RSAConference2020

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HUMAN ELEMENT

SESSION ID: **CRYP-W02**

Tickets, Please!

Ticket Mediated Password Strengthening

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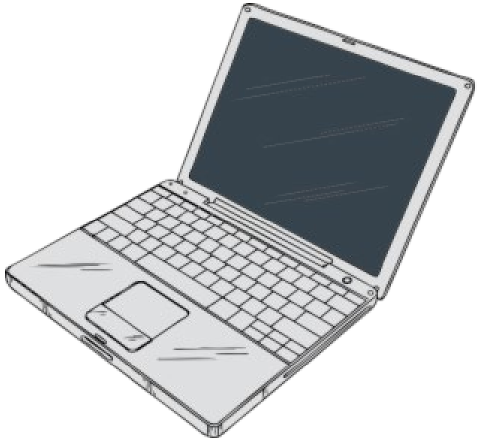
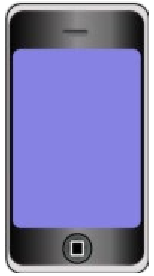
Overview and Background

General Problem: Accessing Local Encrypted Data

- Encrypted data is on my device (laptop, phone, etc.)
  - Probably also extra information: salt, check values, etc.





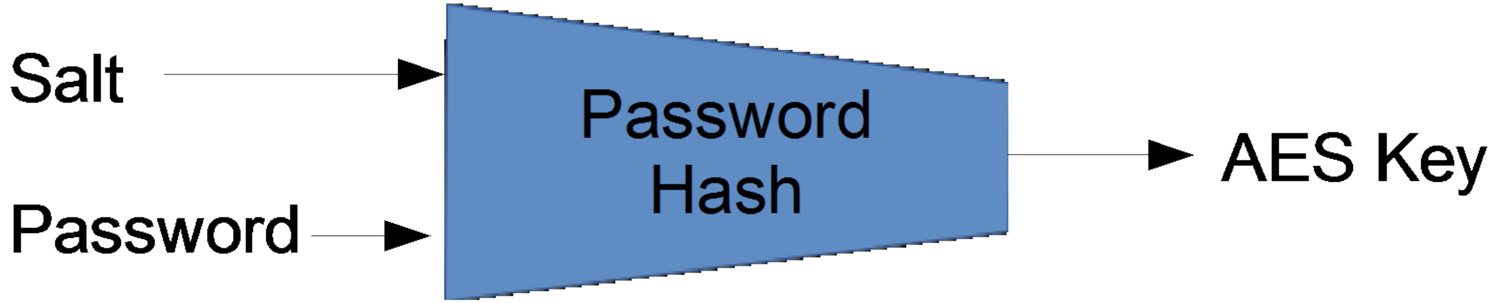
- Only I should be able to unlock it.
  - In practice, this means using a password.

Right password $\Longrightarrow$ unlock the data

Wrong password $\Longrightarrow$ fail

Usual Approach: *Password-Based Key Derivation*

- I have a **password**—need to turn it into an **encryption key**.



- Applications:
  - Disk encryption (laptop)
  - Device encryption (phone, tablet)
  - File encryption (anything)
  - Bitcoin private keys
  - Other cryptographic keys

What Goes Wrong: *Password Guessing Attacks*

Suppose someone steals my device! Can they get my files?

- Online Attack: (User authentication)
  - Each password guess goes through some trusted entity
  - Limit on guesses = how many they will check
  - Easy to rate-limit guesses or lock accounts
- **Offline Attack: (Password-based key derivation)**
  - Attacker moves attack to his own machines
  - Limit on guesses = limit on processors * speed of guessing
  - No way to rate-limit guesses or lock accounts

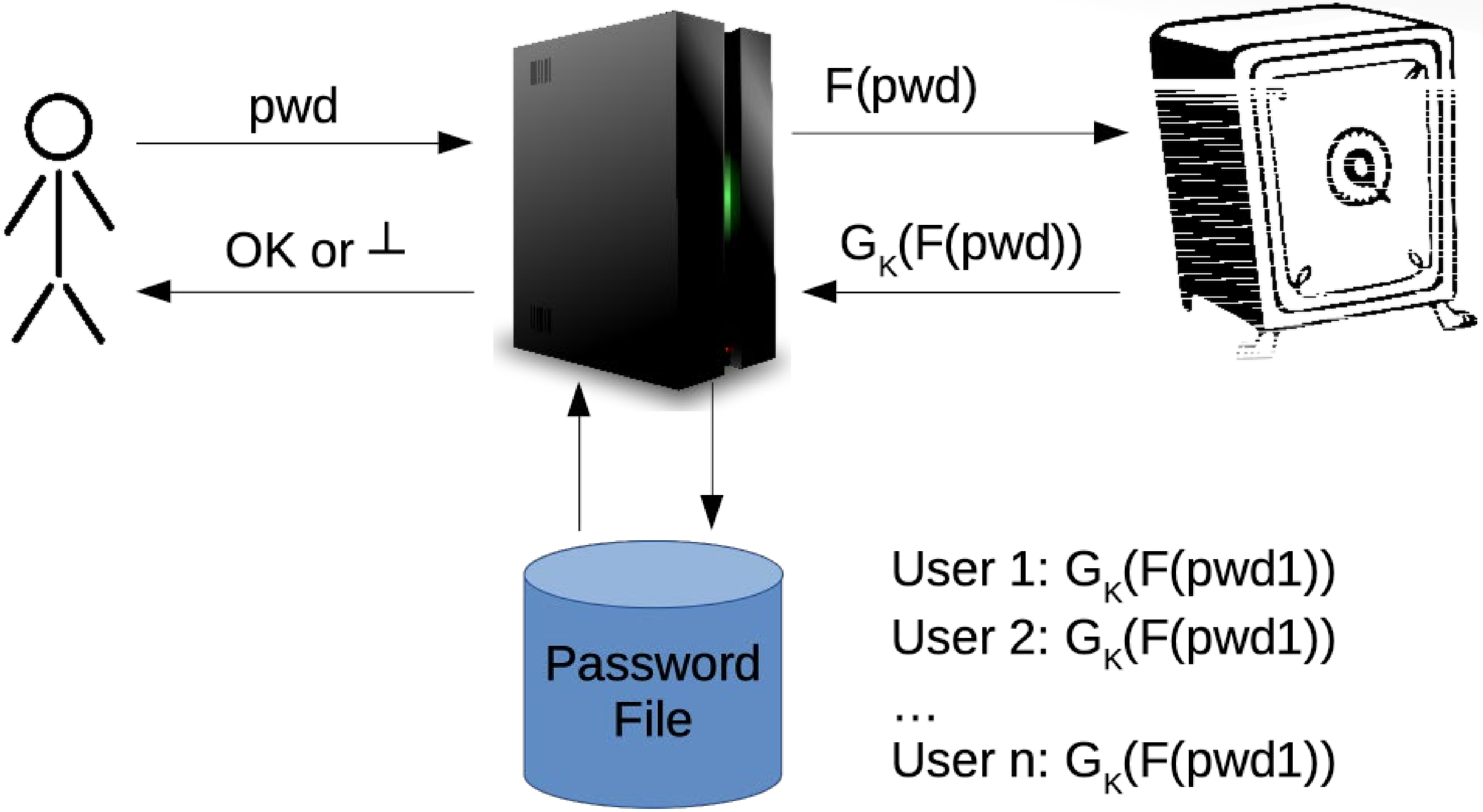
  Same as password guessing after stealing a password file

Potential Solutions

Mostly targeted at logging in, not deriving keys.

- PAKE schemes
  - User and Server establish a shared key from a shared password.
- Password-protected secret sharing
  - User splits secret into shares, gives to many different servers.
  - Password is used along with shares to reconstruct secret.
- **Password strengthening**
  - Use a hardened backend machine to add security

Password Strengthening



- **User:**
  pwd -> Server
- **Server:**
  F(pwd) -> Backend
- **Backend:**
  G(F(pwd)) -> Server
- **Server:**
  Check pwd file
  OK or ⊥ -> User

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TMPS

Ticket Mediated Password Strengthening

TMPS: Elevator Pitch

- Involve server in password-based key derivation.
  - Prevents offline attack, but requires being online to unlock files.
- Interact with server to get ***tickets***.
- Tickets
  - Entitles me to help from server with **one specific computation.**
  - Server will not accept same ticket twice
  - Result: One ticket = one password guess
- Later: Use tickets to unlock my payload key **K***.
  - Have to interact with server to unlock.
- Steal my laptop with 100 tickets on it
  - You can try 100 guesses for my password
  - After that, no way to unlock my files

The Big Idea

- User device has encrypted data and tickets.
  - Tickets can't be used without help of Server.
  - Each ticket bound to ***specific password and payload key***.
- To decrypt data, user device uses password + ticket
  - Interact with Server to decrypt data
  - Server won’t allow ticket to be reused
  - Server learns nothing about password, key, or who’s using ticket.

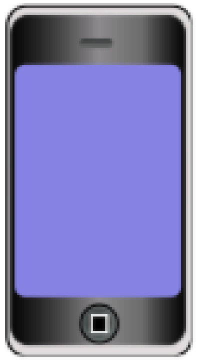
TMPS: The Protocols

In order to make a TMPS scheme work, we need:

- Setup
  - Server establishes its signing and encryption keys.
- **REQUEST**
  - User starts with password **P** and key **K***
  - User ends with t new tickets bound to **(P, K*)**
- **UNLOCK**
  - User starts with password **P’** and a ticket.
  - User interacts with Server.
  - User recovers **K*** **only** if **P’** = **P**, and ticket valid.

REQUEST

- User device must know:
  - **K*** (payload key)
  - **P** (password)
- User forgets **B, C, D** at end.



- Get password **P** from user
- Gen random **S**,**B**
- **E** = Encrypt($\mathbf{PK_s}$,**B**)

Blinded version of **E** →

- Do blind sig

← Blind signature on **E**

- Unblind signature to get **F**
- **C** = Password hash(**S**,**P**)
- **D** = HMAC(**B**,**C**)
- **Z** = Verifiable Enc(**D**,**K***)

- Ticket = (**S**,**E**,**F**,**Z**)

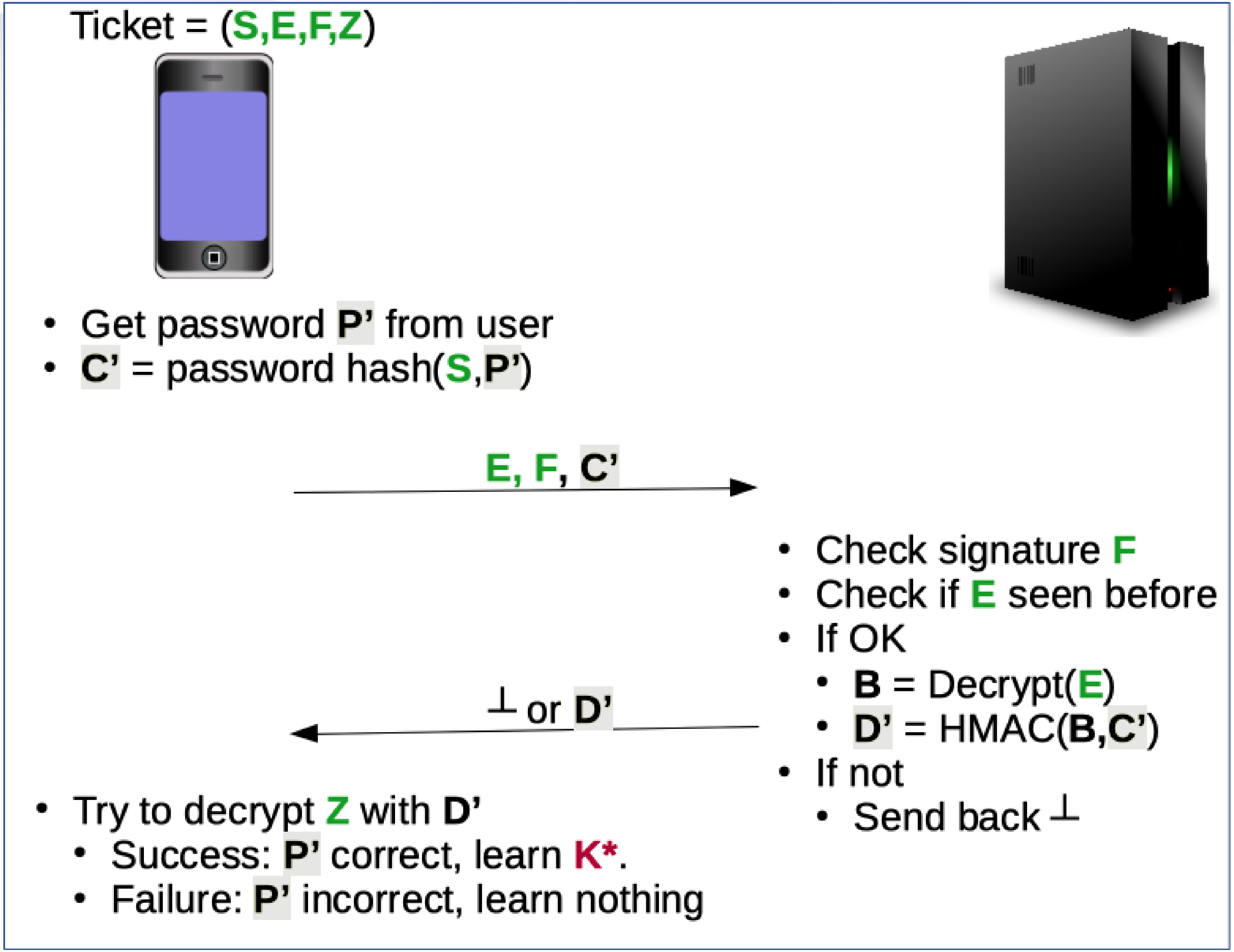
What does a ticket look like?

*Ticket is **S,E,F,Z**.*

- **S** = random salt (different for each ticket)
  - So password hashes sent to server all look different!
- **E** = Secret value **B** encrypted under Server's public key
  - **B** is also different for each ticket
- **F** = blind signature on **E**
  - So Server can't link tickets with users
- **Z** = Verifiable encryption of **K*** under **D**
  - Reminder: **D** is function of salt, password, and **B**
  - Decrypting verifies correctness of password

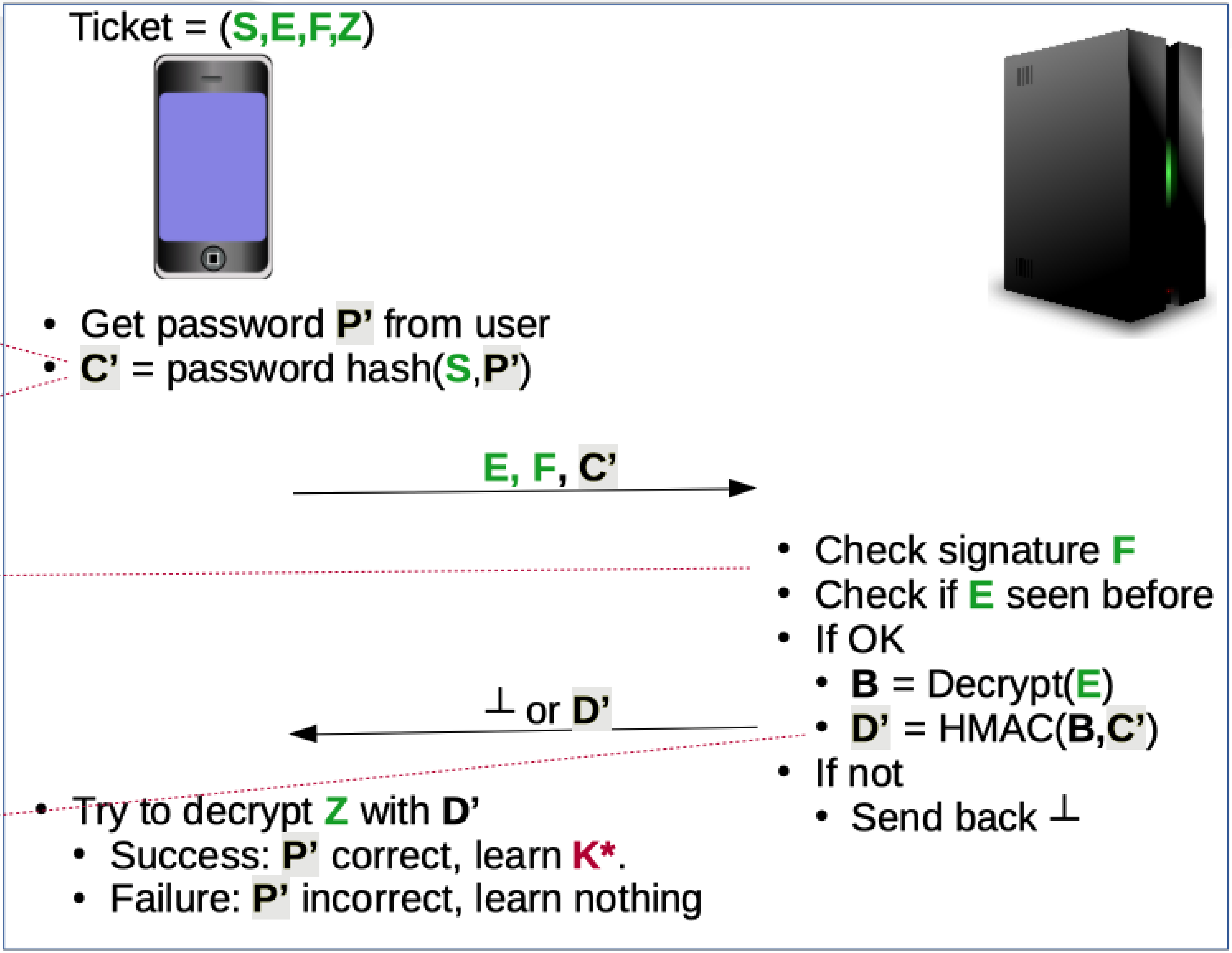
UNLOCK

- Start with ticket and password P’.
- Expend one ticket to test a password guess.



UNLOCK security

1. Random **S** for each ticket: **C’** different for each ticket.
2. Wrong **P’** means wrong **C’**.
3. Repeated or invalid tickets rejected.
4. Wrong C’ -> wrong D’ -> failed decryption



Getting tickets, limiting guesses

- Can only REQUEST new tickets when you know **P** and **K***
  - At device setup, we know both
  - Later, we use a ticket to UNLOCK **K***
    - Then we can run REQUEST as many times as we like!
- Trick for limiting attacker to 10 guesses
  1. REQUEST lots of tickets (say 1000).
  2. Use K* to derive an encryption key K_T.
  3. Encrypt all but 10 tickets with K_T.
  4. Each time we UNLOCK **K***, derive K_T and decrypt tickets
     - *Till we have 10 left again.*

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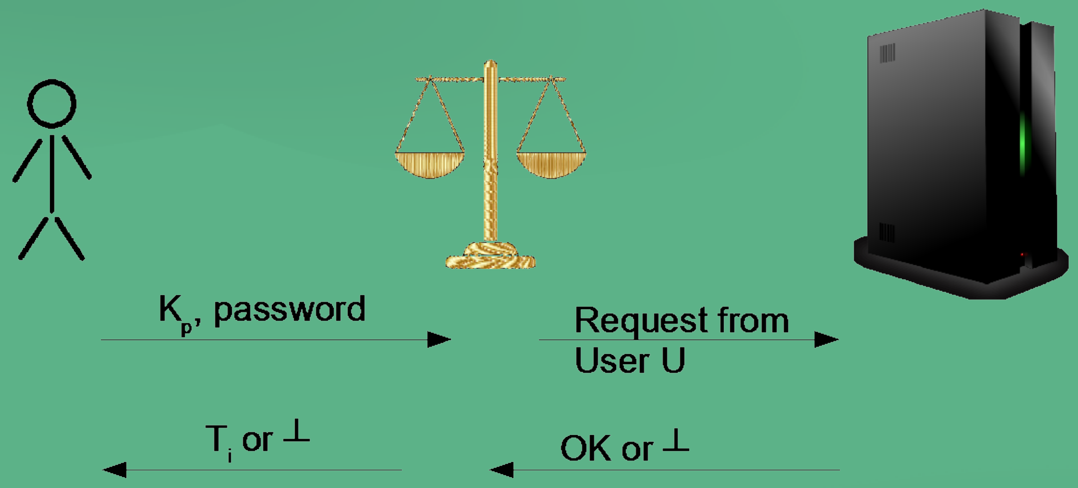

Security and Performance

We took a mixed approach to proving security

- Started with a lot of informal analysis
  - Trying to break it.
- Defined ideal functionality
  - UC Model proof: ideal functionality indistinguishable from our protocols.
- Game-based proofs built on top of UC model proofs
  - Show that ideal functionality actually guarantees our security goals.
  - Give an intuitive definition of what security we achieve.
- Example:

Given t tickets and N possible passwords, attacker unlocks **K*** with prob

$$t/N + \epsilon$$

See paper for details

Memory Requirements

Assuming: RSA with 3072-bit keys, 10 tickets per user per day

- User Device
  - Each ticket takes <1 KiB
  - One year’s supply about 4 MiB
  - This will fit easily on a phone
- Server
  - Need to store/check list of used tickets.
  - Each used ticket needs 16 bytes of storage.
  - 1000 users, one year's worth of tickets: 64 MiB.
  - This will fit in a hash table in RAM.

Computing Requirements: Experimental Results

**We did a minimal Python implementation with no optimizations.*

REQUEST:

Password hash, RSA encryption, blind/unblind signature

- Our implementation: REQUEST 100 tickets:
  - User: 0.7 seconds
  - Server: 7.6 seconds*

UNLOCK:

Password hash, RSA decryption, verify signature

- Our implementation:UNLOCK 1 ticket:
  - User: : 0.0049 seconds
  - Server: 0.002 seconds

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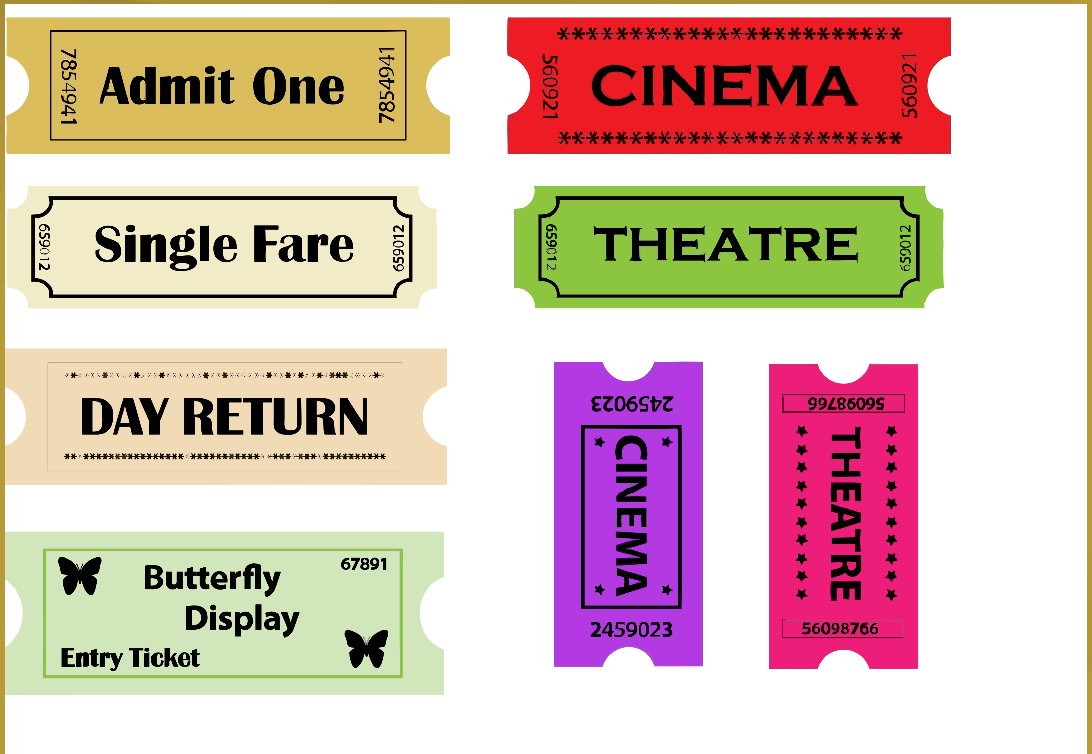
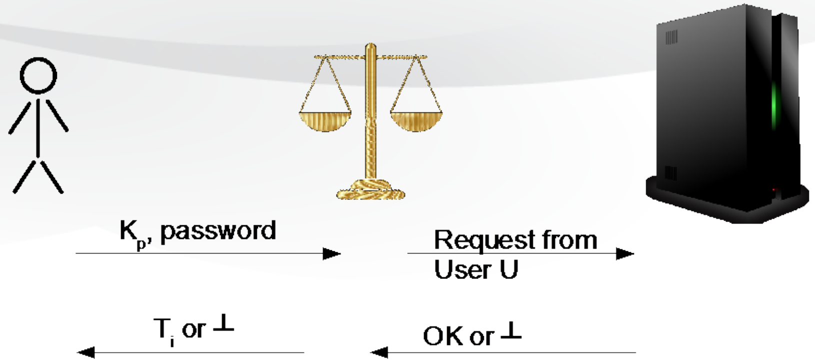


Wrapup

Applying (1)



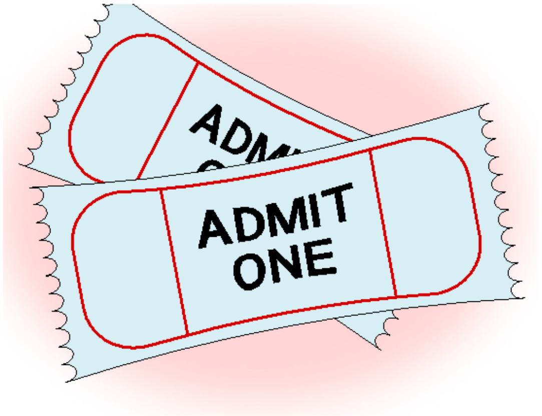
- We introduced TMPS protocol

  Server-assisted local key derivation
  - Someone steals your device = not such a big problem
  - …but you can only unlock your device if you're online

- Many variants described in the paper
  - Offline access (with a security cost)
  - Group signatures instead of blind signatures
  - Proof of work instead of blind signatures

Applying (2)

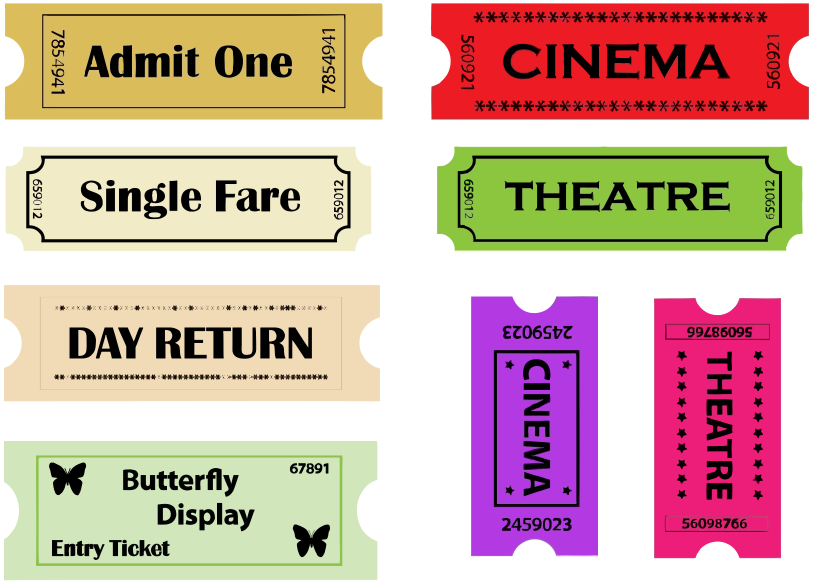
- We have introduced the idea of *tickets*
  - Allow a limited number of cryptographic operations
  - Preserve user privacy
  - Limit access to authorized users



- Tickets seem like a generally useful tool

  Where else could we use them?
  - Enforcing limits on DB queries with differential privacy?
  - Preventing reuse of hash-based signatures?
  - Other stuff?

Questions?


Admit One
7854941
CINEMA
560921
Single Fare
659012
THEATRE
659012
DAY RETURN
2459023
CINEMA
2459023
56098766
THEATRE
56098766
Butterfly Display
67891
Entry Ticket

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Extra Slides

TMPS: Security Goals

- User needs Server and tickets to do anything:
  - Test password guess
  - Learn K*.
  - So when attacker steals my laptop, he can’t do offline attack.
- Server will only help with a valid ticket.
  - Server won't allow reuse of tickets.
  - Can't generate new tickets to help with unknown password/ticket.
- Server learns nothing about:
  - Password **P**
  - Whether **P** right or wrong
  - **K***
  - Which user unlocking key

Main TMPS Protocol: Algorithms and Requirements

- Algorithms we need:
  - Public key encryption
  - Blind signatures*
  - Password hash
  - HMAC

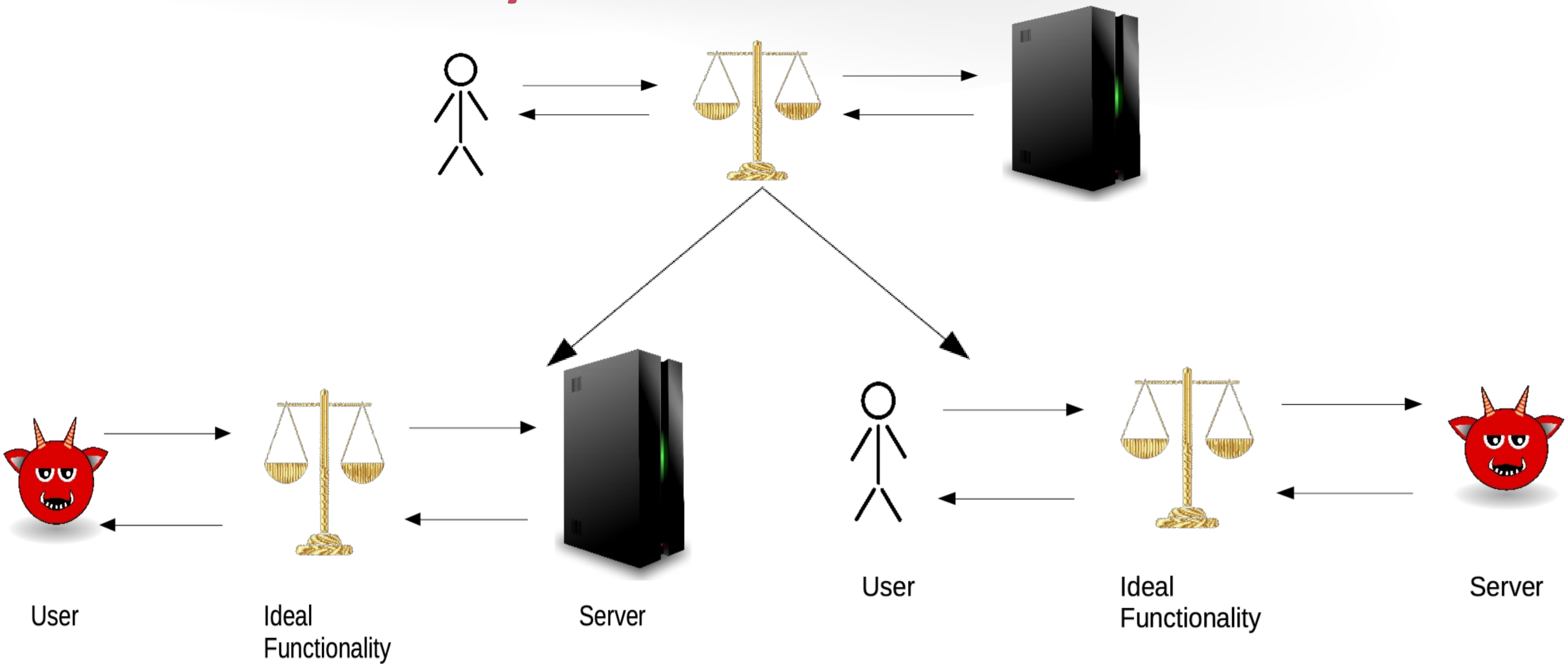
- REQUEST and UNLOCK require interaction with server
- Server stores hashes of all previously-used tickets

Unlock: Why does this work?

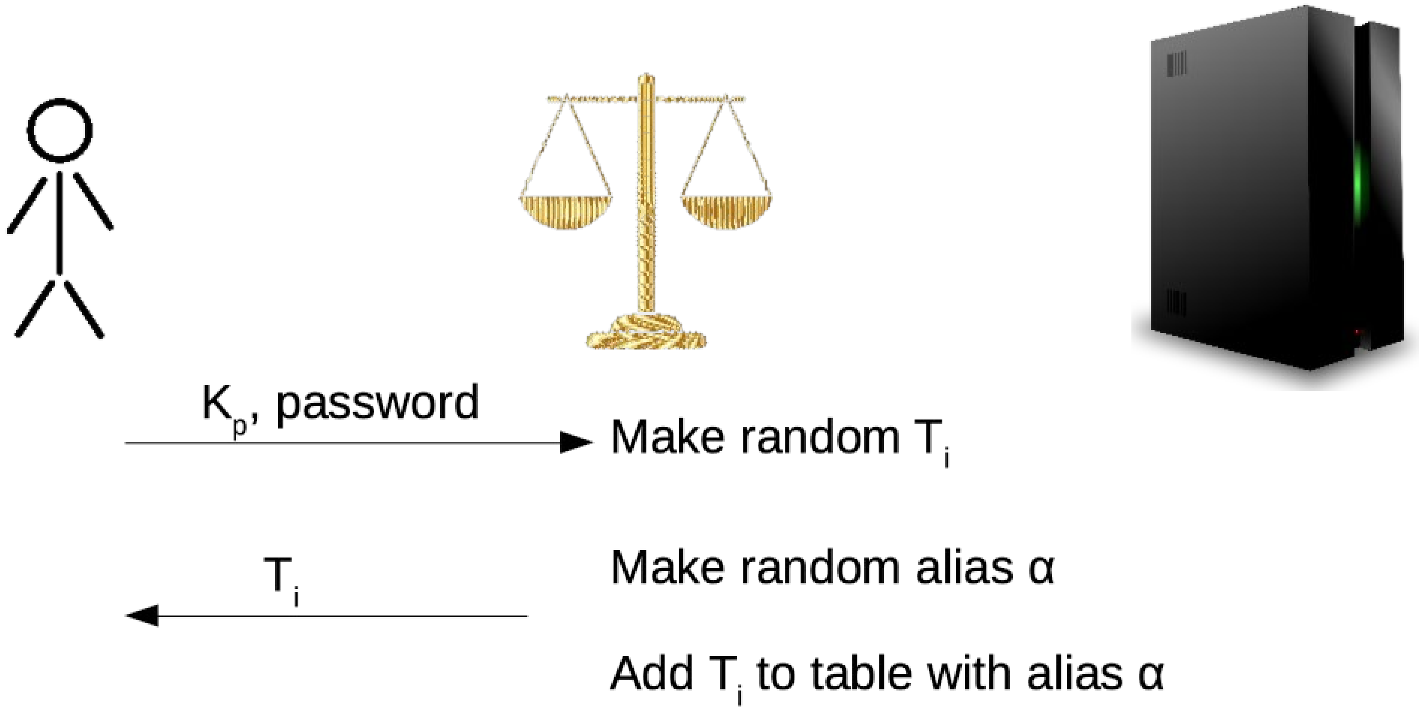
Note: P' is user-entered password, K is payload key,* ticket is **S,E,F,Z**

- User:
  - Hash Password: **C'** = password hash(**S,P'**) ← If **P'** is wrong, **C'** is wrong
  - Send **E,F,C'** to Server.
- Server:
  - Make sure **E** hasn't been used before. ← Previously used tickets get caught here.
  - Check signature in **F.** ← Made-up / unauthorized tickets stop here.
  - Decrypt **E** to get **B**
  - Compute **D'** = HMAC(**B,C'**) ← If **P'** wrong, we get the wrong value for **D'**
  - Send **D'** back to User
- User:
  - Try to decrypt **Z** with **D'** ← If P' wrong, D' wrong, so this fails.

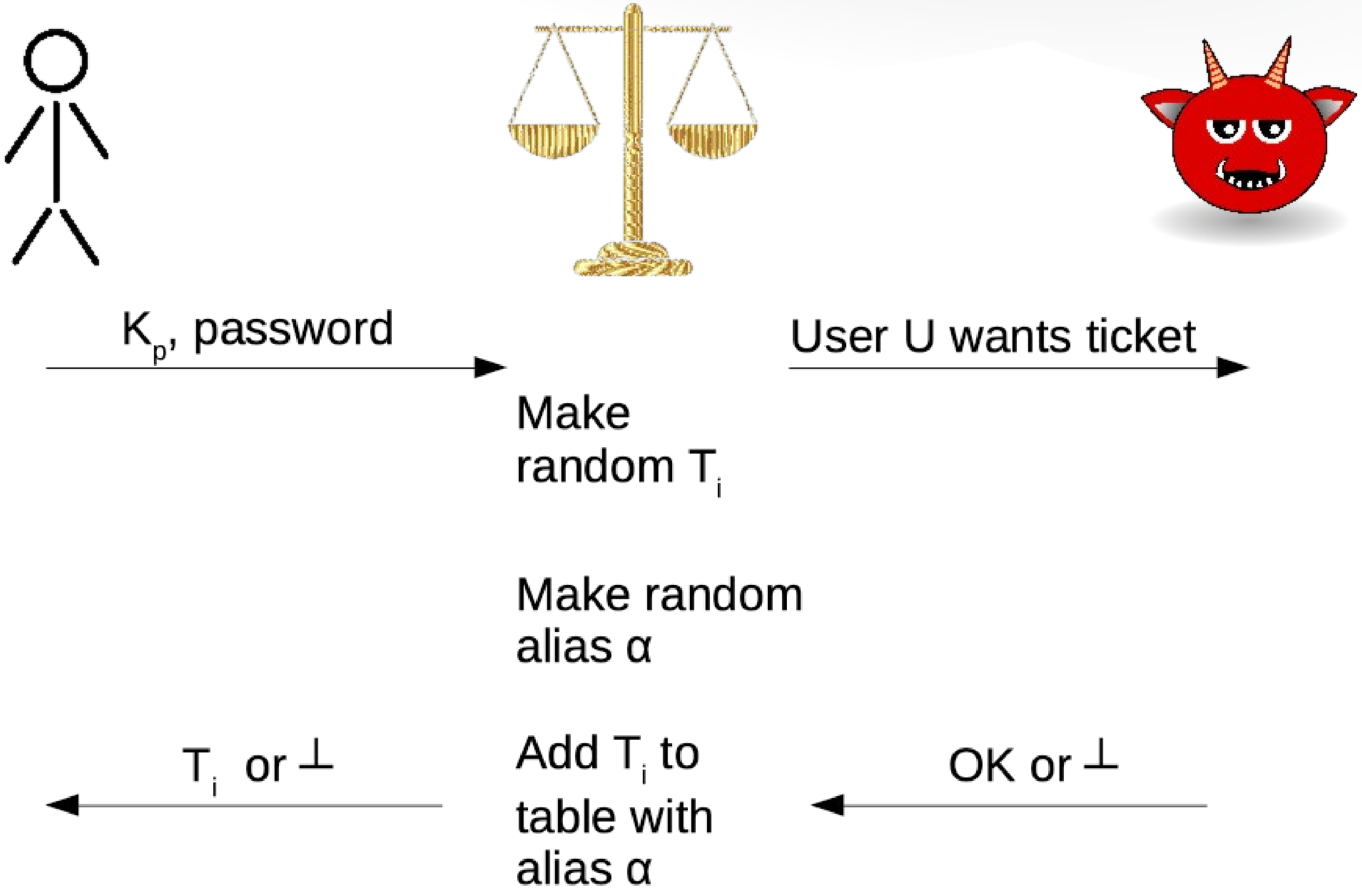
Ideal Functionality



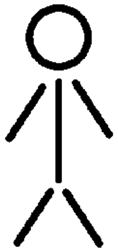
Ideal Functionality: REQUEST with honest server



Ideal Functionality: REQUEST with dishonest server



Ideal Functionality: UNLOCK with honest server



T_i, password →

IF

T_i in not inTable

OR

Password wrong for T_i

THEN

Return $\perp$

← K_p or $\perp$

ELSE

Return K_p

Delete T_i from Table

Ideal Functionality: UNLOCK with dishonest user

T_i, password $\longrightarrow$

IF

T_i in not inTable

OR

Password wrong for T_i

THEN

Return $\perp$

$\longleftarrow$ K_p or $\perp$

ELSE

Return K_p

Delete T_i from Table