Security models and proofs: Insights and examples

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Historical perspective

1981 Dolev and Yao, *On the Security of Public Key Protocols.*

1984 Simmons, *Authentication Theory/Coding Theory.*

1993 Bellare and Rogaway, *Entity Authentication and Key Distribution.*

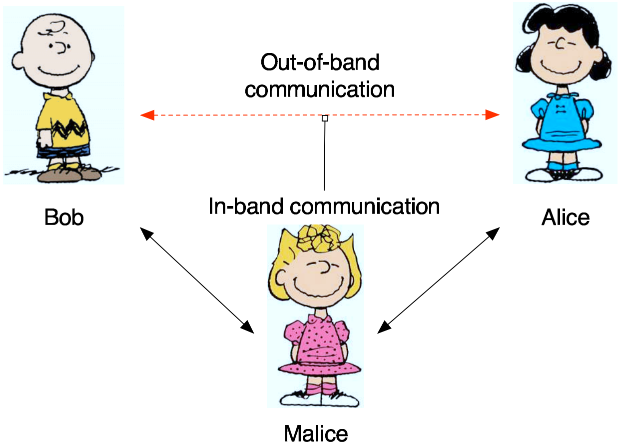
2000 Pfitzmann, Schunter, Waidner
Cryptographic Security of Reactive Systems.

2002 Canetti, Lindell, Ostrovsky, Sahai,
Universally composable two-party and multi-party secure computation.

2003 Lindell, *General Composition and Universal Composability in Secure Multi-Party Computation.* (Security in arbitrary comp. context.)

2005 Serge Vaudenay, *Secure Communications over Insecure Channels Based on Short Authenticated Strings.*

Authentication: stand-alone security model

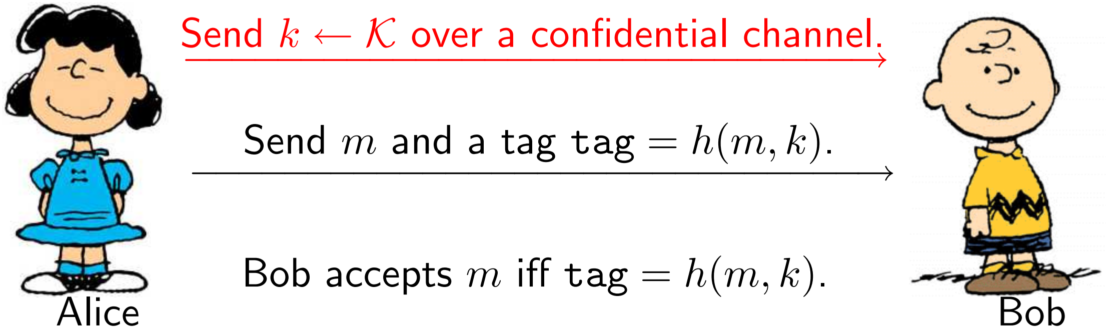


In-band communication is routed via malicious adversary, Malice, who can read, insert, drop and modify messages.

Out-of-band communication is authentic and sometimes secret. Malice can only read, delay and reorder messages.

Malice succeeds in deception if Alice and Bob accept different outputs.

Classical message authentication



Send $k \leftarrow \mathcal{K}$ over a confidential channel.

Send m and a tag $\mathtt{tag} = h(m, k)$.

Bob accepts m iff $\mathtt{tag} = h(m, k)$.

As Malice does not know the secret key k there are two attack types:

- Impersonation attacks. Malice tries to inject a message $\widehat{m}$ when Alice has not sent any messages.
- Substitution attacks. Malice tries to change a message m into $\widehat{m}$ by choosing a proper $\widehat{\mathtt{tag}}$.

Necessary properties of the hash functions

Impersonation attacks. For every message m, the tag distribution

$$\mathcal{D}_m = \{h(m,k) : k \leftarrow \mathcal{K}\}$$

must be (computationally) close to uniform distribution.

Substitution attacks. The tag $h(m,k)$ should reveal minimal amount of information about the key and tag, i.e., a (computational) conditional entropy $H(h(\widehat{m},k)|h(m,k)),\ m \neq \widehat{m}$ must be maximal.

There are hash-functions (*perfect hash functions*) that provide optimal information-theoretic security for a single protocol run. Many fast and computationally secure message authentication codes are built on top of information-theoretic counterparts using pseudorandom generators.

Towards Bellare-Rogaway model

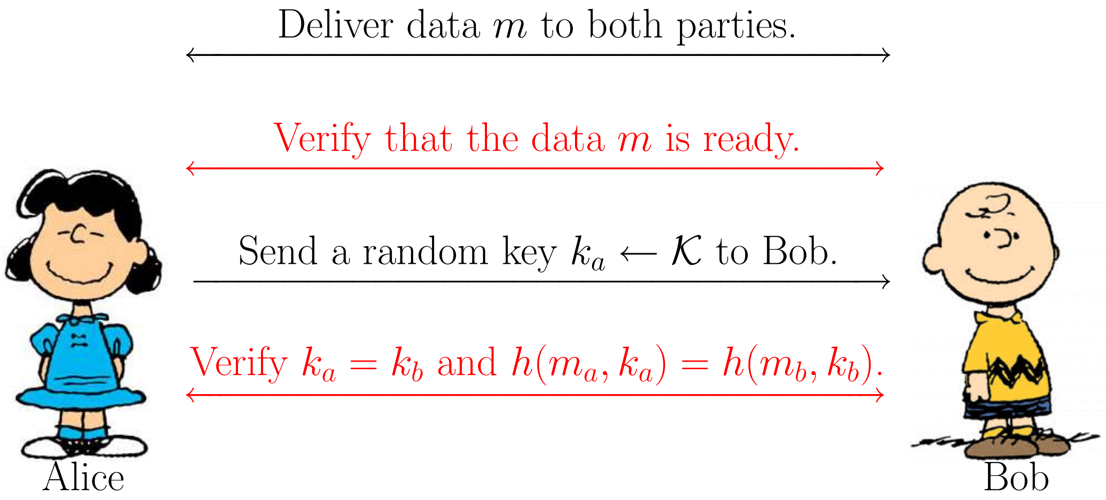
Add to the stand-alone model

- Man-in-the-middle attack
- Interleaving attack
- Random timing
- Worst possible scenario

Security in Bellare-Rogaway model

- Is the classical message authentication protocol secure in BR-model?
- If not under which restrictions this protocol is secure?
- How to construct a corresponding mutual authentication protocol?

MANA II protocol



Deliver data m to both parties.

$\longleftrightarrow$

Verify that the data m is ready.

$\longleftrightarrow$

Send a random key $k_a \leftarrow \mathcal{K}$ to Bob.

$\longrightarrow$

Verify $k_a = k_b$ and $h(m_a, k_a) = h(m_b, k_b)$.

$\longleftrightarrow$

Alice

Bob

Security proof

- What happens if Malice does not deliver data before synchronisation?
- What happens if Malice changes k to $\widehat{k}$?
- How is the remaining attack called? Which properties must h satisfy?

Security in Bellare-Rogaway model

Let the final check value of MANA II be 2ℓ bits long (i.e. $2^{-\ell}$-secure). Let q be the maximal number of protocols run in parallel.

- Show that MANA II is not secure in BR-model?
- Give a simple lower bound on security w.r.t. q and ℓ?
- Is the lower bound w.r.t. q and ℓ also the upper bound?
- If not under which restrictions this protocol is secure?

Rewinding is incompatible with parallel runs

Example: Blum's coin flipping protocol run in parallel.

Alice sends a commitment Com(x) for $x \leftarrow \{0,1\}$ to Bob.

Bob sends $y \leftarrow \{0,1\}$ to Alice who opens Com(x) and both output $x \oplus y$.

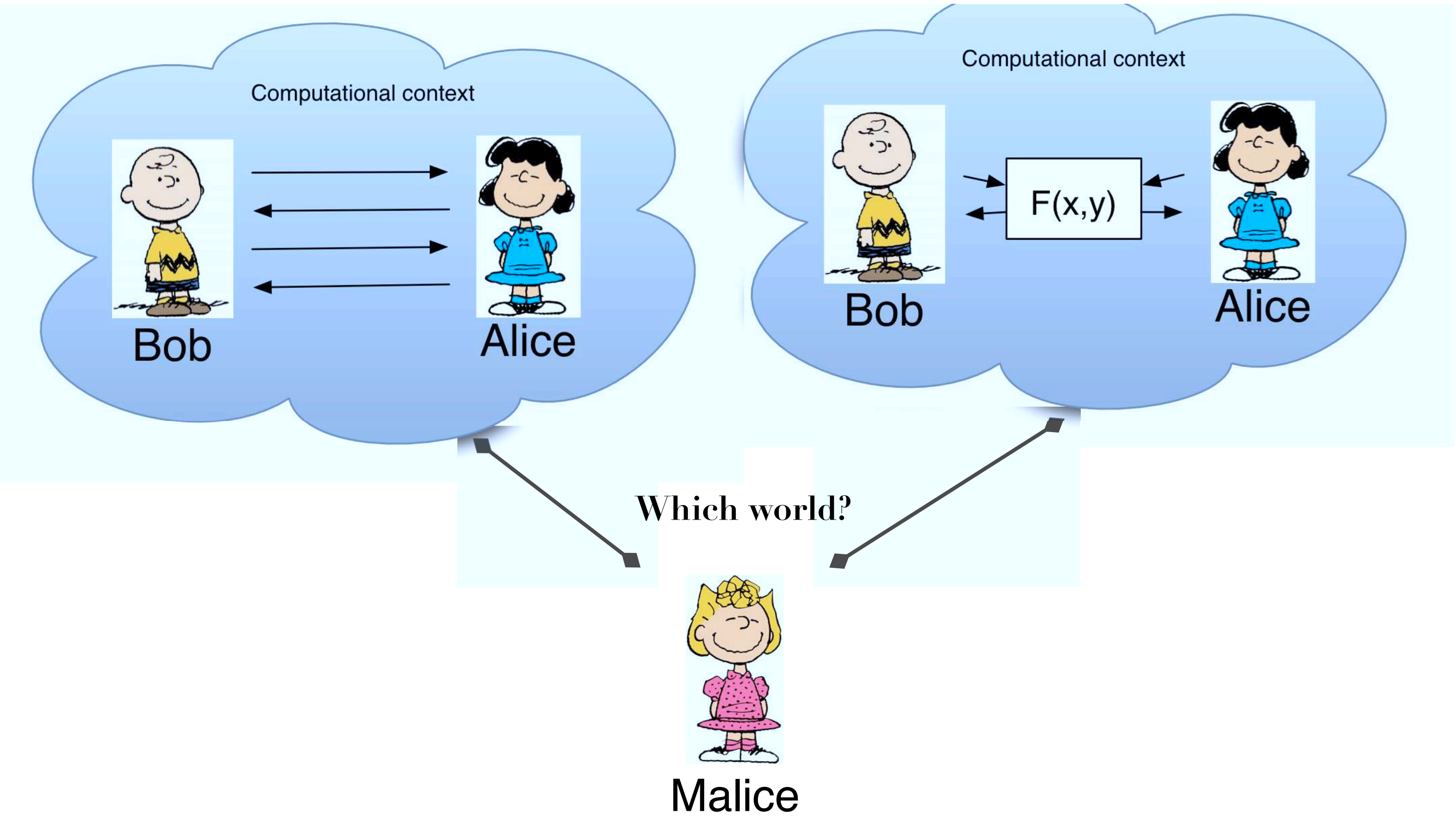
Task 1: Force the output $x \oplus y = 0$ by sending different Com(x) values.

Task 2: Force the output $x_i \oplus y_i = 0,\ i = 0,1$ by sending:

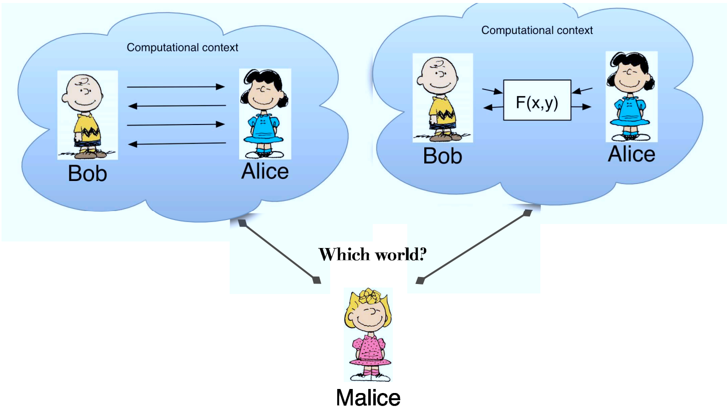
- different Com(x) values sequentially to Bob;
- different Com(x) values concurrently to Bob.

Where is the catch? Why there is a state space explosion?

Security in any computational context



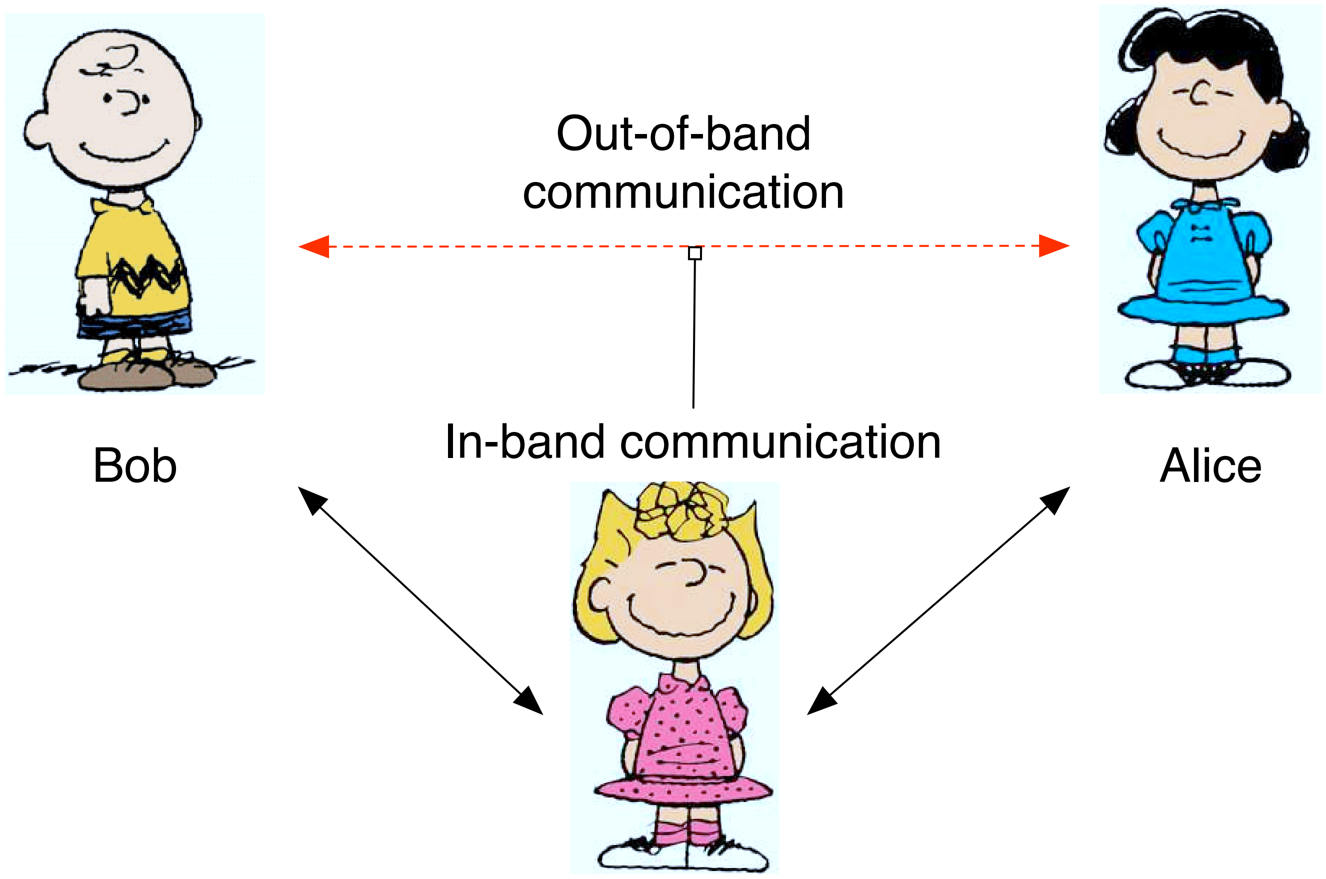
Security in any computational context



A protocol is secure in any computational context if:

- The protocol is secure in the stand-alone model.
- There is no rewinding arguments in the proof.
- Simulators used in the proofs are black-box and universal.
- Protocol messages can be separated from other messages

What is the biggest challenge in stand-alone model?



Out-of-band communication

In-band communication

Bob

Alice

Malice

Classification of authentication protocols

- Based on long pre-shared values:
  - (a) Classical message authentication (*pre-shared secrets*)
    - HMAC
    - CBC-MAC.
  - (b) Public key infrastructure (*pre-shared certificates*)
    - X.509 certificates and authentication

- Based on interactive authentic communication:
  - (a) Password-based authentication (*short confidential messages*)
    - WPA-PSK, WEP-TKIP
    - EKE, EKE2, SPEKE
  - (b) Manual authentication (*short authentic test tags*)
    - MANA II
    - MANA IV

Manually authenticated key exchange

- Classical key exchange + Manual authentication
  – MA–DH (*specially optimised*)
- Hybrid encryption + Manual authentication
  – manually authenticated hybrid encryption
- ???

Known upper bounds and corresponding attacks

- Guessing attack with success $2^{-\ell}$ affects
  - classical authentication
  - password-protected key exchange

- Simple collision attack with success $2^{-\ell}$ affects
  - manual authentication