Lecture 16: Tokens

CS 181S

Fall 2020

Review: Authentication of humans

- Something you are
  fingerprint, retinal scan, hand silhouette, a pulse
- Something you know
  password, passphrase, PIN, answers to security questions
- Something you have
  physical key, ticket, {ATM, prox, credit} card, token

Authentication tokens

Exercise 1: Authentication Tokens

- What hardware authentication tokens and/or phone apps have you used in real life?

Threat Model: Eavesdropper

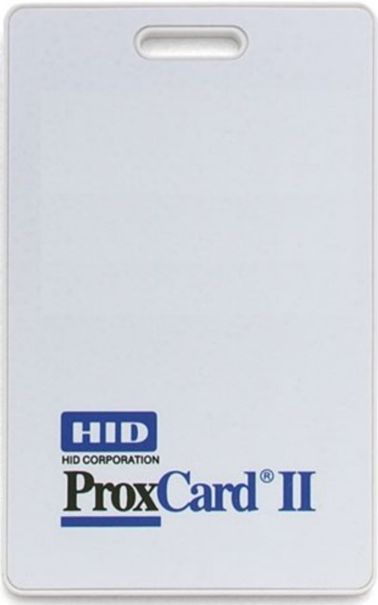
- Adversary can read read and replay messages
- Adversary cannot change messages during protocol execution (not full Dolev-Yao)

Fixed codes (Keyless Entry)

- Token stores a secret value id_T (e.g., key, id, password)
- Reader stores list of authorized ids
- To enter: `T->B: id_T`

- **Attack:** replay: thief sits in car nearby, records serial number, programs another token with same number, steals car
- **Attack:** brute force: serial numbers were 16 bits, devices could search through that space in under an hour for a single car (and in a whole parking lot, could unlock some car in under a minute)
- **Attack:** insider: serial numbers typically show up on many forms related to car, so mechanic, DMV, dealer's business office, etc. must be trusted

Fixed codes (RFIDs)



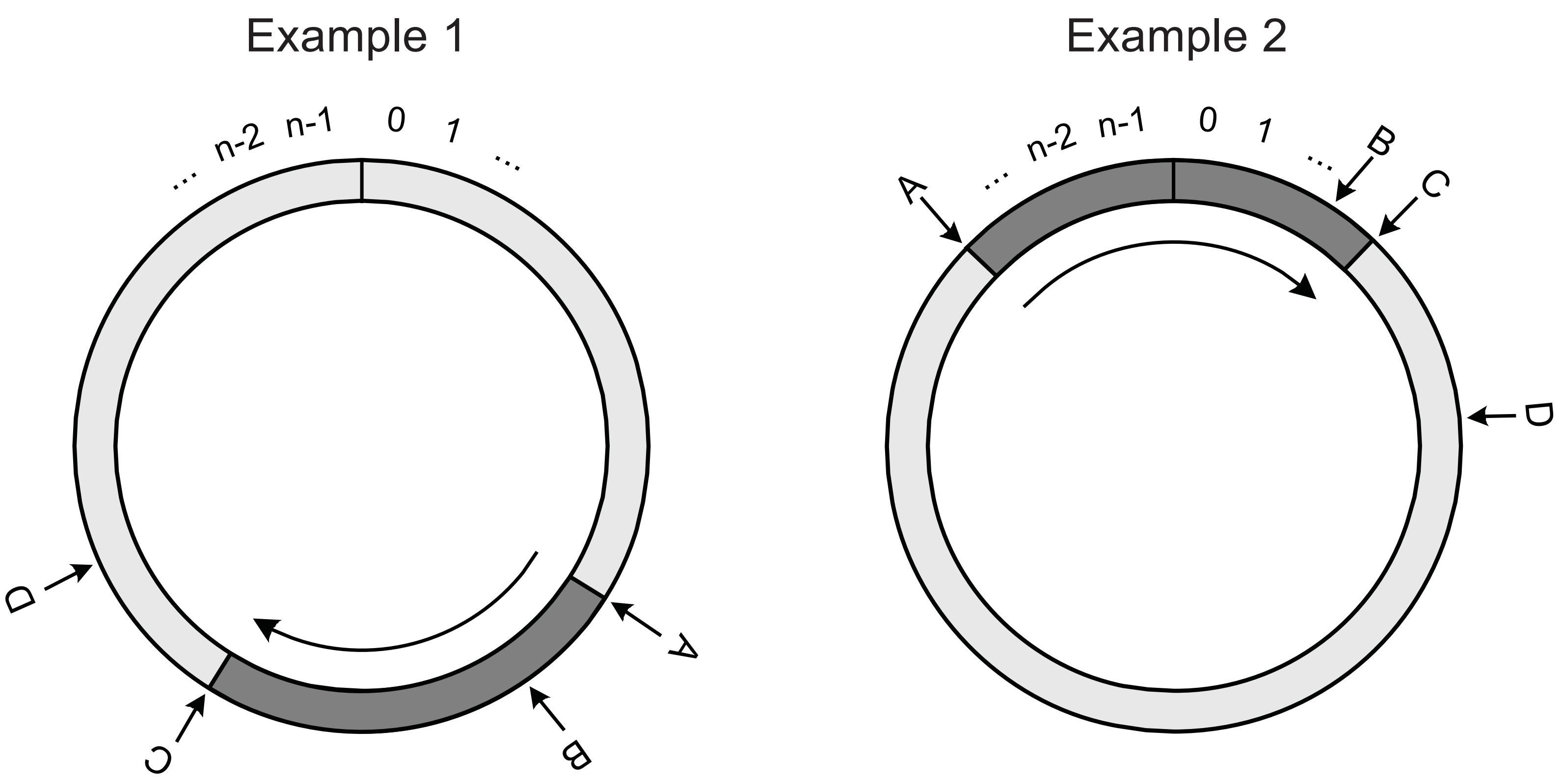
- Token stores a secret value id_T (e.g., key, id, password)
- Reader stores list of authorized ids
- To enter: `T->B: id_T`

- **Attack:** replay: thief sits nearby, records serial number, programs another token with same number, authenticates
- **Attack:** privacy: adversary tracks token usage across system and learns user attributes and/or behaviors

"Rolling" codes

- There is a root key, rk, for the barrier
- Token stores:
  - serial number T
  - shared key k, which is H(rk, T)
  - nonce N, which is a sequence counter
- Barrier stores:
  - serial numbers and current nonces for all authorized tokens
  - as well as root key rk
- To enter: **`T->B:  T, MAC(T, N; k)`**
  - And T increments N
  - So does B if MAC tag verifies
- **Problem:** desynchronization of nonce

Rolling window



A - Value from last valid message

B - Accepted counter values

C - End of window

D - Rejected counter values

Image source: [Atmel]

One-Time Passwords

- OTP may be deemed valid only once (the first time)
- Adversary cannot predict future OTPs, even with complete knowledge of what passwords have already been used

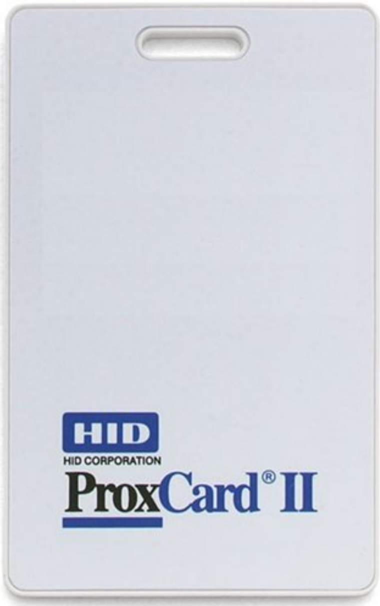
Unique challenge: MACs

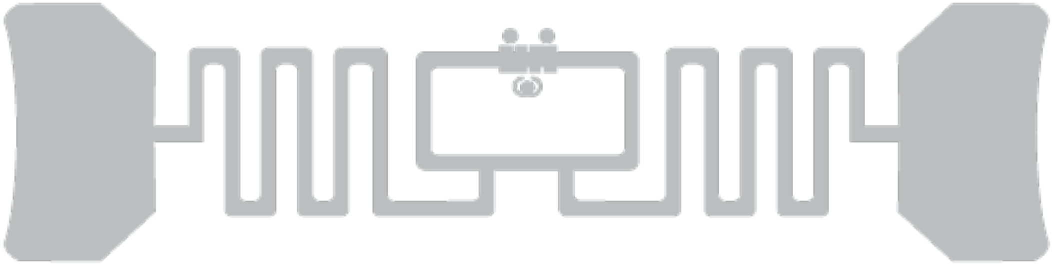
Assume: B stores a MAC key for each token,
i.e., a set of tuples (id_T, uid, k_T), and T stores k_T

```
1. U->B: I want to authenticate with T
2. B: invent unique nonce N
3. B->T: N
4. T: t=MAC(N; k_T)
5. T->B: id_T, t
6. B: lookup (uid, kT) for id_T;
      U is authenticated as uid if t=MAC(N; k_T)
```

Non-problem: key distribution: already have to physically distribute tokens
Problem: key storage at B: what if key is stolen?

EPC Gen2v2 RFID Cards





Exercise 2: Digital Signatures

Assume: B stores a MAC key for each token and T stores k_T

Assume: B stores a verification key for each token and T stores signing key k_T

```
1. U->B: U,T
2. B: invent nonce N
3. B->T: N
4. T: t=MAC(N; k_T)
5. T->B: id_T, t
6. B: U is auth as uid
if t=MAC(N; k_T)
```

Exercise 2: Digital Signatures

Assume: B stores a MAC key for each token and T stores k_T

```
1. U->B: U,T
2. B: invent nonce N
3. B->T: N
4. T: t=MAC(N; k_T)
5. T->B: id_T, t
6. B: U is auth as uid if t=MAC(N; k_T)
```

Assume: B stores a verification key for each token and T stores signing key k_T

```
1. U->B: U,T
2. B: invent nonce N
3. B->T: N
4. T: s=Sign(N; k_T)
5. T->B: id_T, s
6. B: U is auth as uid if Ver(N; s; K_T)
```

U2F

Remote Authentication

- (Usually) No communication from server to token
- Usability considerations render challenge-response impractical

Hypothetical protocol

Assume: S stores a set of tuples (id_T, uid, kT, pin), and T stores kT

```
1. U->L: I want to authenticate as uid to S
2. L and S: establish secure channel
3. L->U: Enter PIN and code on my keyboard
4. T->U: code = MAC(time@T, id_T; kT)
5. U->L: pin, code
6. L: compute h = H(pin, code)
7. L->S: uid, h
8. S: lookup (pin, id_T, kT) for uid;
      id_Hu is authenticated
        if h=H(pin, MAC(time@S, id_T; kT))
```

Engineering challenge: clock synchronization

Exercise 3: Clock Synchronization

- Assume that timestamps have a granularity of 1 second
- Assume that T and S last synchronized their clocks 24 hours ago
- Assume that the network latency is 1-10 seconds
- Assume that the clock drift between the two clocks is at most 10%

- If S receives a message at noon, what is the maximum and minimum timestamp it should accept?

Exercise 3: Clock Synchronization

- Assume that timestamps have a granularity of 1 second
- Assume that T and S last synchronized their clocks 24 hours ago (at noon the previous day)
- Assume that the network latency is 1-10 seconds
- Assume that the clock drift between the two clocks is at most .01 seconds per second

- If S receives a message at noon, what is the maximum and minimum timestamp it should accept?

SecurID

- Token: displays code that changes every minute
  - LCD display
  - Internal clock (1 minute granularity)
  - No input channel
  - Can compute hashes, MACs
  - Stores a secret
- Ideas used:
  - replace nonce with current time
  - use L to input PIN
  - server checks $\pm$10 minutes to allow for clock drift

Hash chains

- Let $H^i(x)$ be i iterations of H applied to x
  - $H^0(x) = x$
  - $H^{i+1}(x) = H(H^i(x))$
- **Hash chain:** $H^1(x), H^2(x), H^3(x), ..., H^n(x)$

OTPs from hash chains

- Given a randomly chosen, large, secret seed s...
- **Bad idea:** generate a sequence of OTPs as a hash chain: $H^1(s)$, $H^2(s)$, ..., $H^n(s)$
  - Suppose untrusted public machine learns $H^i(s)$
  - From then on can compute next OTP $H^{i+1}(s)$ by applying H, because hashes are easy to compute in forward direction
  - But hashes are hard to invert...
- **Good idea [Lamport 1981]:** generate a sequence of OTPs as a reverse hash chain: $H^n(s)$, ..., $H^1(s)$
  - Suppose untrusted public machine learns $H^i(s)$
  - Next password is $H^{i-1}(s)$
  - Computing that is hard!

Protocol (almost)

Assume: S stores a set of tuples (uid, n_u, s_u)

```
1. U->L->S: uid
2. S: lookup (n_u, s_u) for uid;
      let n = n_u;
      let otp = H^n(s_u);
      decrement stored n_u
3. S->L->U: n
4. U: p = H^n(s_u)
5. U->L->S: p
6. S: uid is authenticated if p = otp
```

Problem: S has to compute a lot of hashes if authentication is frequent

Solution to S's hash burden

- S stores **`last`**: last successful OTP for id_Hu, where **`last`** = $H^{n+1}(s)$
- S receives **`next`**: next attempted OTP, where if all is well **`next`** = $H^{n}(s)$
- S checks its correctness with a single hash:
  - H(**`next`**) = $H(H^{n}(s)) = H^{n+1}(s)$ = **`last`**
- And if correct S updates last successful OTP: **`last := next`**

Next problem: what if Hu and S don't agree on what password should be used next? i.e., become *desynchronized*

- network drops a message
- attacker does some online guessing (impersonating Hu) or spoofing (impersonating S)

Solution to desynchronization

- Hu and S independently store index of last used password from their own perspective, call them m_Hu and m_S
  - Neither is willing to reuse old passwords (i.e., higher indexes)
  - But both are willing to skip ahead to newer passwords (i.e., lower indexes)
- To authenticate:
  - S requests index m_S
  - Hu computes min(m_S, m_Hu), sends that along with OTP for it
  - S and Hu adjust their stored index

Next problem: running out of passwords: have to bother sysadmin periodically

Salted passwords as seed

- Compute OTP as H^n(pass,salt)
- Whenever Hu wants to generate new set of OTPs:
  - find a local machine Hu trusts (could be offline, phone, ...)
  - request new salt from S
  - enter pass
  - generate as many new OTPs as Hu likes by running hash forward
  - let S know how many were generated and what the last one was

S/KEY

[RFC 1760]:

- Instantiation of that protocol for particular hash algorithms and sizes
- But same idea works for newer hashes and larger sizes

Exercise 4: Feedback

1. Rate how well you think this recorded lecture worked
   1. Better than an in-person class
   2. About as well as an in-person class
   3. Less well than an in-person class, but you still learned something
   4. Total waste of time, you didn't learn anything

2. How much time did you spend on this video lecture (including time spent on exercises)?

3. Do you have particular questions you would like me to address class?

4. Do you have any other comments or feedback?