Crypto protocols

ACS R209: Computer Security –
Principles and Foundations
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Security Protocols

- Security protocols are the intellectual core of security engineering
- They are where cryptography and system mechanisms meet
- They allow trust to be taken from where it exists to where it's needed
- But they are much older then computers…

Real-world protocol

- Ordering wine in a restaurant
  - Sommelier presents wine list to host
  - Host chooses wine; sommelier fetches it
  - Host samples wine; then it's served to guests
- Security properties?

Real-world protocol

- Ordering wine in a restaurant
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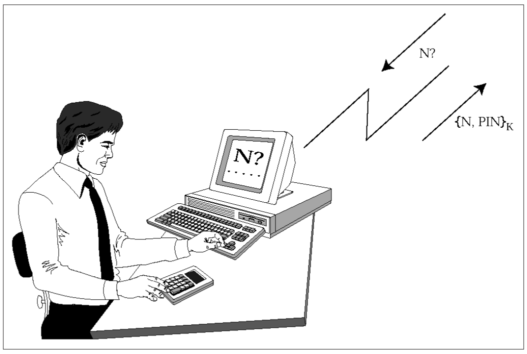
- Security properties
  - Confidentiality – of price from guests
  - Integrity – can't substitute a cheaper wine
  - Non-repudiation – host can't falsely complain

Car unlocking protocols

- Principals are the engine controller E and the car key transponder T
- Static ($T \rightarrow E$: KT)
- Non-interactive
  $T \rightarrow E$: T, $\{T,N\}_{KT}$
- Interactive
  $E \rightarrow T$: N
  $T \rightarrow E$: $\{T,N\}_{KT}$
- N is a ‘nonce’ for ‘number used once’. It can be a serial number, a random number or a timestamp

Two-factor authentication



$S \rightarrow U$: N
$U \rightarrow P$: N, PIN
$P \rightarrow U$: $\{N, PIN\}_{KP}$

Key management protocols

- Suppose Alice and Bob each share a key with Sam, and want to communicate?
  - Alice calls Sam and asks for a key for Bob
  - Sam sends Alice a key encrypted in a blob only she can read, and the same key also encrypted in another blob only Bob can read
  - Alice calls Bob and sends him the second blob
- How can they check the protocol's fresh?

Needham-Schroder

- 1978: uses 'nonces' rather than timestamps

  $A \rightarrow S$: A, B, NA

  $S \rightarrow A$: $\{N_A, B, K_{AB}, \{K_{AB}, A\}_{KBS}\}_{KAS}$

  $A \rightarrow B$: $\{K_{AB}, A\}_{KBS}$

  $B \rightarrow A$: $\{NB\}_{KAB}$

  $A \rightarrow B$: $\{NB - 1\}_{KAB}$
- The bug, and the controversy…

Identify Friend or Foe (IFF)

- Basic idea: fighter challenges bomber

  $F \rightarrow B$: N

  $B \rightarrow F$: $\{N\}_K$

- What can go wrong?

Identify Friend or Foe (IFF)

- Basic idea: fighter challenges bomber

  $F \rightarrow B$: N

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- What if the bomber reflects the challenge back at the fighter's wingman?

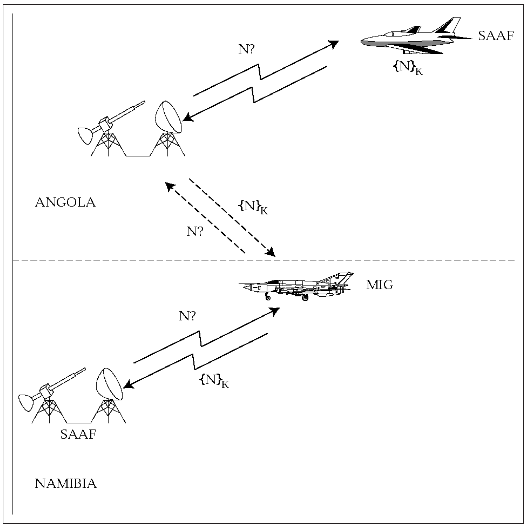
  $F \rightarrow B$: N

  $B \rightarrow \mathit{F}$: N

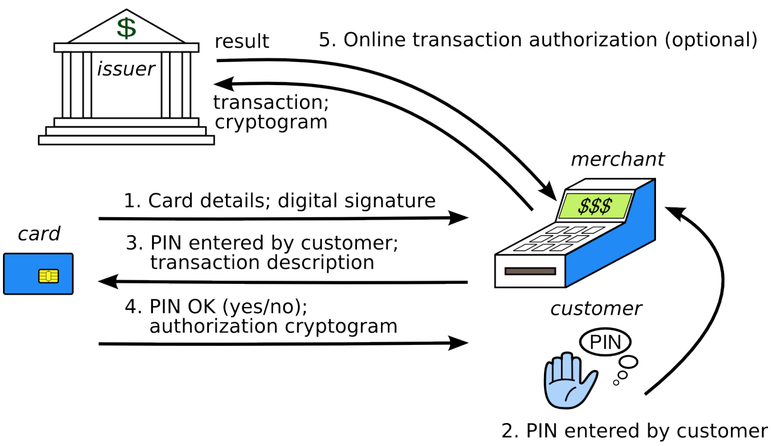
  $\mathit{F} \rightarrow B$: $\{N\}_K$

  $B \rightarrow F$: $\{N\}_K$

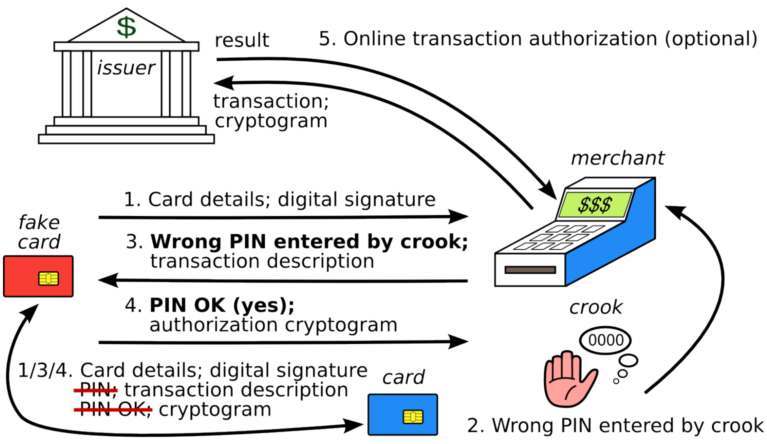
IFF (2)



A normal EMV transaction



The ‘No-PIN’ attack (2010)



Fixing the ‘No PIN’ attack

- In theory: might block at terminal, acquirer, issuer
- In practice: may have to be the issuer (as with terminal tampering, acquirer incentives are poor)
- Barclays introduced a fix July 2010; removed Dec 2010 (too many false positives?); banks asked for student thesis to be taken down from web instead
- Real problem: EMV spec now far too complex
- With 100+ vendors, 20,000 banks, millions of merchants … everyone passes the buck (or tries to sell ECC…)

Hardware Security Modules

API Attacks

- A typical HSM has 50–500 API calls!
- We found that evil combinations of API calls, or API calls with wicked data, can very often break the security policy
- E.g. HSM transaction defined by VISA for EMV for encrypted messaging between a bank and a chip card
- Send key from HSM to card or other HSM as {text | key} – where text is variable-length
- Attack – a bank programmer can encrypt {text | 00}, {text | 01}, etc to get first byte of key, and so on
- API vulnerabilities can turn up in multiple products, so are important to find – but are still hard to find formally

Public Key Crypto Revision

- Digital signatures: computed using a private signing key on hashed data
- Can be verified with corresponding public verification key
- Can't work out signing key from verification key
- Typical algorithms: DSA, elliptic curve DSA
- We'll write $sig_A\{X\}$ for the hashed data X signed using A's private signing key

Public Key Crypto Revision (2)

- Public key encryption lets you encrypt data using a user's public encryption key
- She can decrypt it using her private decryption key
- Typical algorithms Diffie-Hellman, RSA
- We'll write $\{X\}_A$
- Big problem: knowing whose key it is!

PKC Revision – Diffie-Hellman

- Diffie-Hellman: underlying metaphor is that Anthony sends a box with a message to Brutus
- But the messenger's loyal to Caesar, so Anthony puts a padlock on it
- Brutus adds his own padlock and sends it back to Anthony
- Anthony removes his padlock and sends it to Brutus who can now unlock it
- Is this secure?

PKC Revision – Diffie-Hellman (2)

- Electronic implementation:

  $A \rightarrow B$: M^{rA}

  $B \rightarrow A$: M^{rArB}

  $A \rightarrow B$: M^{rB}

- But encoding messages as group elements can be tiresome so instead Diffie-Hellman goes:

  $A \rightarrow B$: g^{rA}

  $B \rightarrow A$: g^{rB}

  $A \rightarrow B$: $\{M\}g^{rArB}$

Public-key Needham-Schroeder

- Proposed in 1978:
  $A \rightarrow B: \{NA, A\}_{KB}$
  $B \rightarrow A: \{NA, NB\}_{KA}$
  $A \rightarrow B: \{NB\}_{KB}$
- The idea is that they then use $NA \oplus NB$ as a shared key
- Is this OK?

Public-key Needham-Schroeder (2)

- Attack found eighteen years later, in 1996:

$A \rightarrow C: \{NA, A\}_{KC}$		
$C \rightarrow B:$	$\{NA, A\}_{KB}$	
$B \rightarrow C:$		$\{NA, NB\}_{KA}$
$C \rightarrow A:$	$\{NA, NB\}_{KA}$	
$A \rightarrow C: \{NB\}_{KC}$		
$C \rightarrow B:$	$\{NB\}_{KB}$	

- Fix: explicitness. Put all names in all messages

Public Key Certification

- One way of linking public keys to principals is for the sysadmin to physically install them on machines (common with SSH, IPSEC)
- Another is to set up keys, then exchange a short string out of band to check you're speaking to the right principal (STU-II, Bluetooth simple pairing)
- Another is certificates. Sam signs Alice's public key (and/or signature verification key)

  $CA = sig_S\{T_S, L, A, K_A, V_A\}$
- But this is still far from idiot-proof…

The Denning-Sacco Protocol

- In 1982, Denning and Sacco pointed out the revocation problem with Needham-Schroder and argued that public key should be used instead

  $A \rightarrow S$: A, B

  $S \rightarrow A$: CA, CB

  $A \rightarrow B$: CA, CB, $\{sig_A\{T_A, K_{AB}\}\}_{KB}$
- What's wrong?

The Denning-Sacco Protocol (2)

- Twelve years later, Abadi and Needham noticed that Bob can now masquerade as Alice to anyone in the world!

$A \rightarrow S$: A, B

$S \rightarrow A$: CA, CB

$A \rightarrow B$: CA, CB, $\{sig_A\{T_A, K_{AB}\}\}_{KB}$

$B \rightarrow S$: B, C

$S \rightarrow B$: CB, CC

$B \rightarrow C$: CA, CC, $\{sig_A\{T_A, K_{AB}\}\}_{KC}$

Public Key Protocol Problems

- It's also very easy to set up keys with the wrong people – man-in-the-middle attacks get more pervasive. Assumptions are slippery to pin down
- Technical stuff too – if the math is exposed, an attacker may use it against you!
- So data being encrypted (or signed) must be suitably packaged
- Many other traps, some extremely obscure…

TLS

- Formerly SSL, became TLS after many bugs fixed:
  - $C \rightarrow S$: C, C#, N_C 'client hello'
  - $S \rightarrow C$: S, S#, N_S CS 'server hello'
  - $C \rightarrow S$: $\{k_0\}_{KS}$ 'k_0 = pre-master secret'
  - $C \rightarrow S$: {finished, MAC_{K1}(everything to date)}
  - $S \rightarrow C$: {finished, MAC_{K2}(everything to date)}
  - K1, K2 hashed from 'master secret' $K1 = h(k_0, N_C, N_S)$
- Formally verified to 'work' but still often used inappropriately (more later…)

TLS (2)

- Why doesn't TLS stop phishing?
  - Noticing an 'absent' padlock is hard
  - Understanding URLs is hard
  - Websites train users in bad practice
  - …
- In short, TLS as used in e-commerce dumps compliance costs on users, who can't cope
- There are solid uses for it though

Chosen protocol attack

- Suppose that we had a protocol for users to sign hashes of payment messages (such a protocol was proposed in 1990s):

  C → M: order

  M → C: X [= hash(order, amount, date, …)]

  C → M: $\mathrm{sig}_K\{X\}$

- How might this be attacked?

Chosen protocol attack (2)

The Mafia demands you sign a random challenge to prove your age for porn sites!