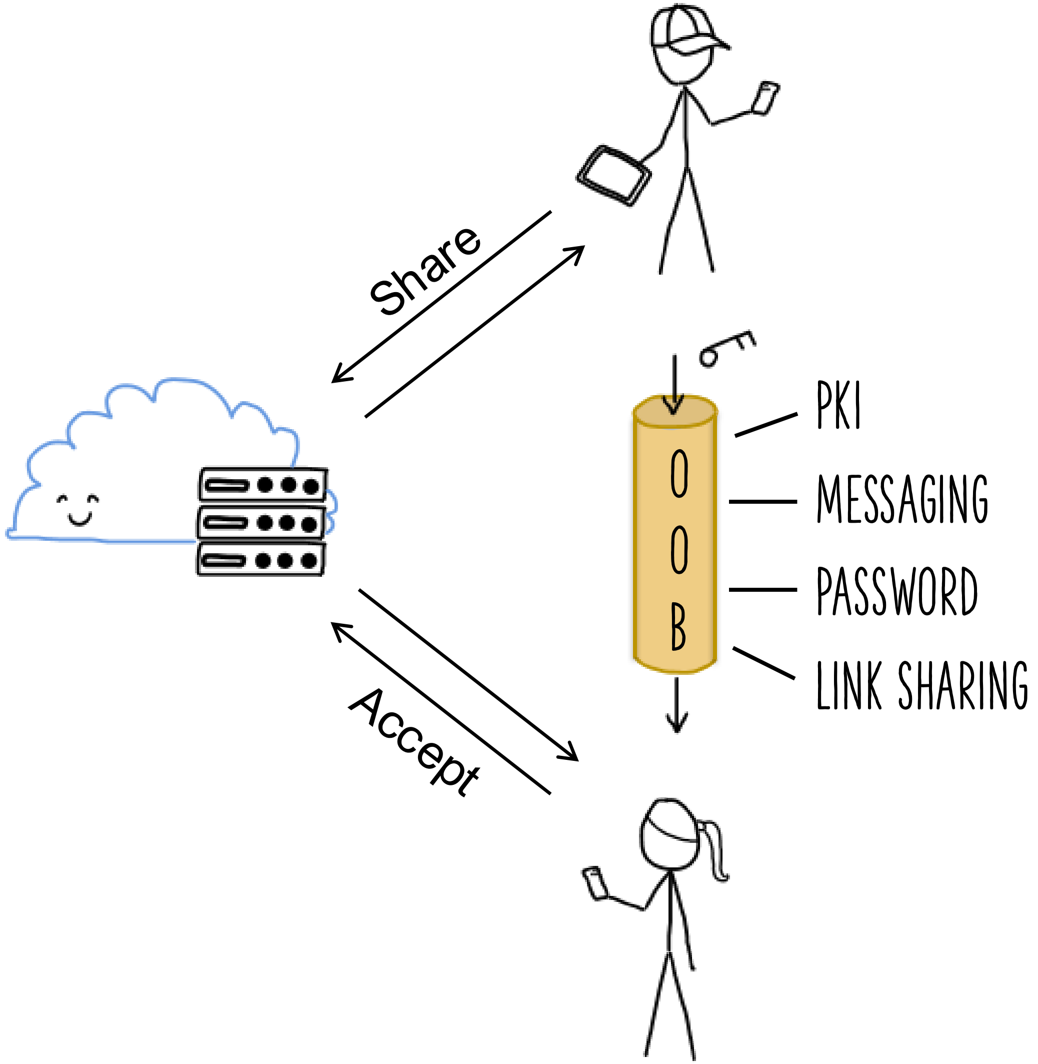
2 FAITHFUL



Syntax "HOW DO WE MAKE THE MODEL USEFUL?"

Model Choices

- Arbitrary interleaving — 2 FAITHFUL
- Abstract OOB channel for sharing — 3 GENERIC



Security

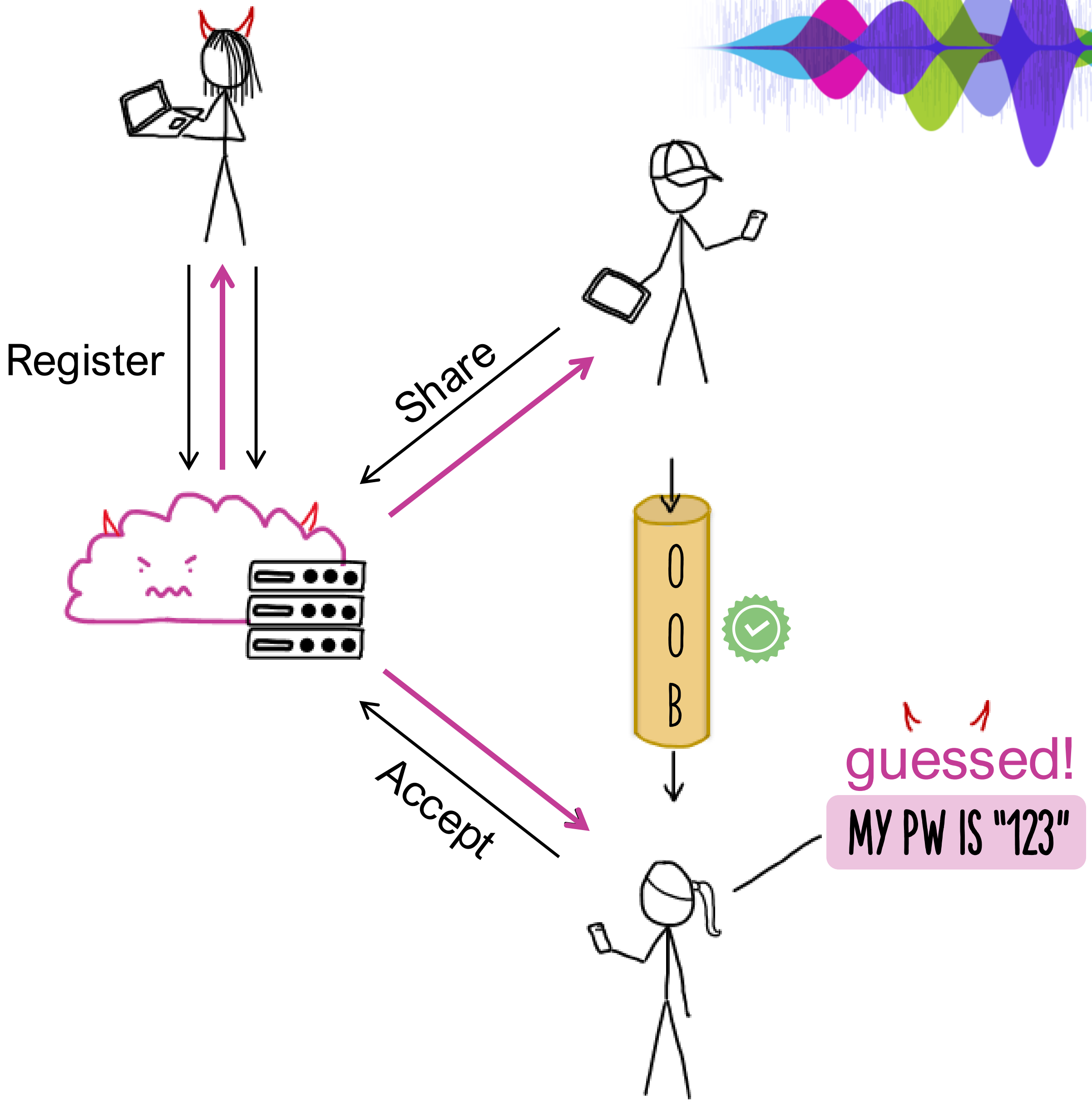
Threat model

- Malicious cloud provider
- Trusted OOB channel

Adversary capabilities

- Control honest client protocol steps
- Guess honest user passwords
- Compromise users

SELECTIVE AND ADAPTIVE



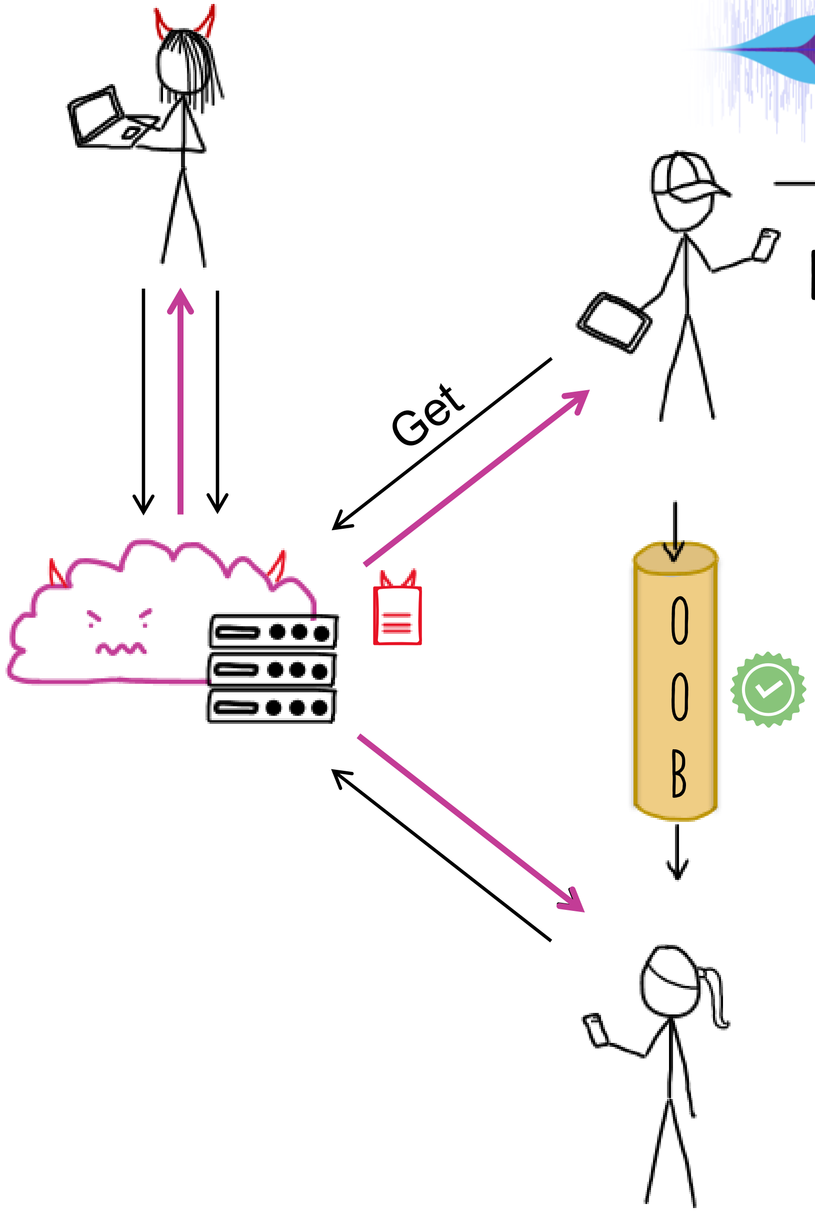
Security "GAME-BASED SECURITY NOTIONS"

To win a game and break security, the adversary must, for an honest user, …

Integrity

- … inject/modify a file.

INT-PTXT-STYLE GAME



Security "GAME-BASED SECURITY NOTIONS"

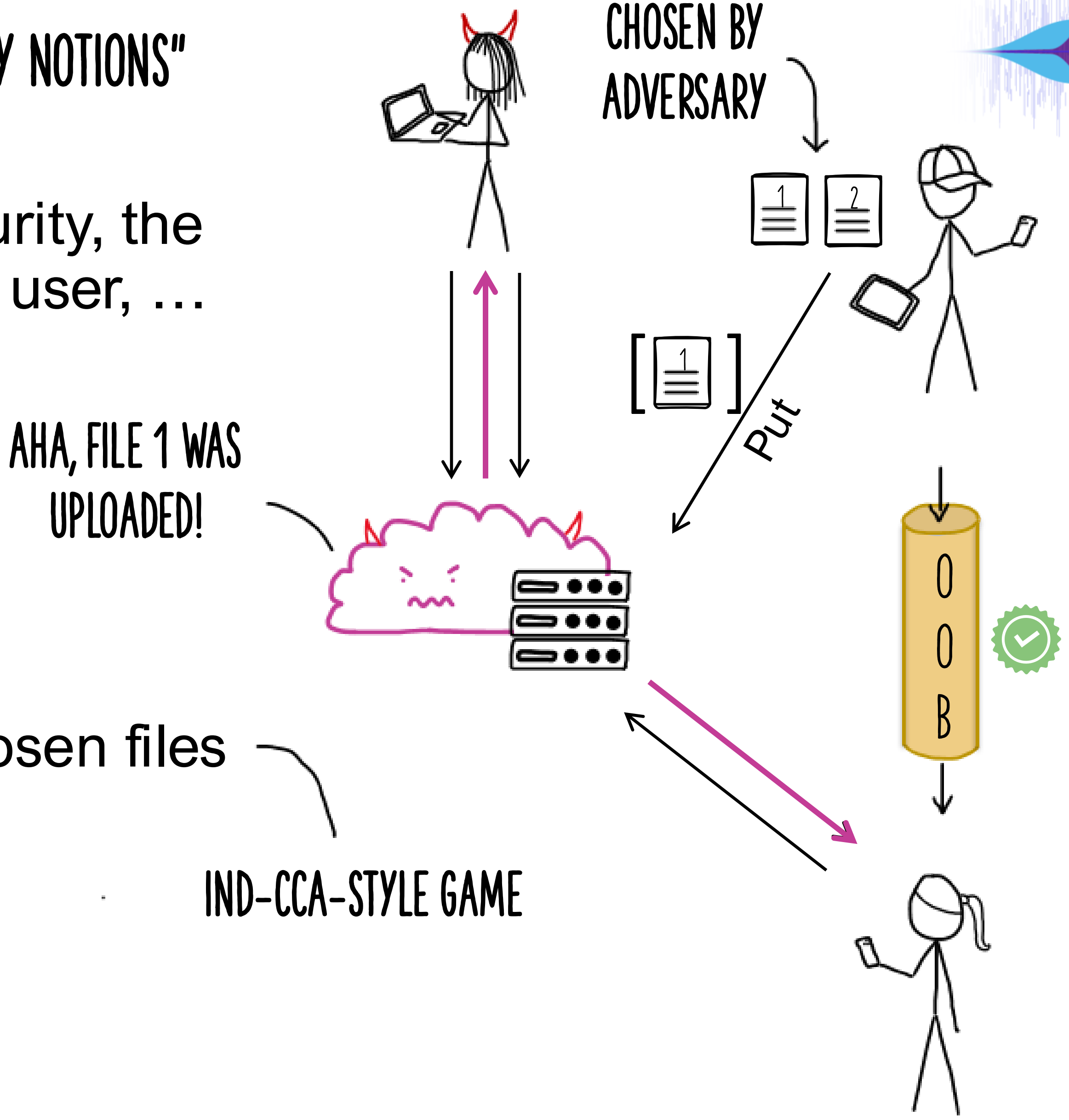
To win a game and break security, the adversary must, for an honest user, …

Integrity

- … inject/modify a file.

Confidentiality

- … distinguish uploaded chosen files



Security "GAME-BASED SECURITY NOTIONS"

To win a game and break security, the adversary must, for an honest user, …

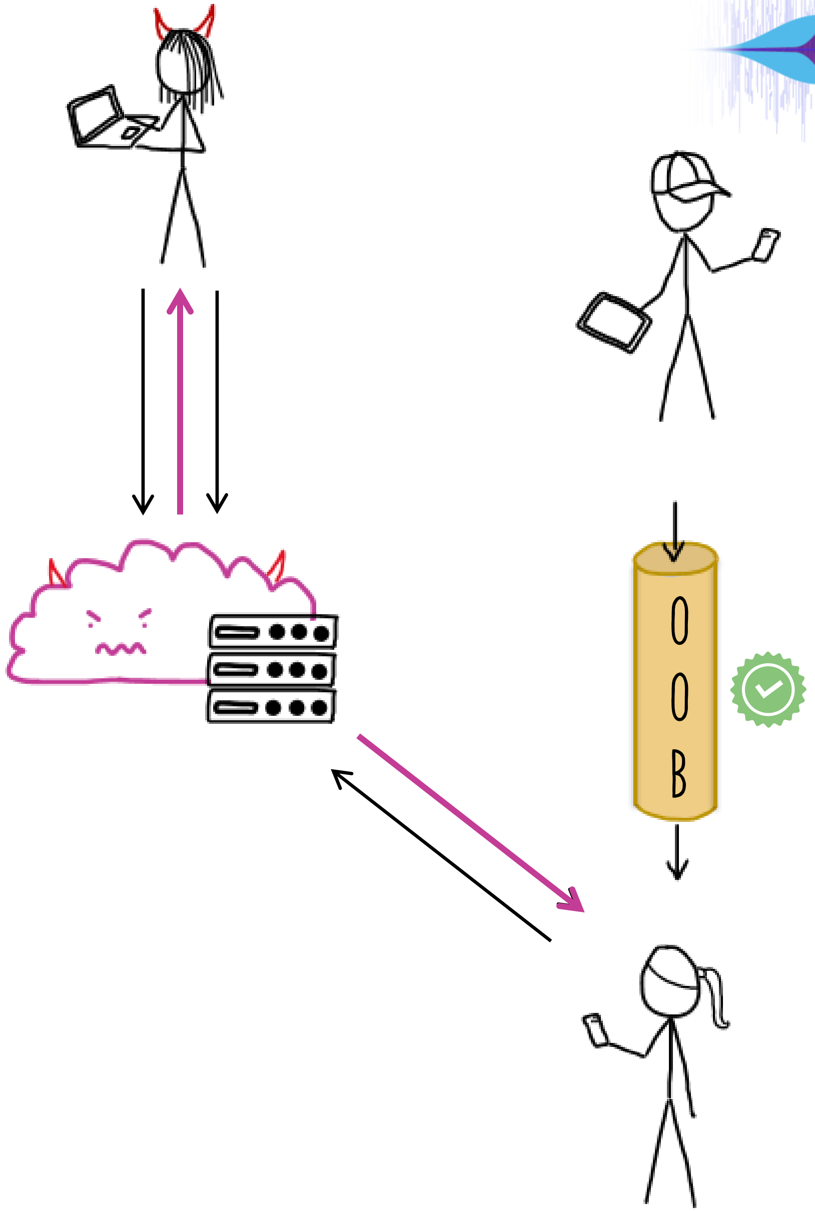
Integrity

- … inject/modify a file.

Confidentiality

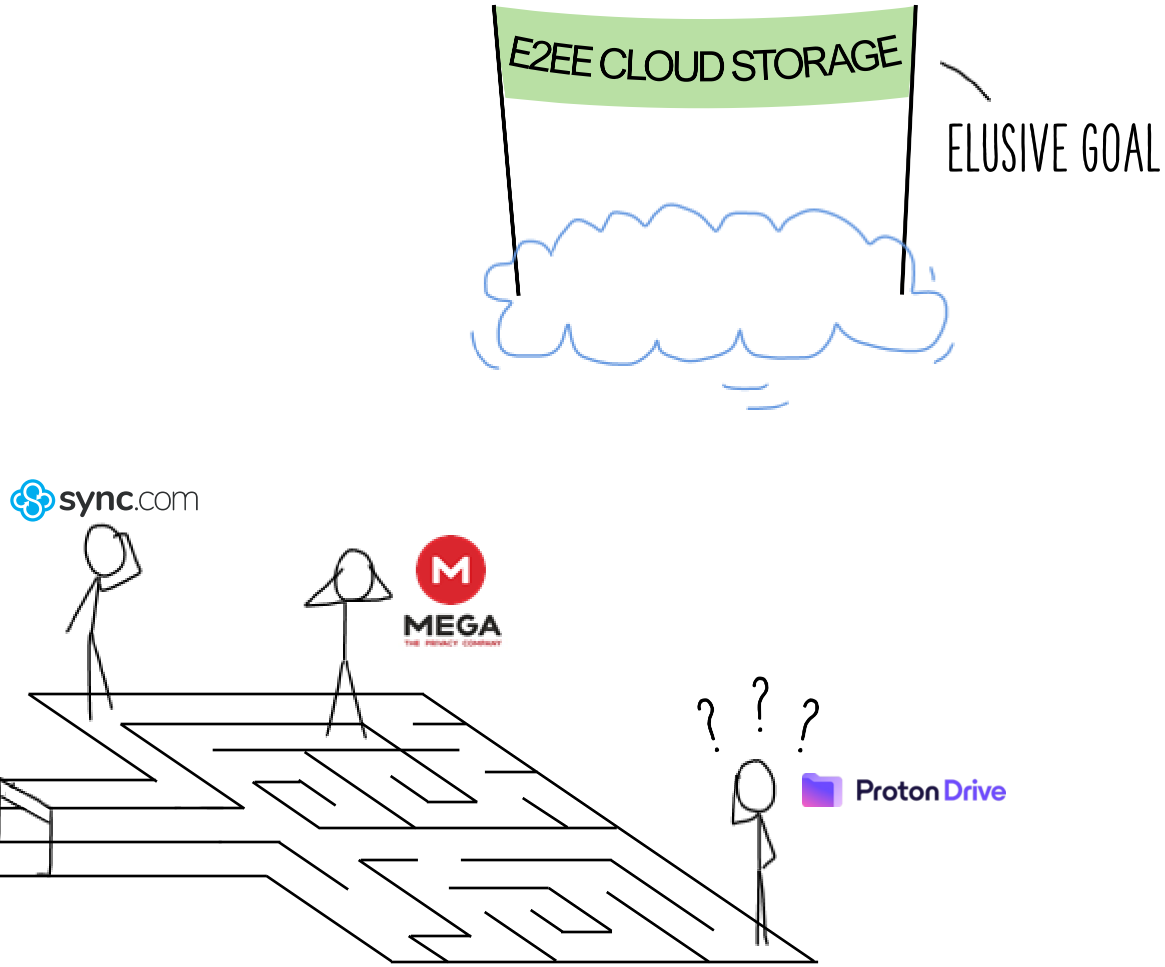
- … distinguish uploaded chosen files

Secure = ”low” winning probability



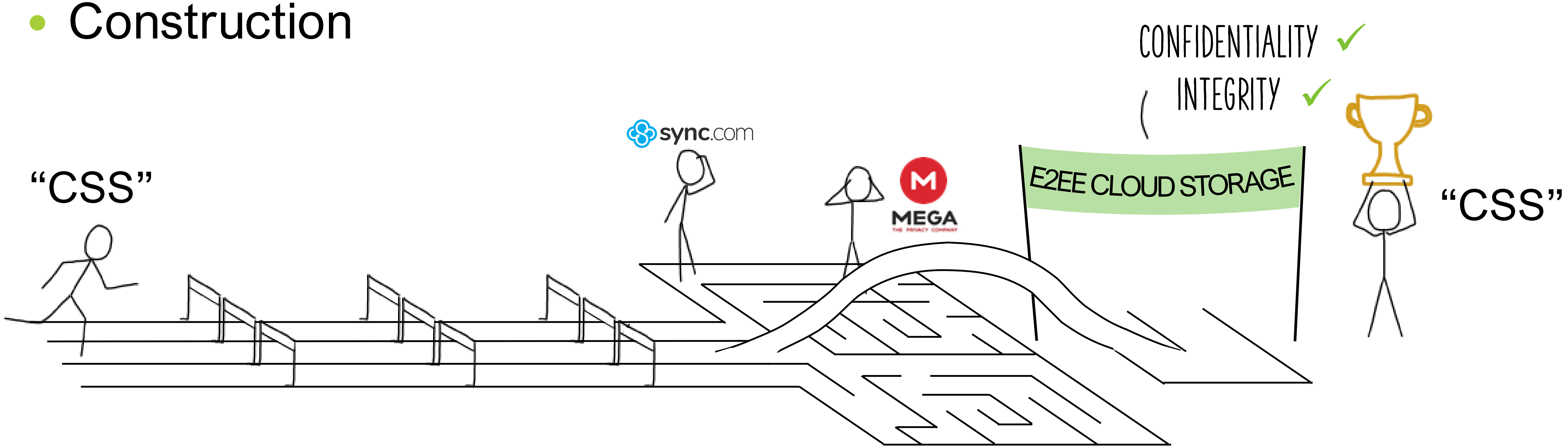
Problem solved?

- Syntax ✓
- Security notions ✓



Problem solved?

- Syntax ✓
- Security notions ✓
- Construction



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Constructing E2EE Cloud Storage

Many Voices.
One Community.

CSS (Cloud Storage Scheme)

INTERACTIVE MULTI-STEP PROTOCOLS

Challenges

1 key distribution

2 pw-based security

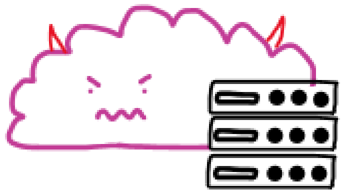
3 file sharing

Core Functionality

- Register (create account)
- Authenticate (log in)
- Put (upload a file)
- Update (modify content)
- Get (download)
- Share
- Accept (receive share)

Threat Model

- Malicious server



- Trusted OOB channel

CSS: Building Blocks

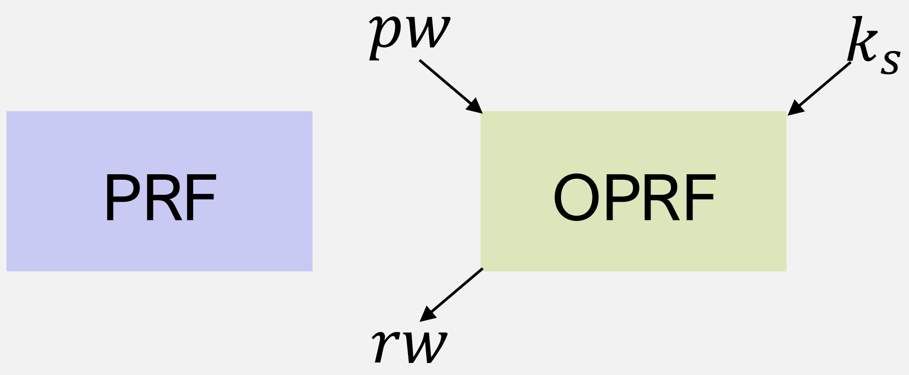
Pseudo-Random Function

PRF

for key derivation

CSS: Building Blocks

(OBLIVIOUS) Pseudo-Random Function



for key derivation
(INTERACTIVE)

Authenticated Encryption

AEAD

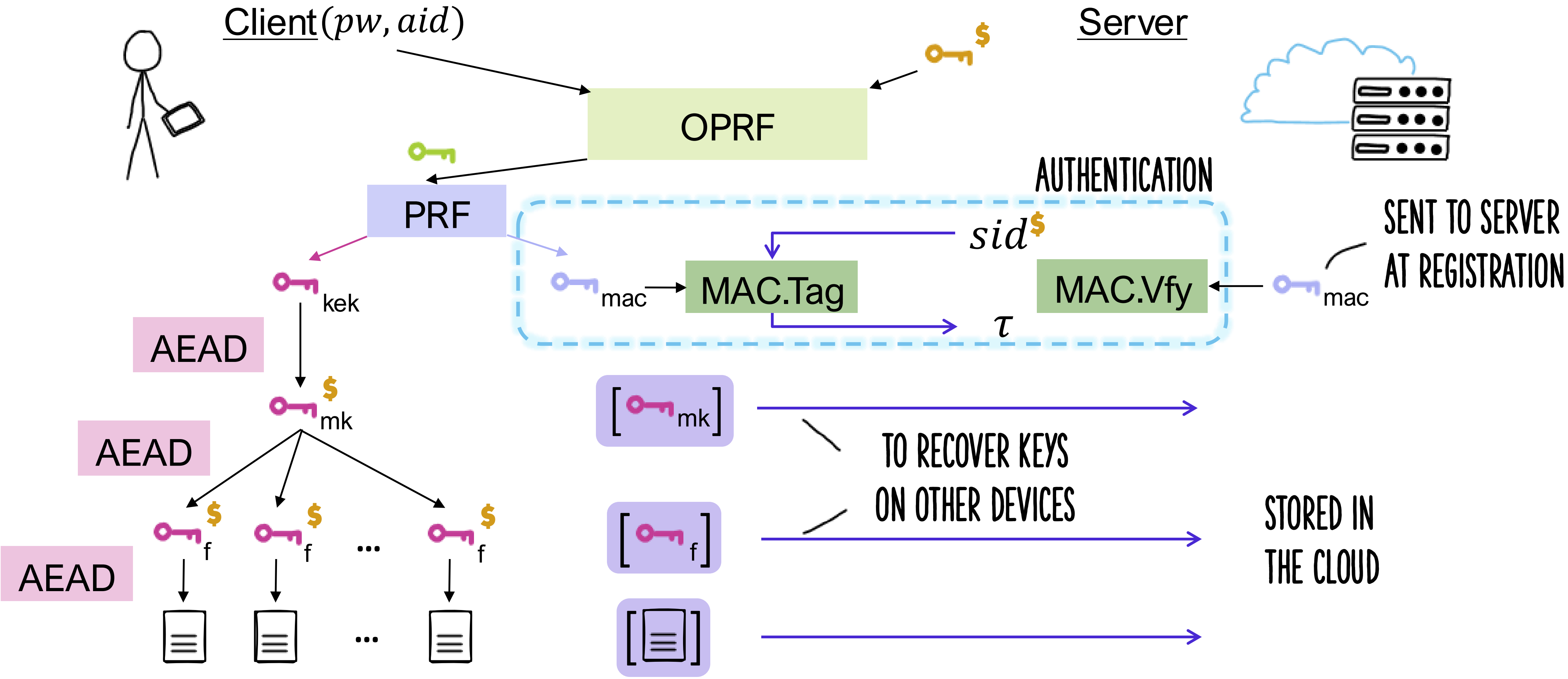
for data confidentiality and integrity

Message Authentication Code

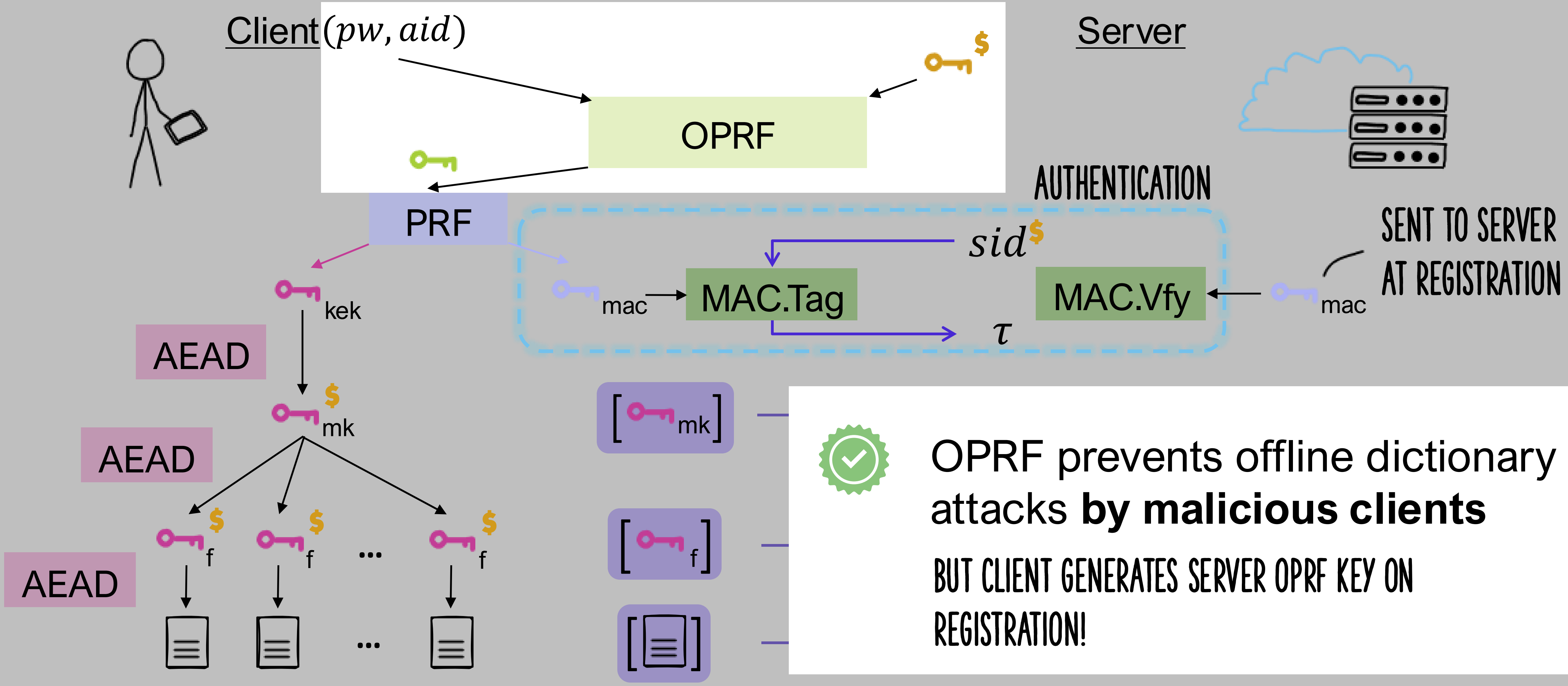
MAC

for user authentication

CSS: Authentication & File Encryption



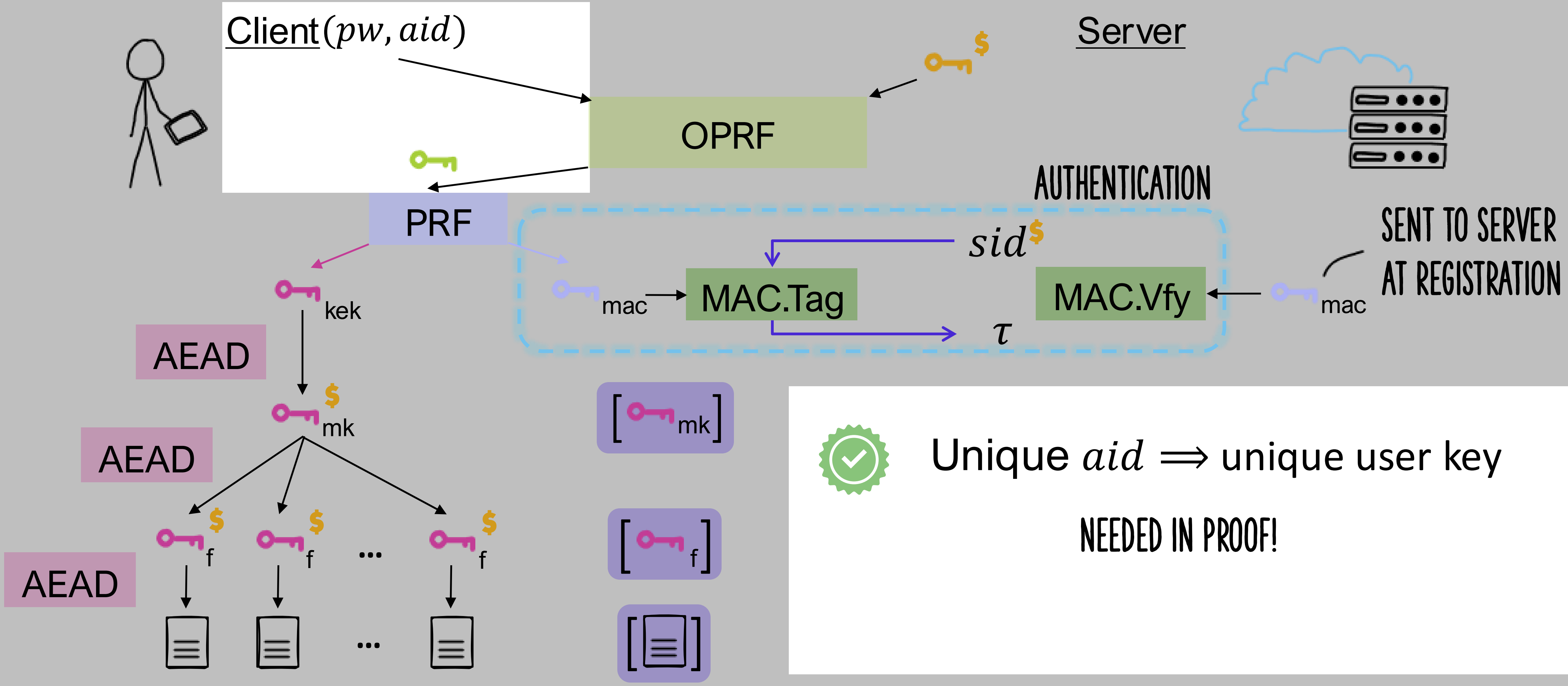
CSS: Authentication & File Encryption



OPRF prevents offline dictionary attacks **by malicious clients**

BUT CLIENT GENERATES SERVER OPRF KEY ON REGISTRATION!

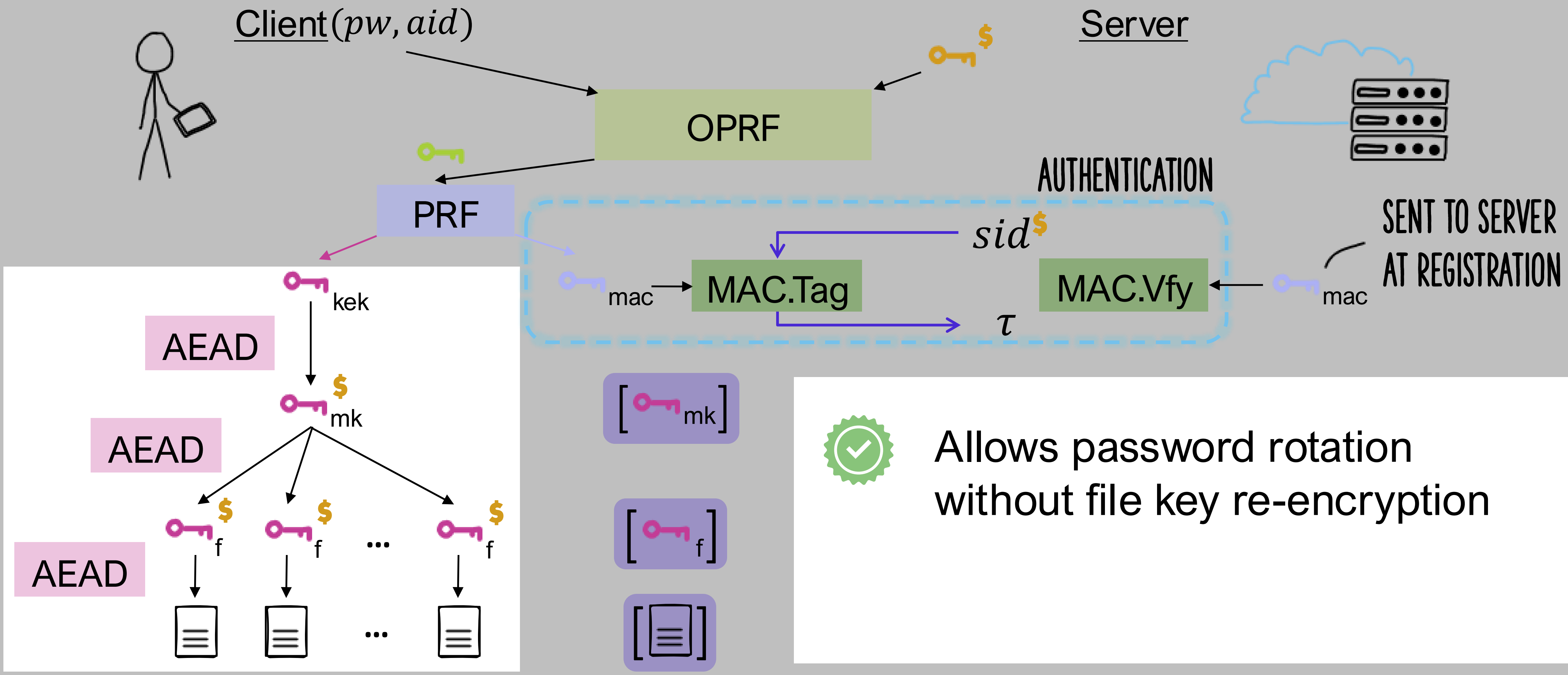
CSS: Authentication & File Encryption



✓ Unique $aid \Longrightarrow$ unique user key

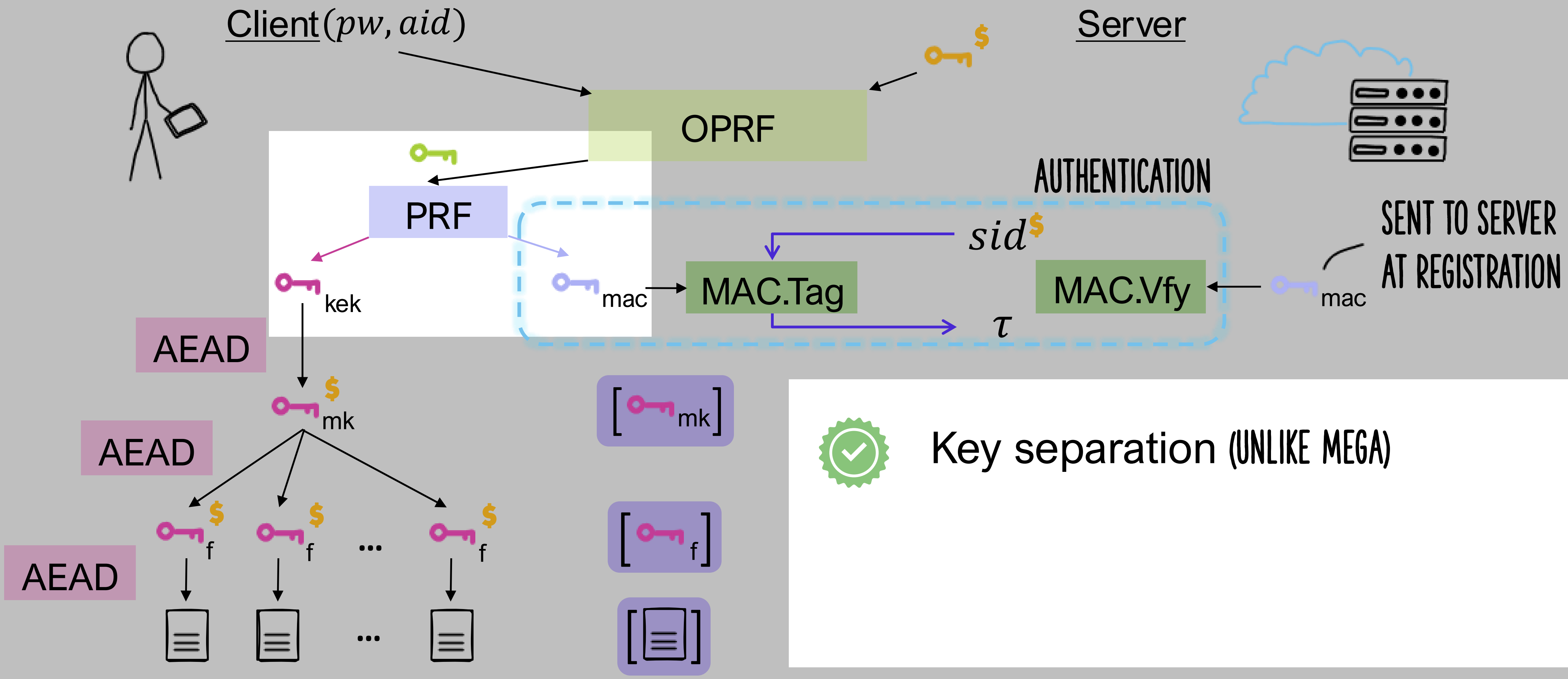
NEEDED IN PROOF!

CSS: Authentication & File Encryption



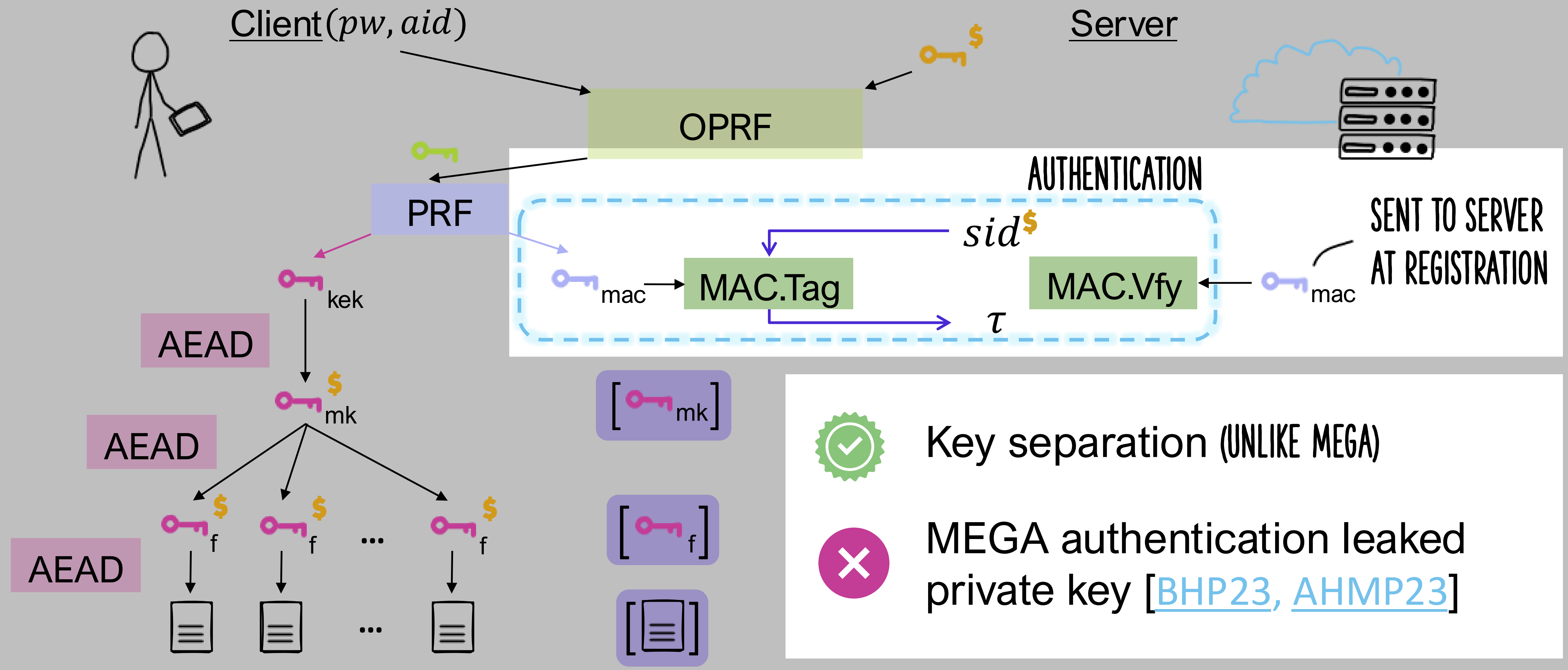
✓ Allows password rotation without file key re-encryption

CSS: Authentication & File Encryption



✓ Key separation (UNLIKE MEGA)

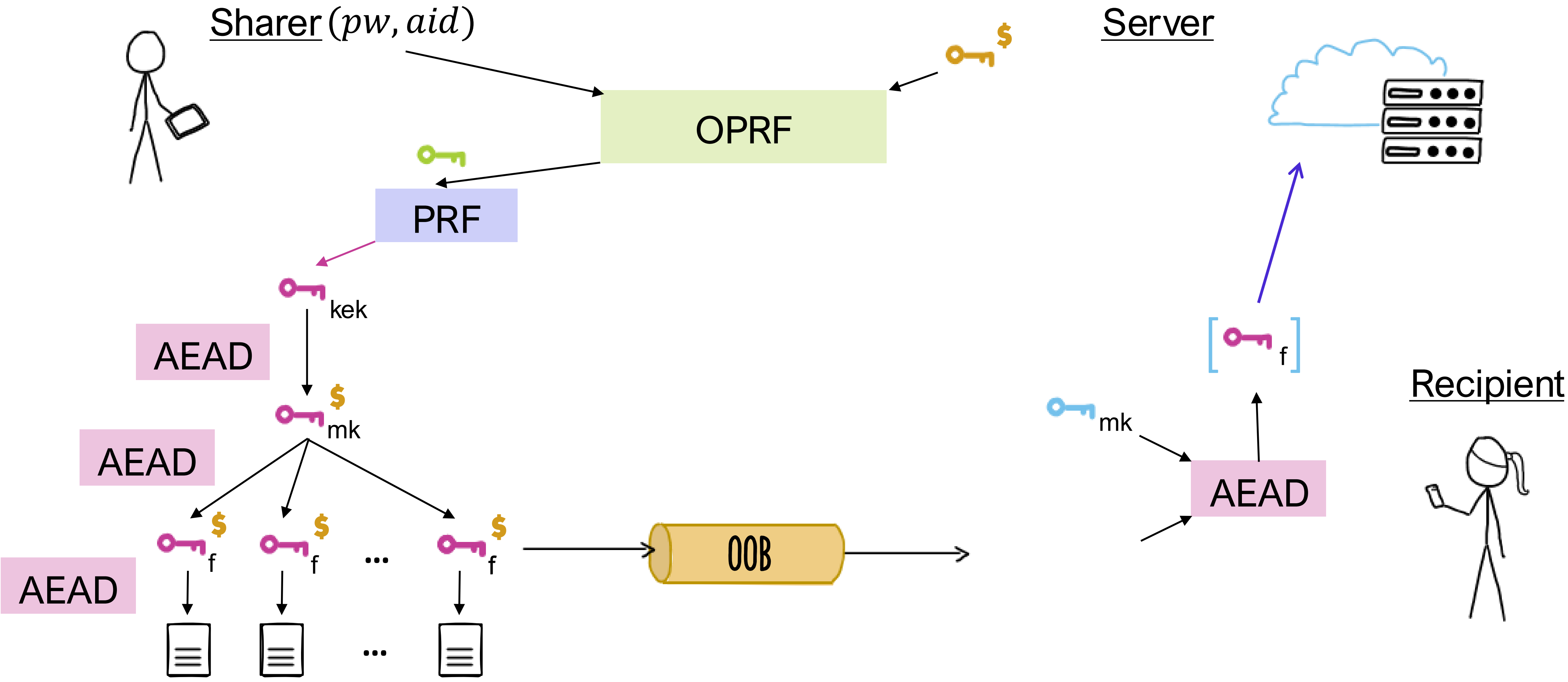
CSS: Authentication & File Encryption



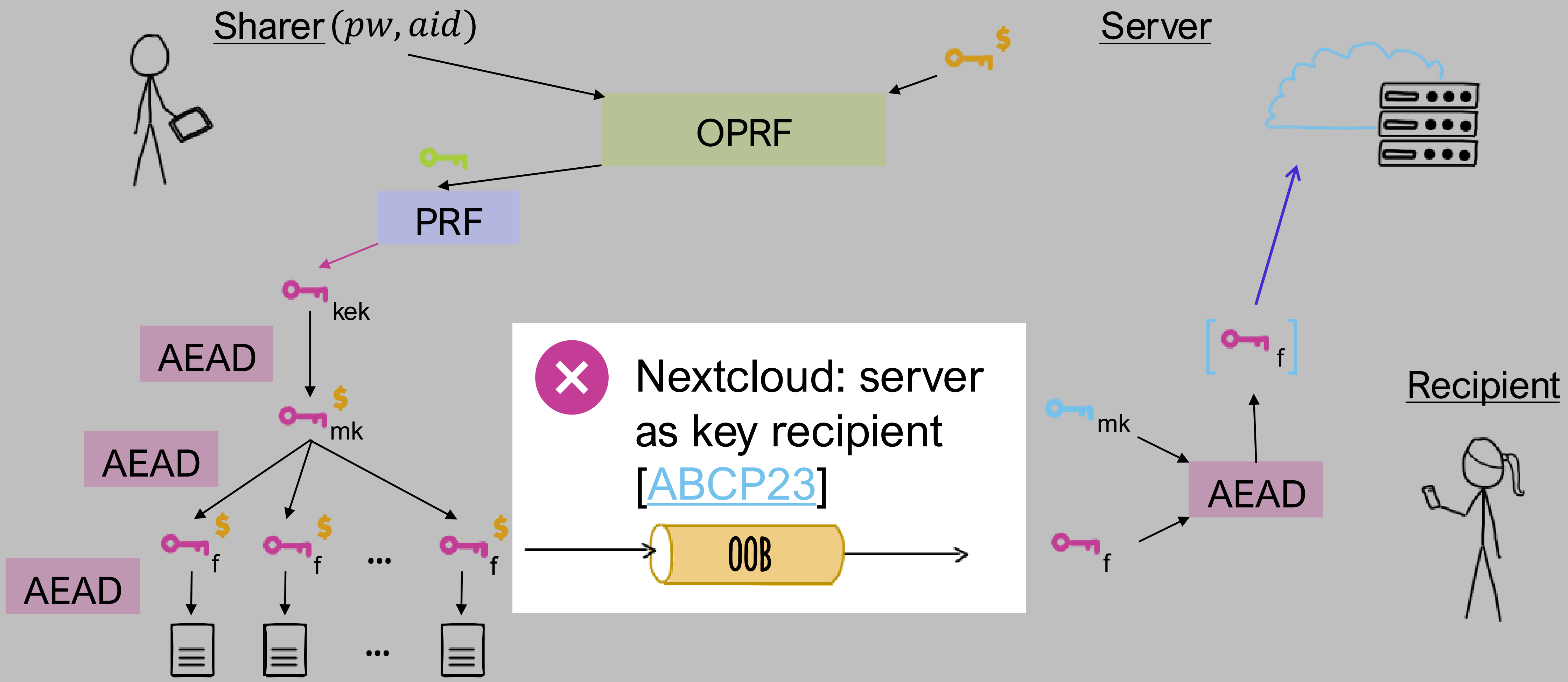
✓ Key separation (UNLIKE MEGA)

✗ MEGA authentication leaked private key [BHP23, AHMP23]

CSS: File Sharing



CSS: File Sharing



Nextcloud: server as key recipient [ABCP23]

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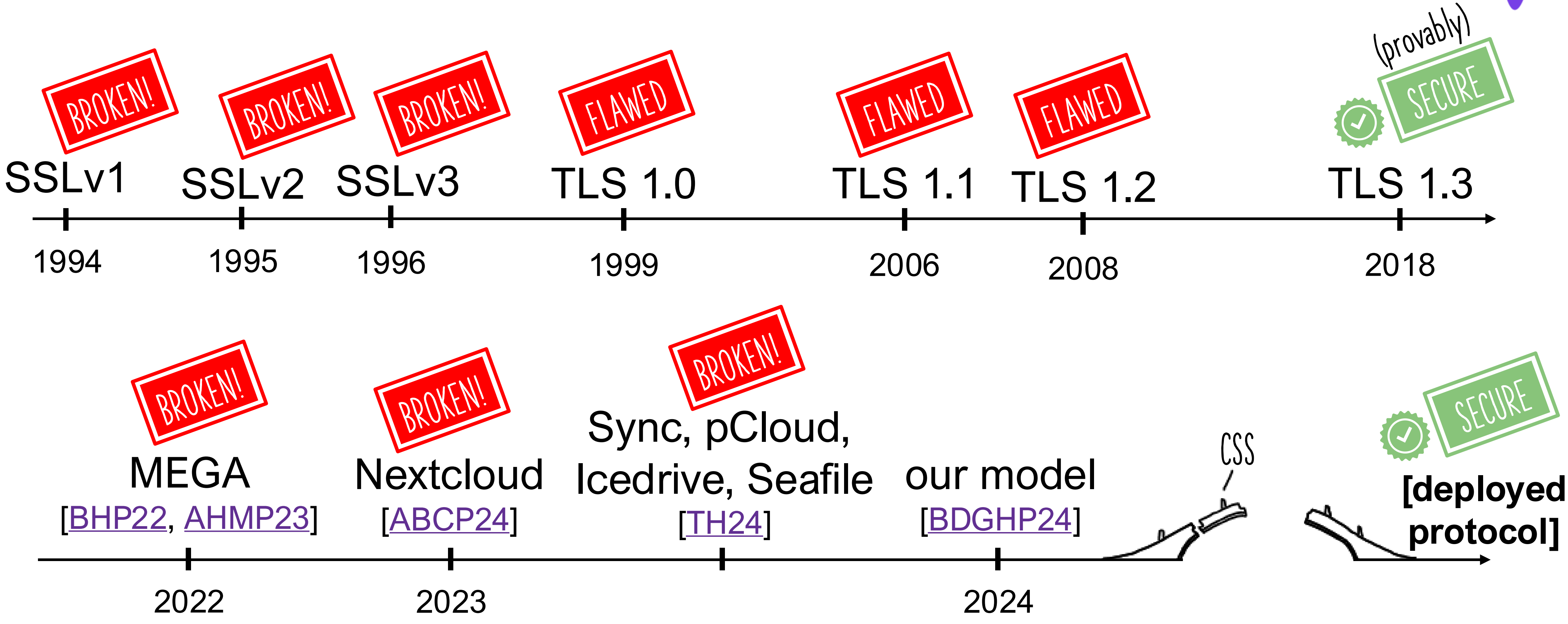
Why Provable Security Is Important

Many Voices.
One Community.

Provable Security



SSLv1 1994

SSLv2 1995

SSLv3 1996

TLS 1.0 1999

TLS 1.1 2006

TLS 1.2 2008

TLS 1.3 2018

MEGA [BHP22, AHMP23] 2022

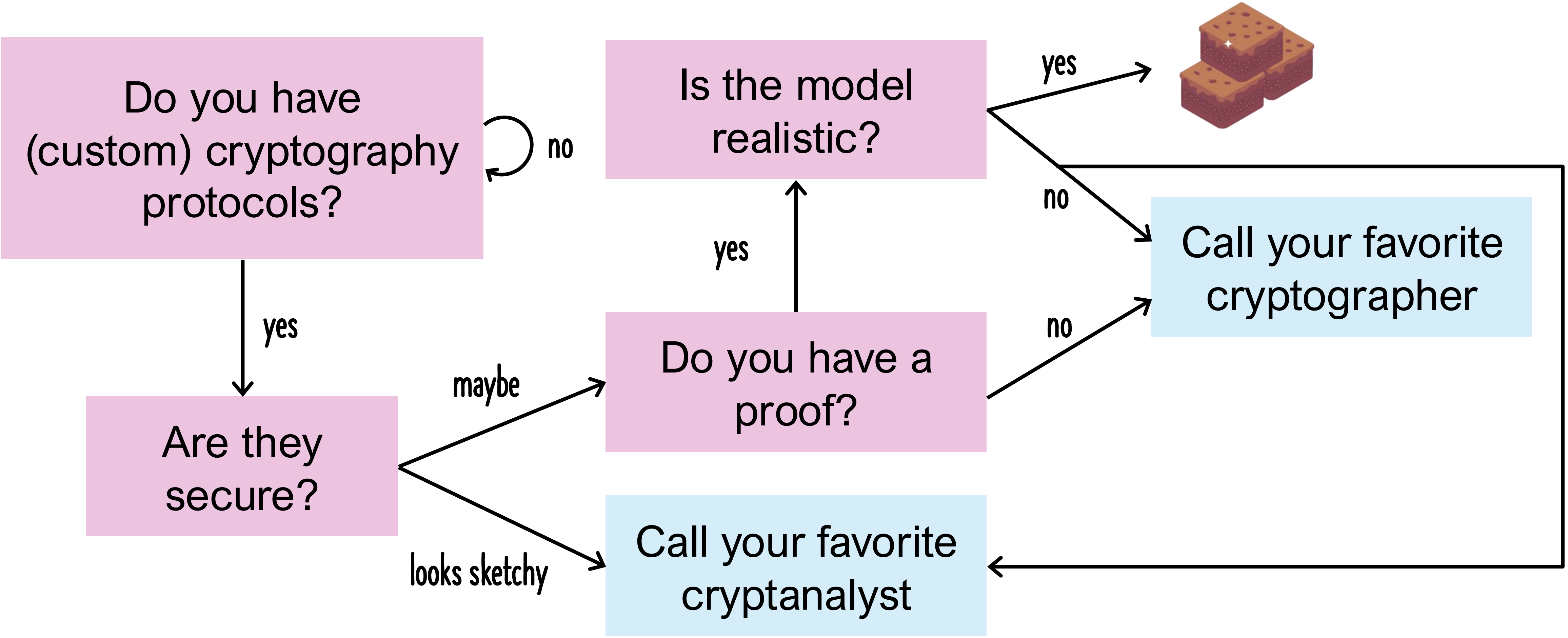
Nextcloud [ABCP24] 2023

Sync, pCloud, Icedrive, Seafile [TH24]

our model [BDGHP24] 2024

[deployed protocol]

APPLIED ~~Apply~~ Cryptography



Do you have (custom) cryptography protocols?

no

yes

Are they secure?

maybe

looks sketchy

Do you have a proof?

yes

no

Is the model realistic?

yes

no

Call your favorite cryptographer

Call your favorite cryptanalyst

Brownie from flaticon

Provable Security for E2EE Cloud Storage

eprint.iacr.org/2024/989

Joint work with:

Matilda Backendal,
Hannah Davis,
Felix Günther,
and Kenny Paterson

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