Applied Symmetric Cryptography
Protocols, Attacks, Implementation Flaws

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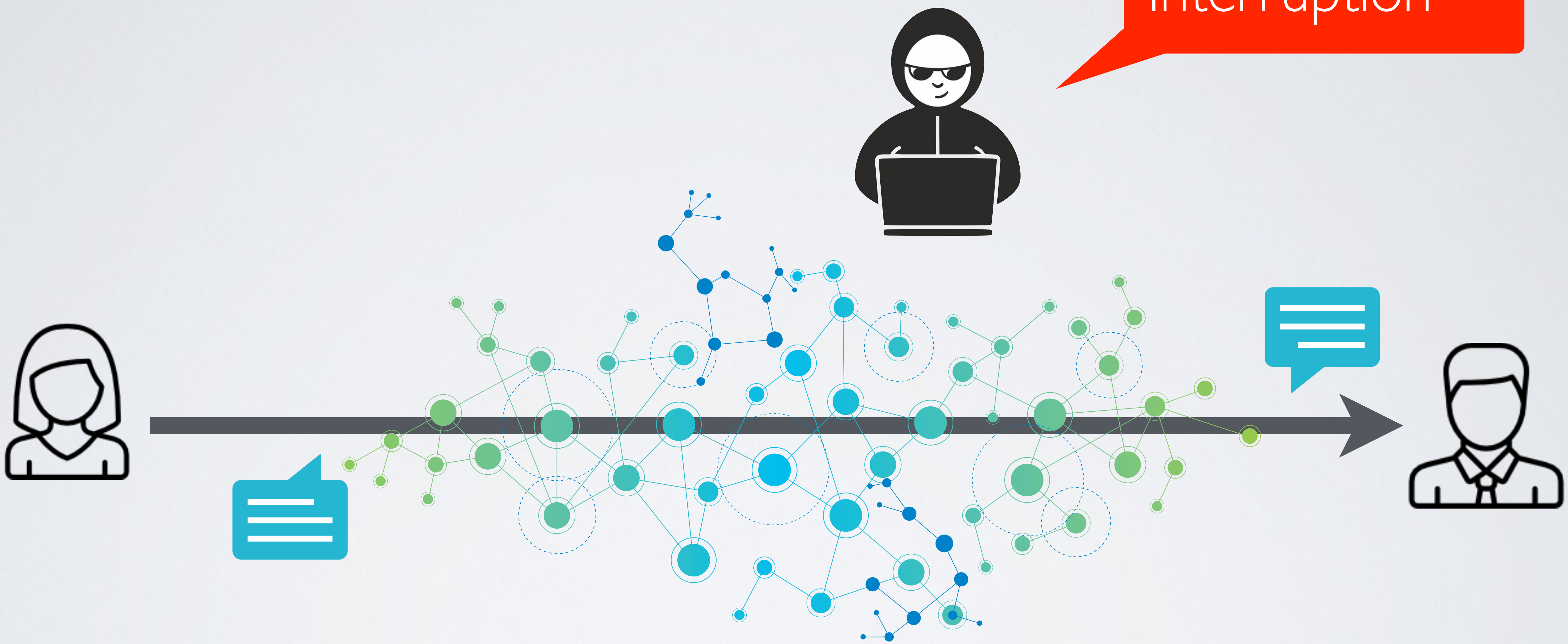
Refresher

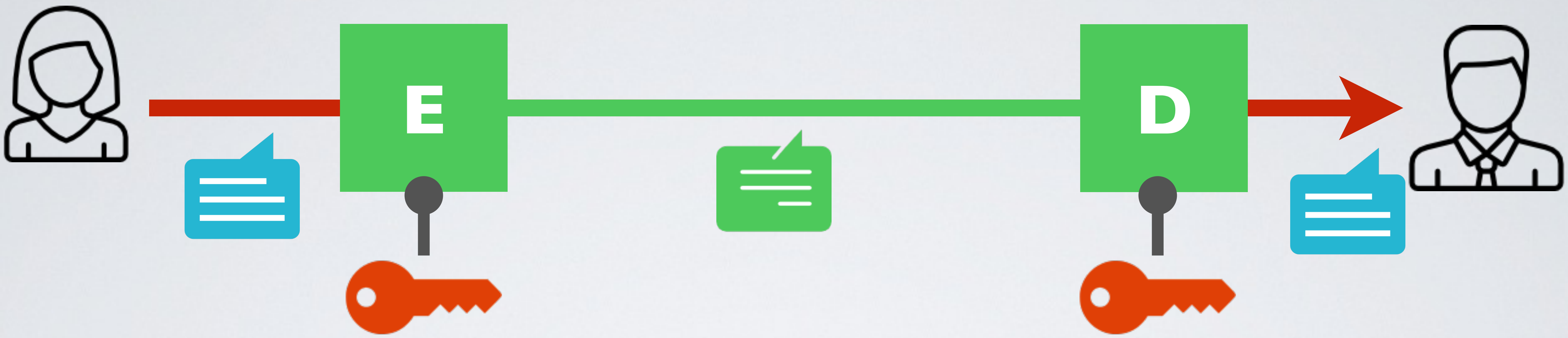
Security goals vs attacker's model

Interception
Modification
Fabrication
Interruption



Let us consider **confidentiality, integrity ~~and availability~~**

Symmetric Key Encryption

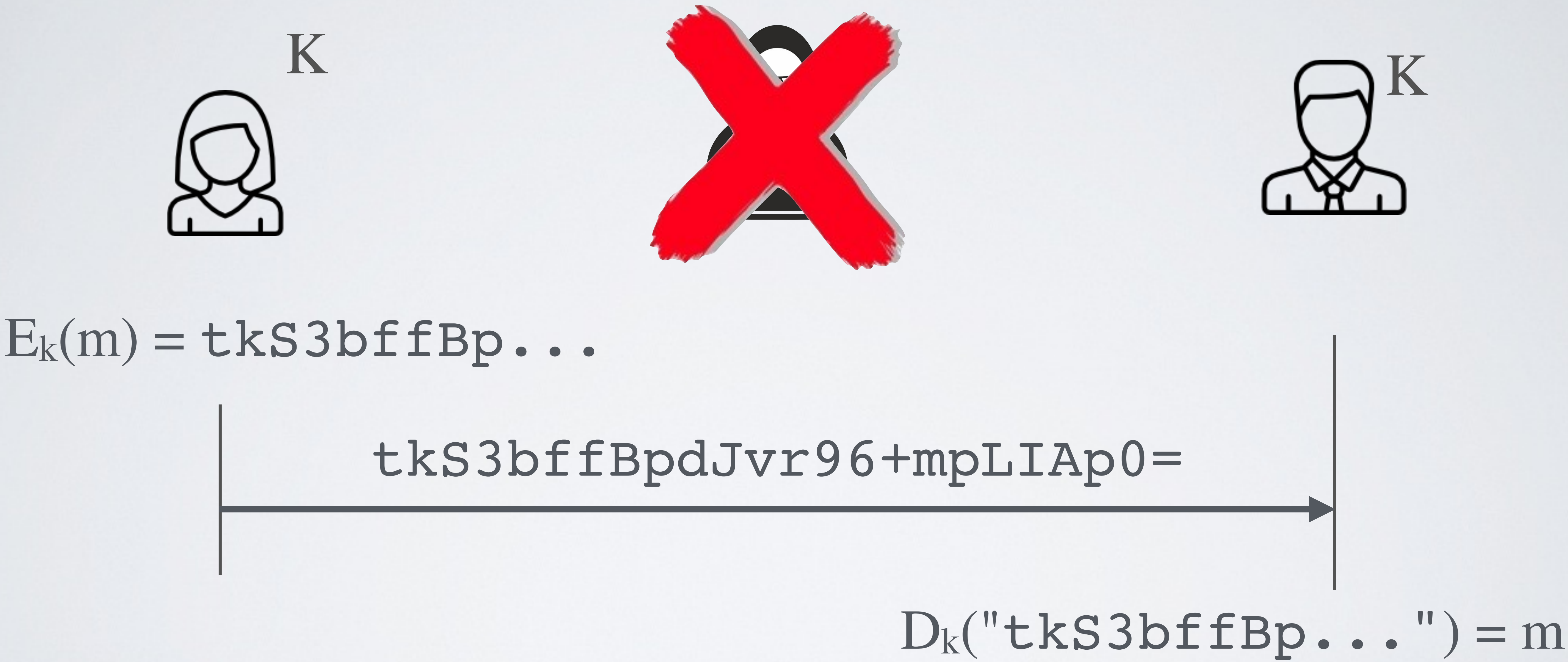


➡ The same key **k** is used for encryption **E** and decryption **D**

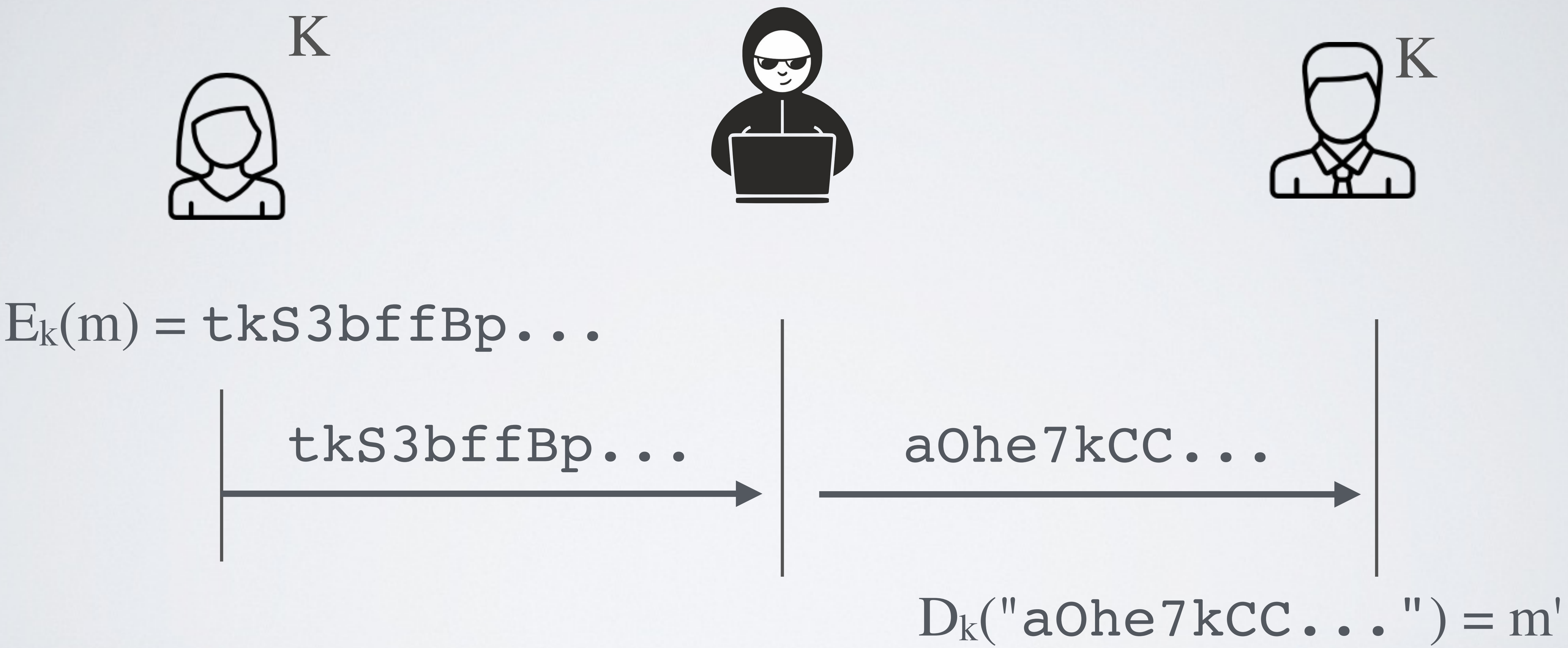
1. $D_k(E_k(m))=m$ for every **k**, E_k is an injection with inverse D_k
2. $E_k(m)$ is easy to compute (either polynomial or linear)
3. $D_k(c)$ is easy to compute (either polynomial or linear)
4. $c = E_k(m)$ finding **m** is hard without **k** (exponential)

Protocols

(pure) encryption ensures confidentiality ...

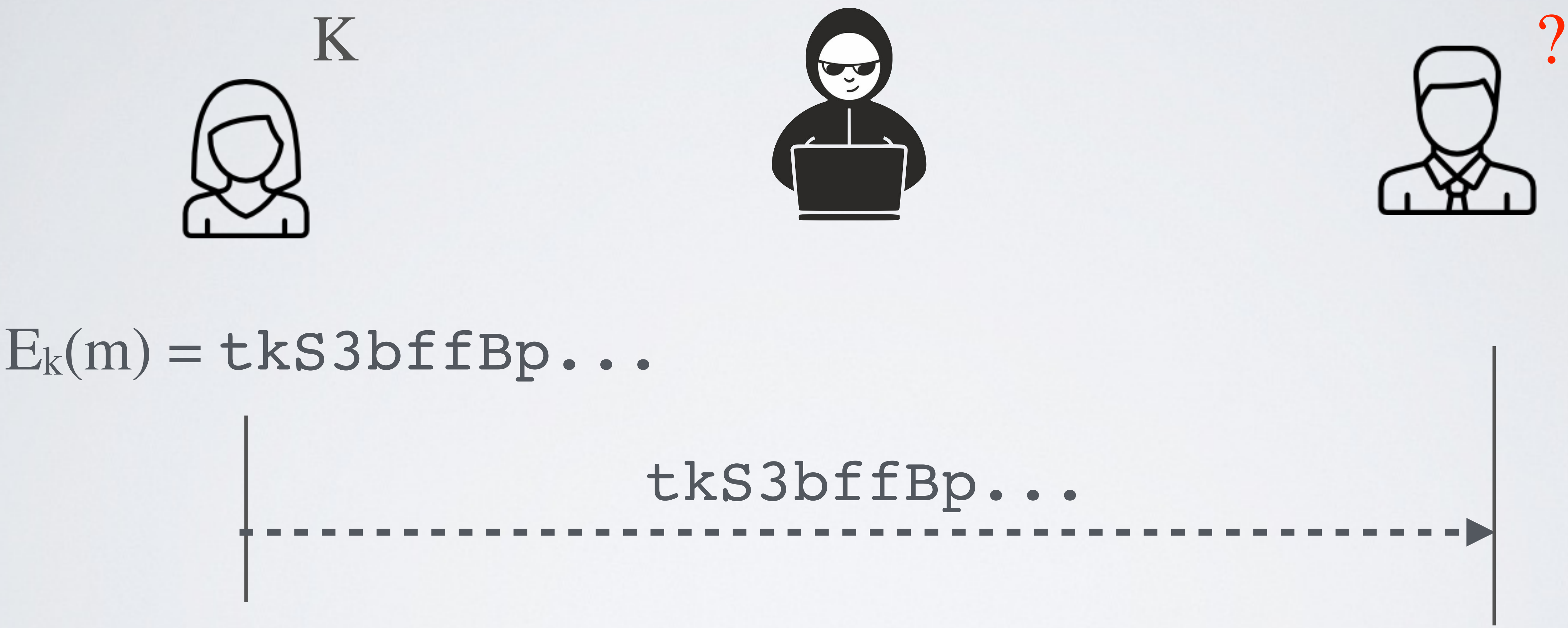


... but does not ensure integrity !



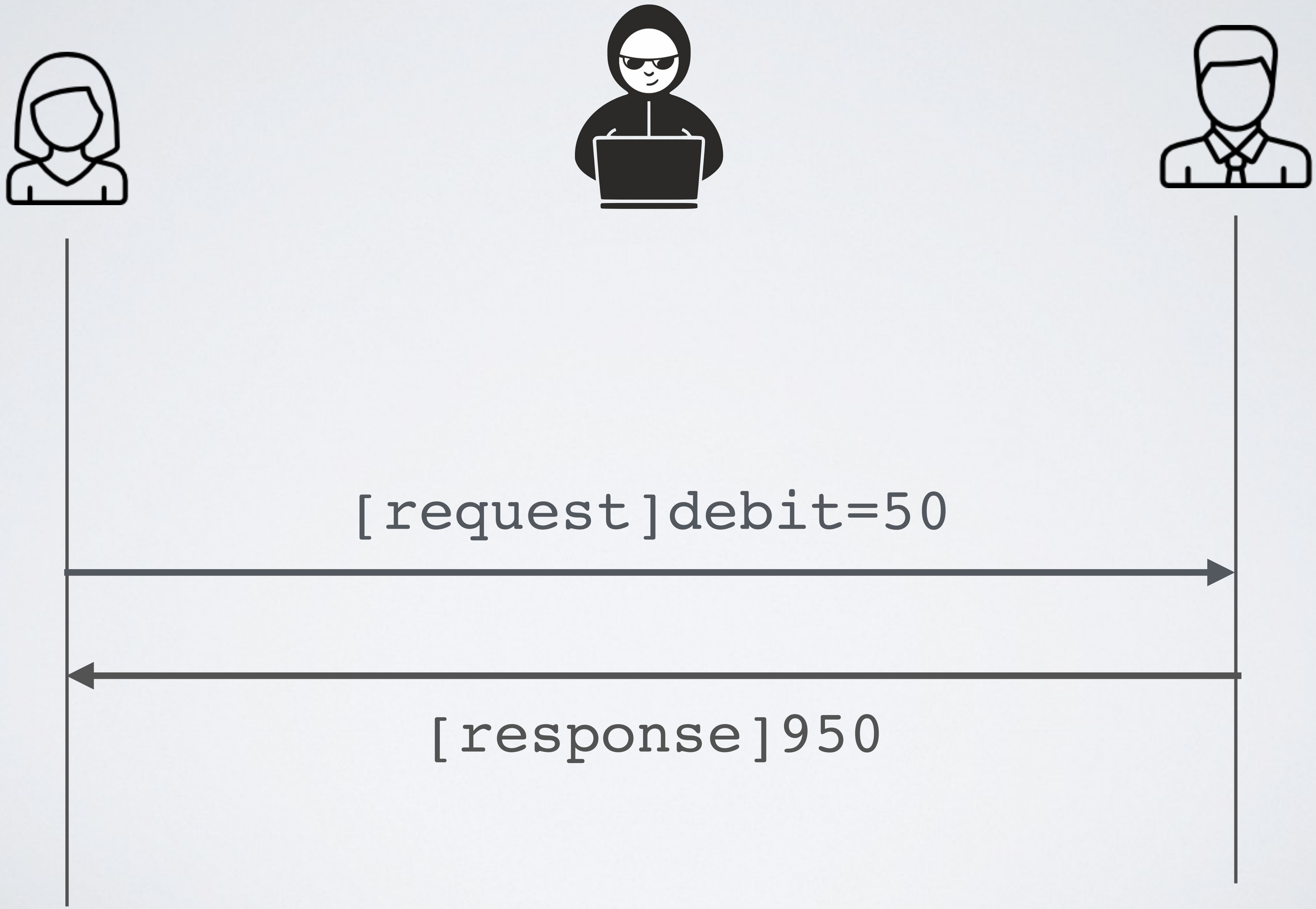
- Encrypting a message does not authenticate it

One more issue ...



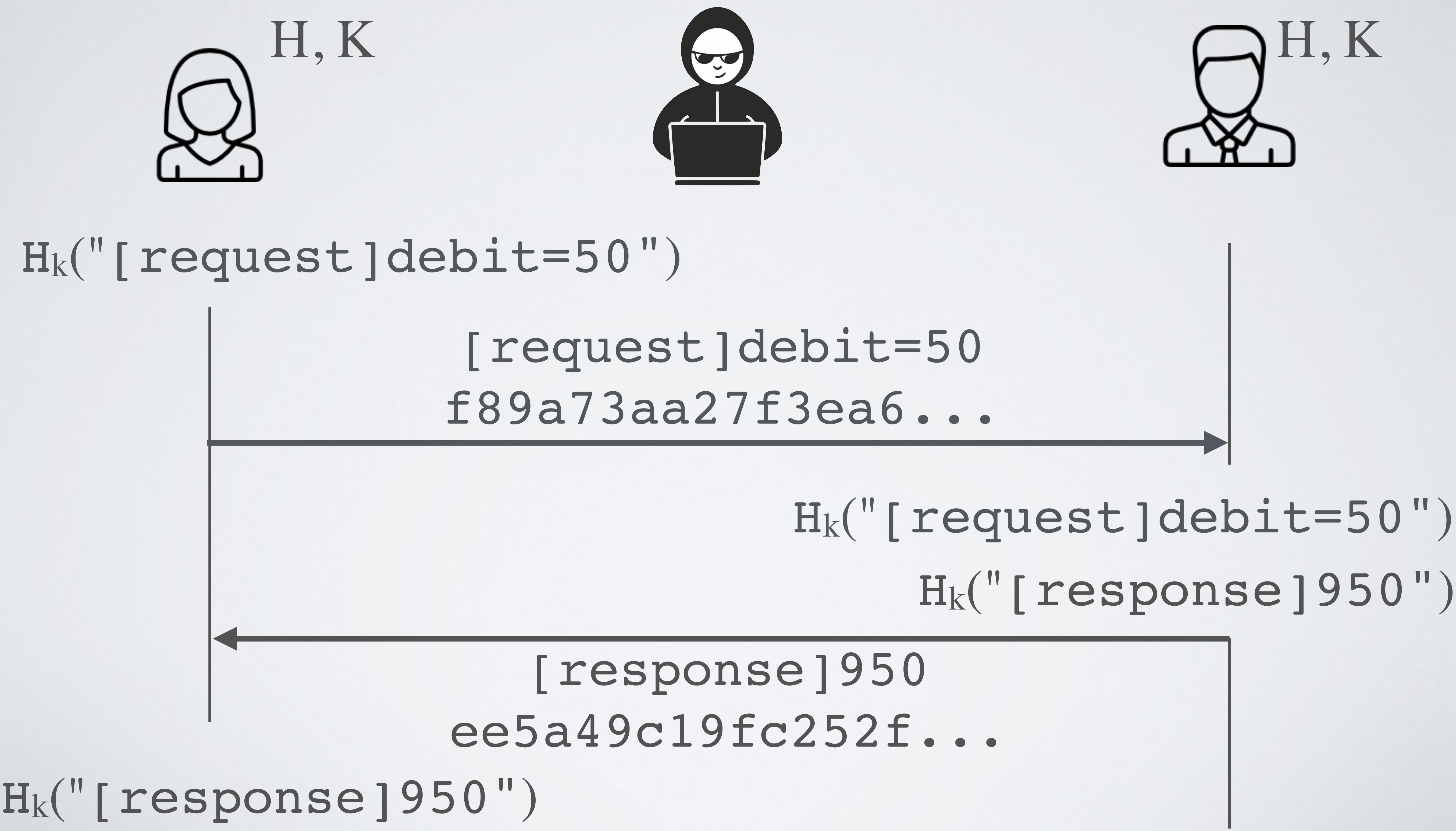
- How does Alice and Bob agree on a symmetric key?

Example



Ensuring confidentiality with encryption

Ensuring integrity with an HMAC

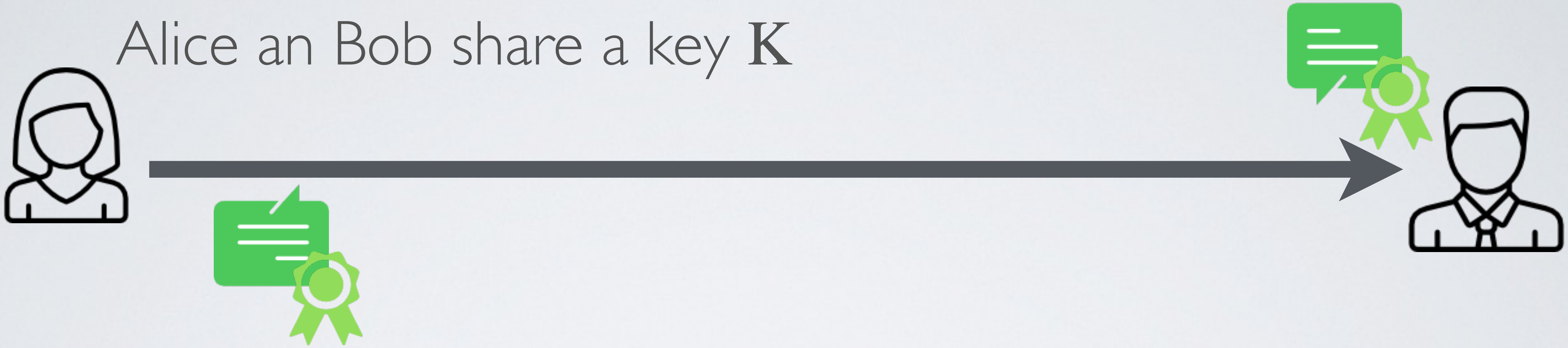


Security mechanisms

	Encryption	MAC	Authenticated Encryption
Confidentiality	✓	✗	✓
Integrity	✗	✓	✓

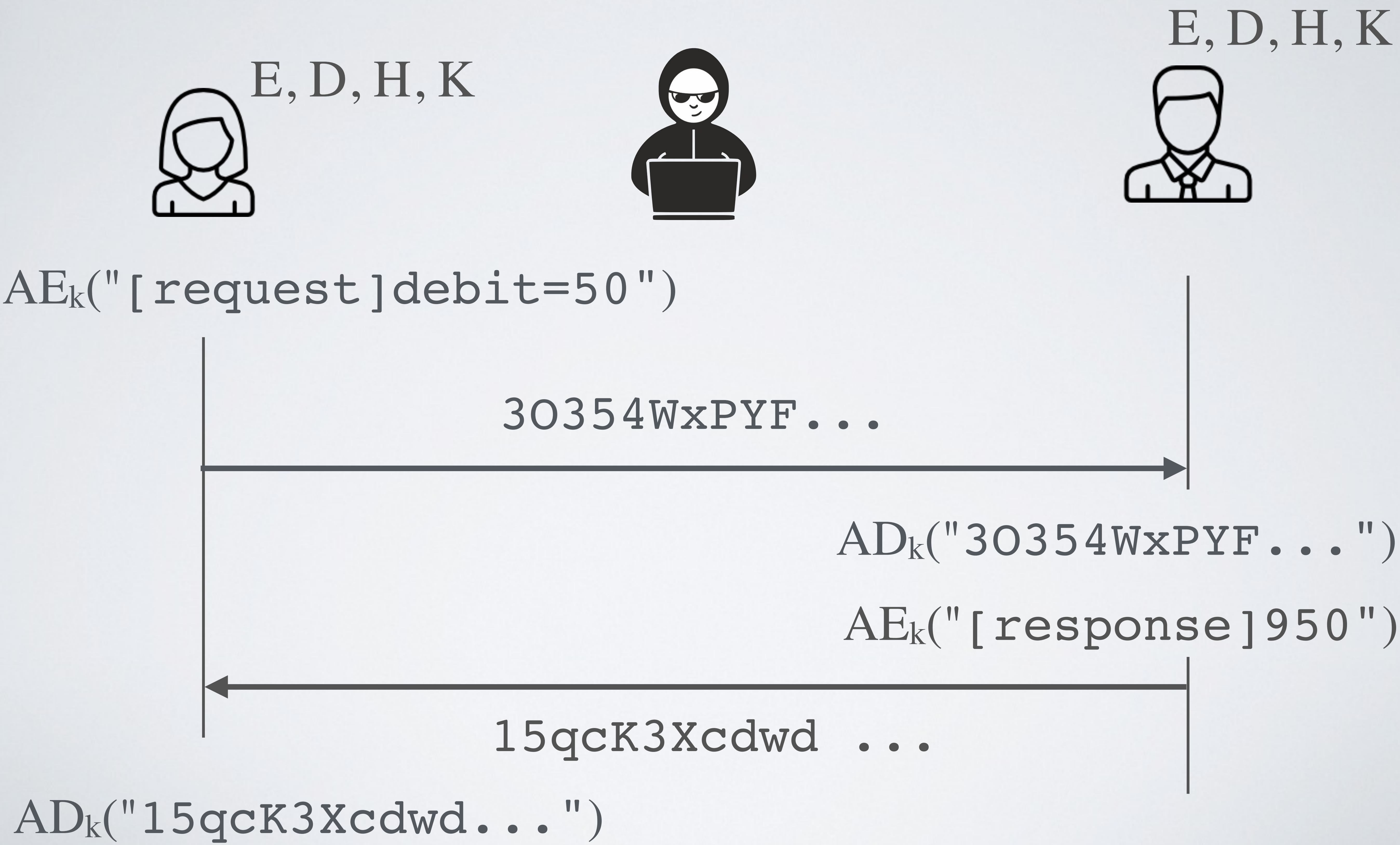
Authenticated Encryption (2013)

Alice an Bob share a key **K**



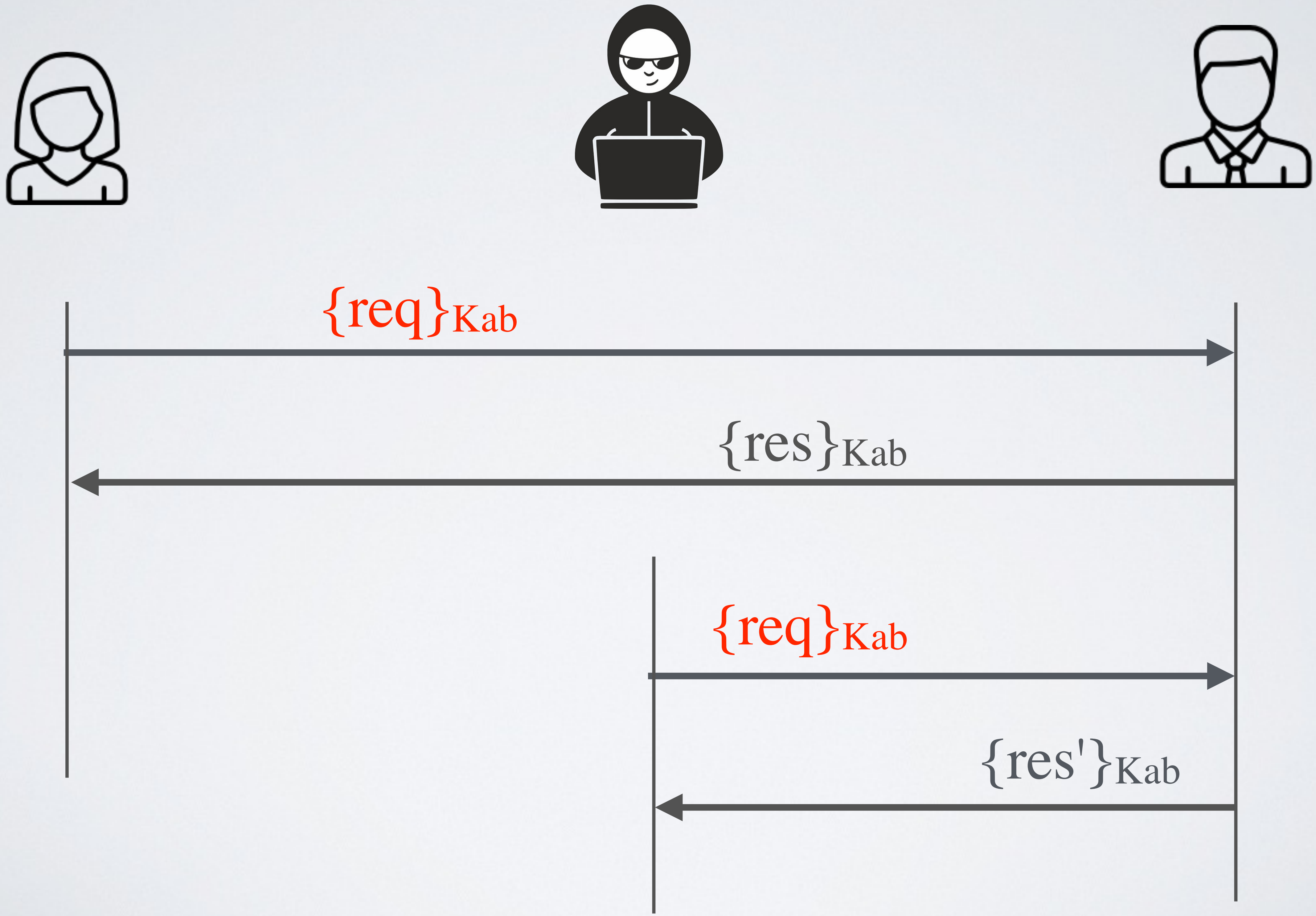
Encrypt-and-MAC (E&M)	$AE_k(m) = E_K(m) \parallel H_K(m)$	*SSH*
MAC-then-Encrypt (MtE)	$AE_k(m) = E_K(m \parallel H_K(m))$	*SSL*
Encrypt-then-MAC (EtM)	$AE_k(m) = E_K(m) \parallel H_K(E_K(m))$	*AES-GCM*

Ensuring confidentiality and integrity with Authenticated Encryption



Replay attacks

Replay attack

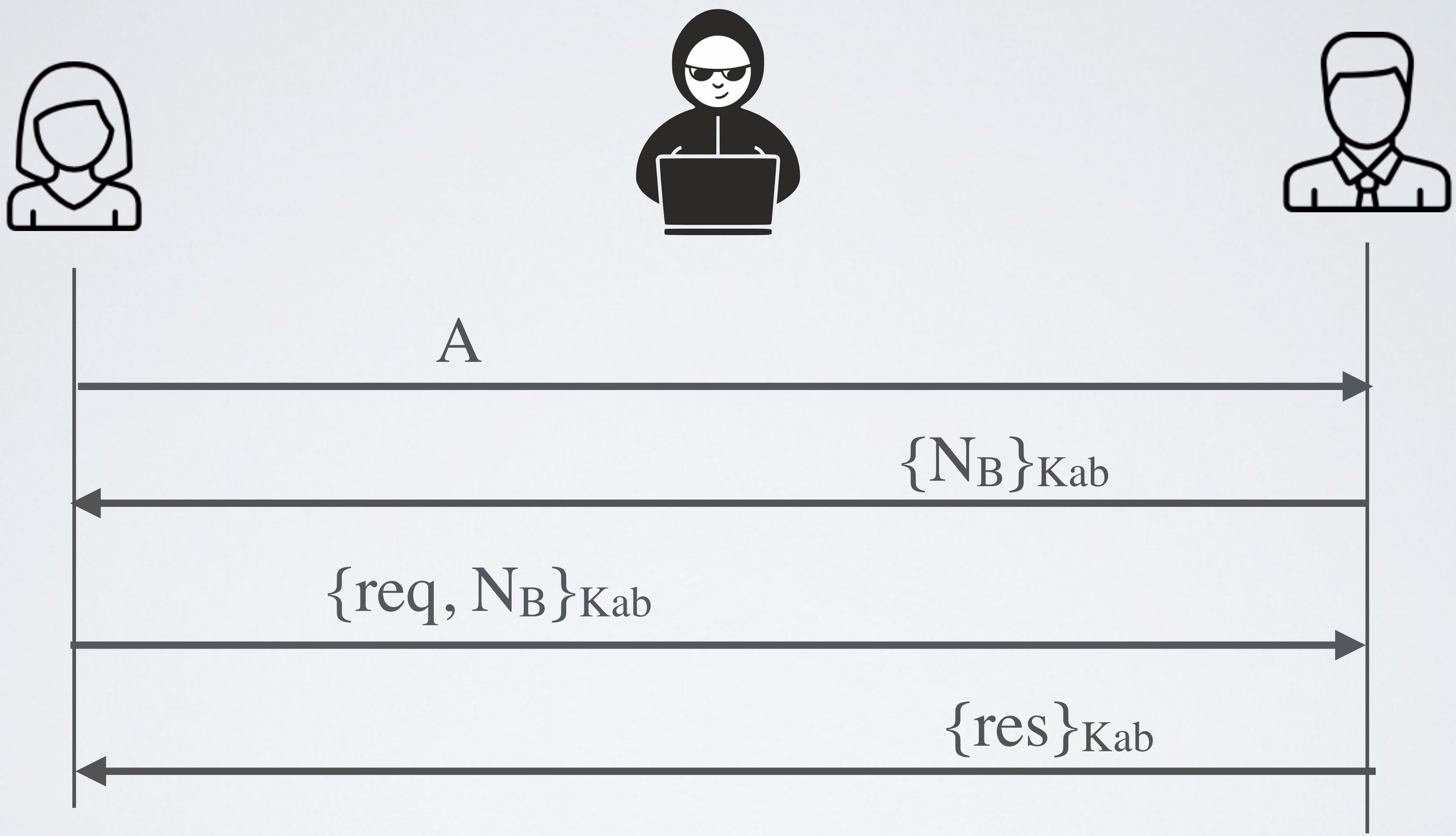


Counter replay attacks

Several solutions:

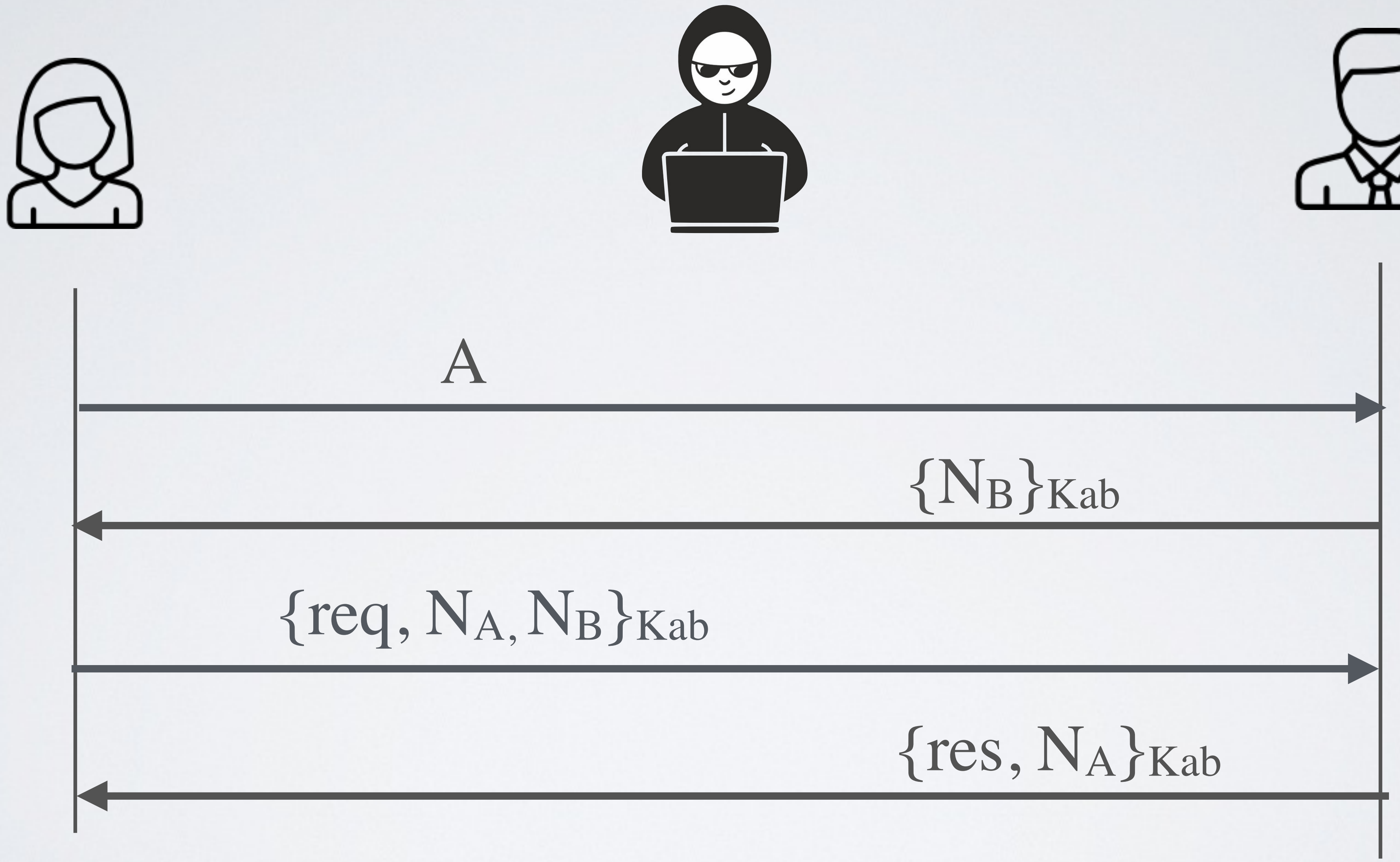
- **use a nonce (random number)**
- use sequence numbers
- use timestamps
- have fresh key for every transaction
  (key distribution problem)

Defeat replay attack with a nonce (not fully secured)



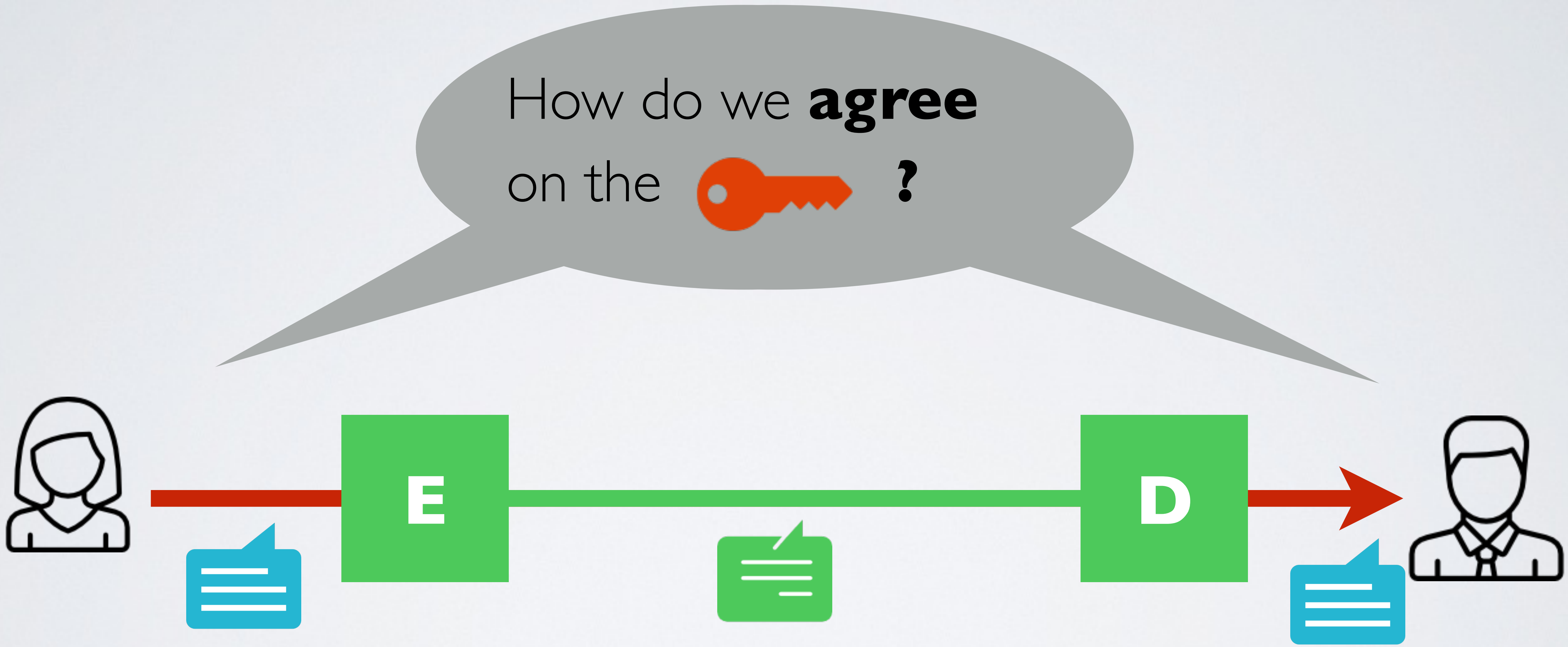
Replay attack on the response!

Defeat replay attack with a double nonce

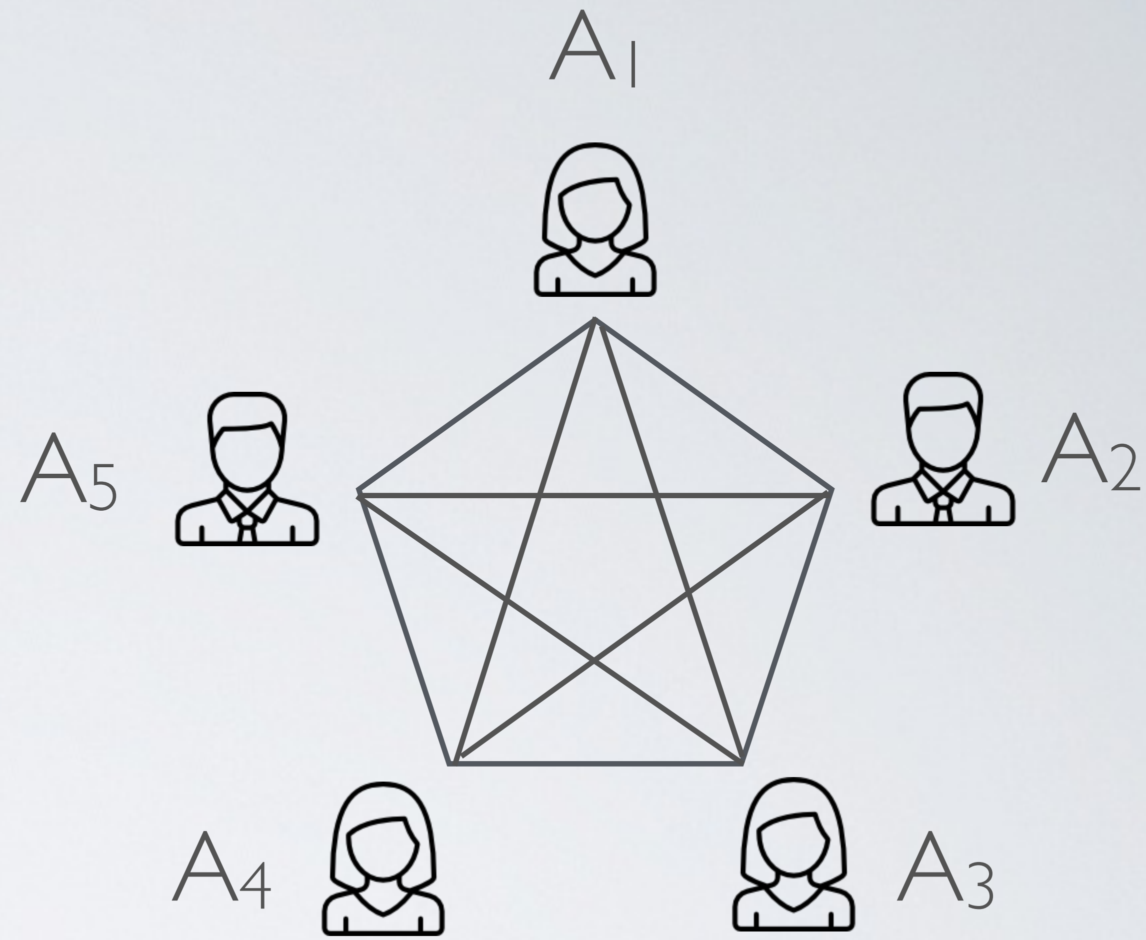


The challenge of key exchange

The big challenge with symmetric cryptosystems?



Naive Key Management

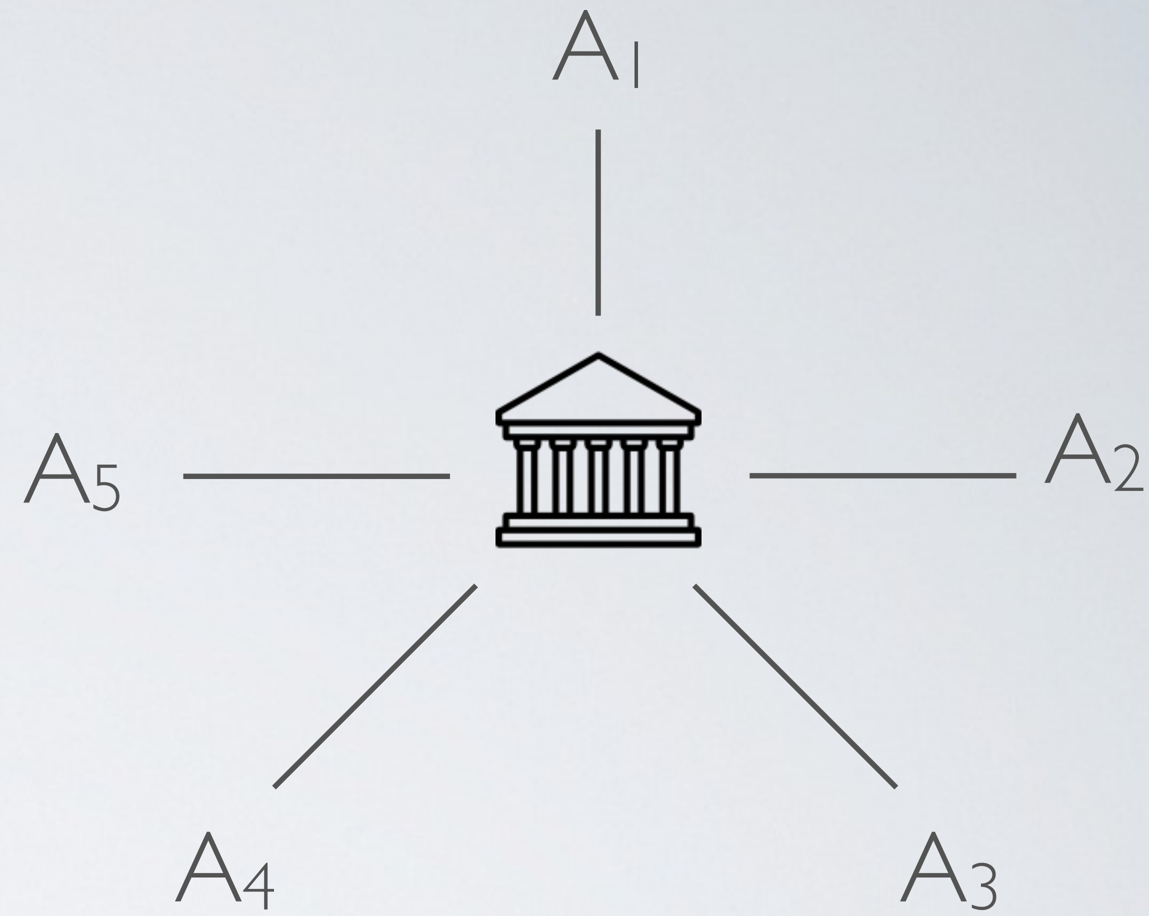


A_1, A_2 … A_5 want to talk

➡ Each pair needs a key : $n (n-1) / 2$ keys

- Keys must be exchanged physically using a secure channel

(Better) centralized solution



$A_1, A_2 \ldots A_5$ can talk to the KDC (Key Distribution Center)

- ➡ When A_i and A_j want to talk, the KDC can generate a new key and distribute it to them
- ◉ We still have n keys to distribute somehow using a secure channel
- ◉ The KDC must be trusted
- ◉ The KDC is a single point of failure
- ➡ The is how *Kerberos* works

The Needham-Shroeder symmetric protocol for key exchange

Assumptions

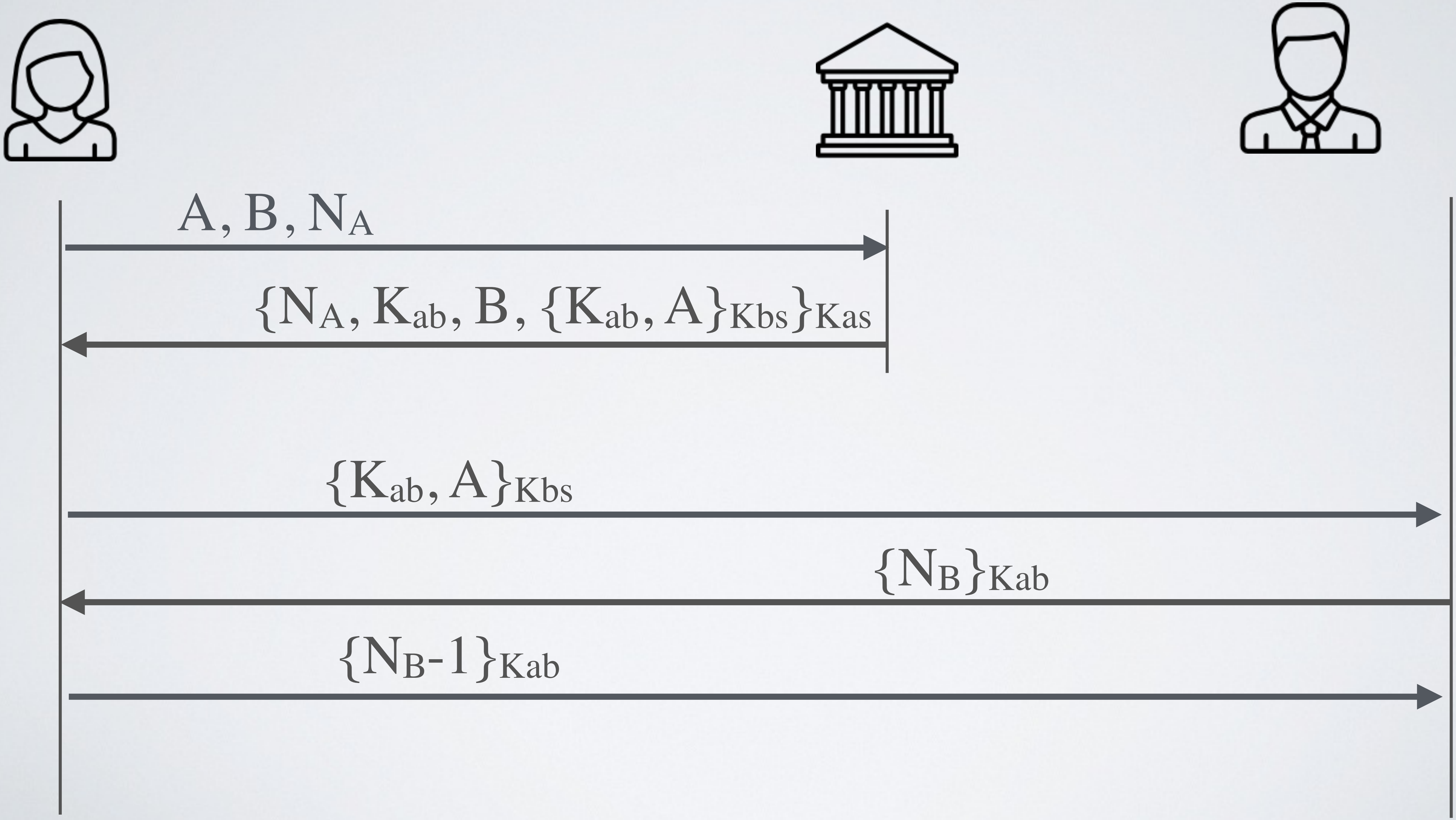
- 4 principals : **A**lice, **B**ob, **M**allory, Key Distribution **S**erver
- **S** shares a key with **A**, **B** and **M** respectively K_{as}, K_{bs}, K_{ms}
- **A**, **B**, **M** and **S** talk to each other using the same protocol

Goals

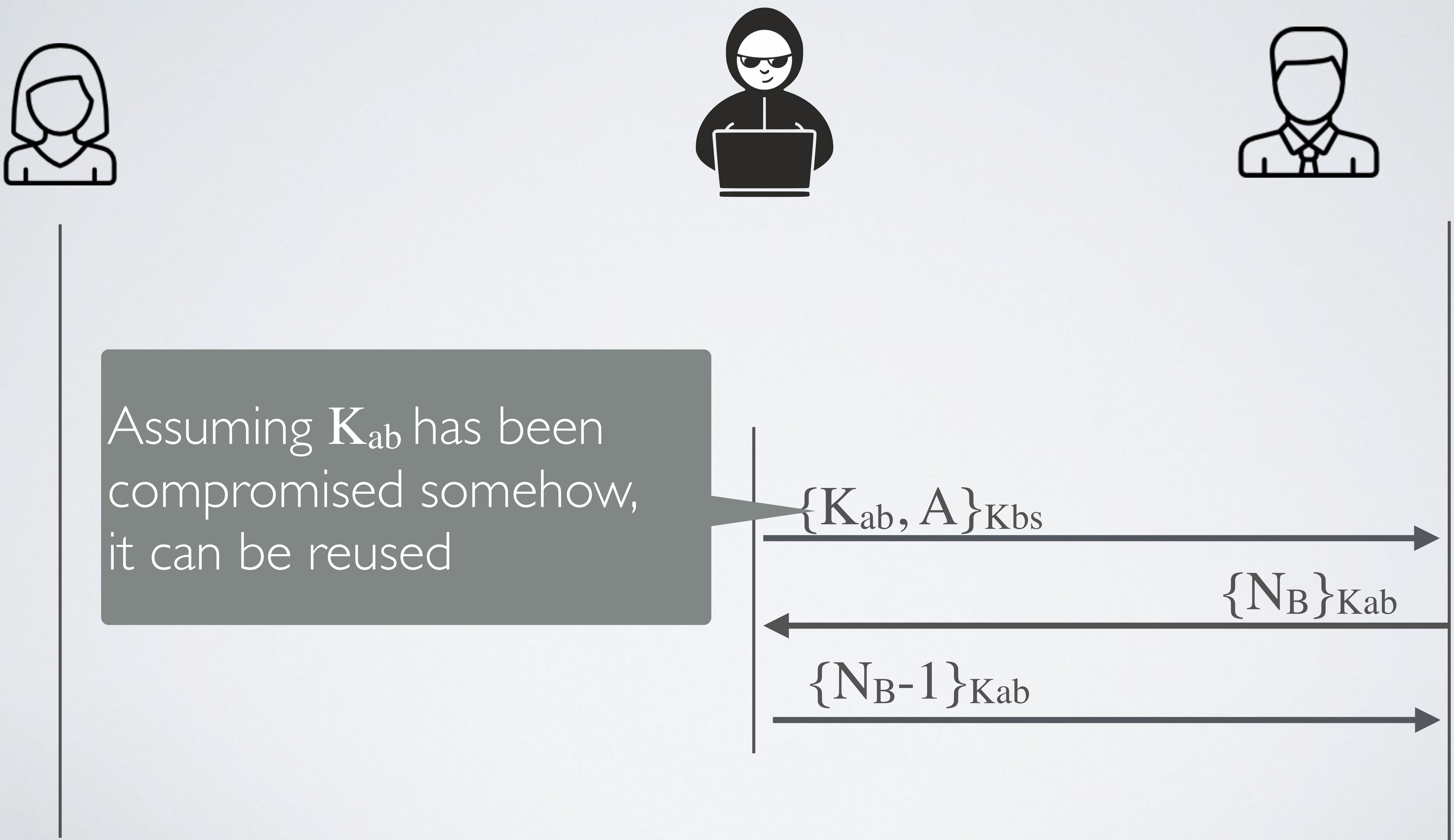
When two parties want to engage in the communication, they want to

1. make sure that they talk to the right person (authentication)
2. establish a session key

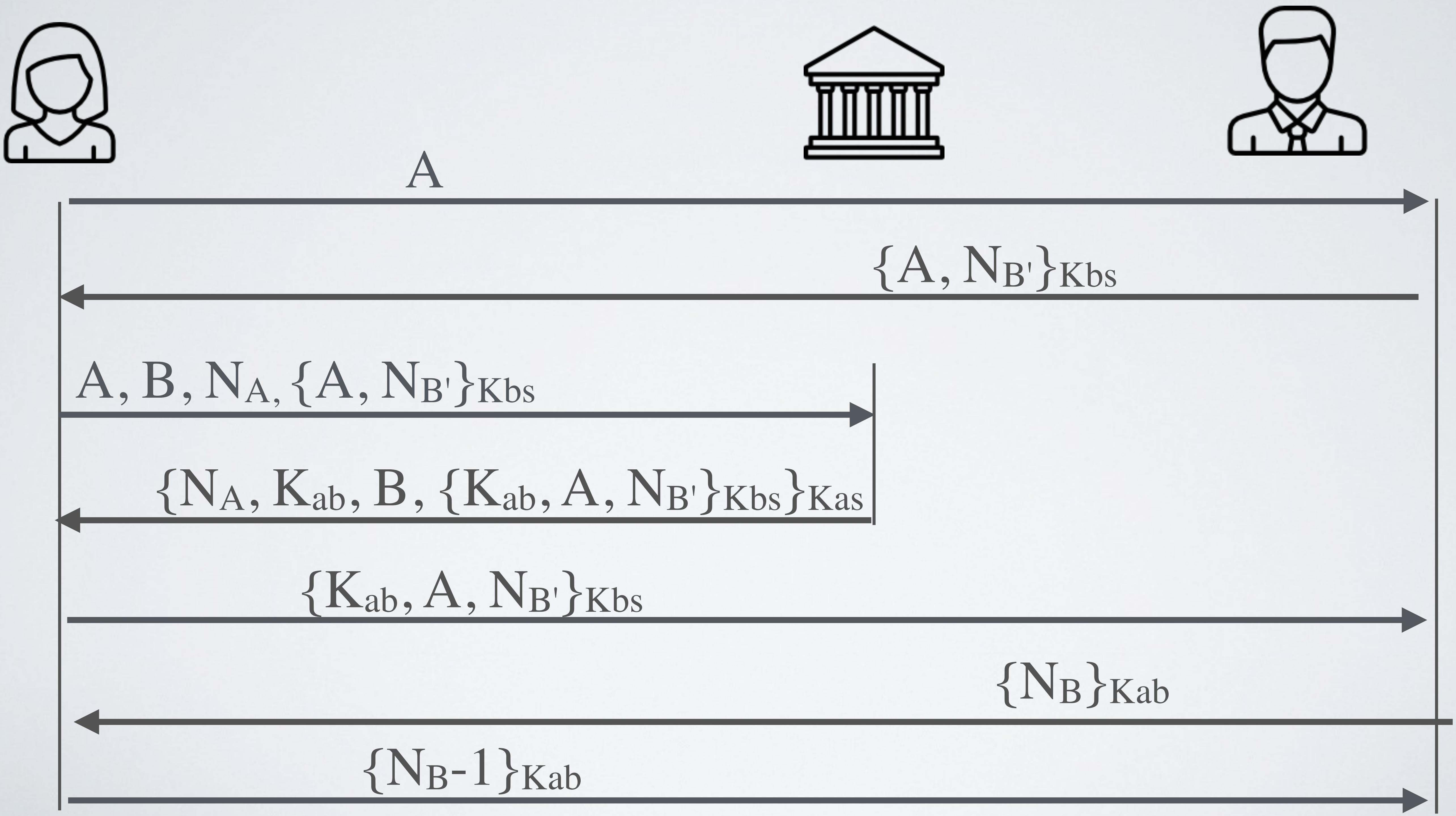
The vulnerable version of the protocol (1978)



Replay attack (1981)



The fix (1987)


A
{A, NB'}Kbs
A, B, NA, {A, NB'}Kbs
{NA, Kab, B, {Kab, A, NB'}Kbs}Kas
{Kab, A, NB'}Kbs
{NB}Kab
{NB-1}Kab

Limitations of using a key distribution centre

The key distribution server is a bootleneck and **weak link**

- The attacker could record the key exchange and the encrypted session, if one day either **Kas** or **Kbs** is broken, the attacker can decrypt the session

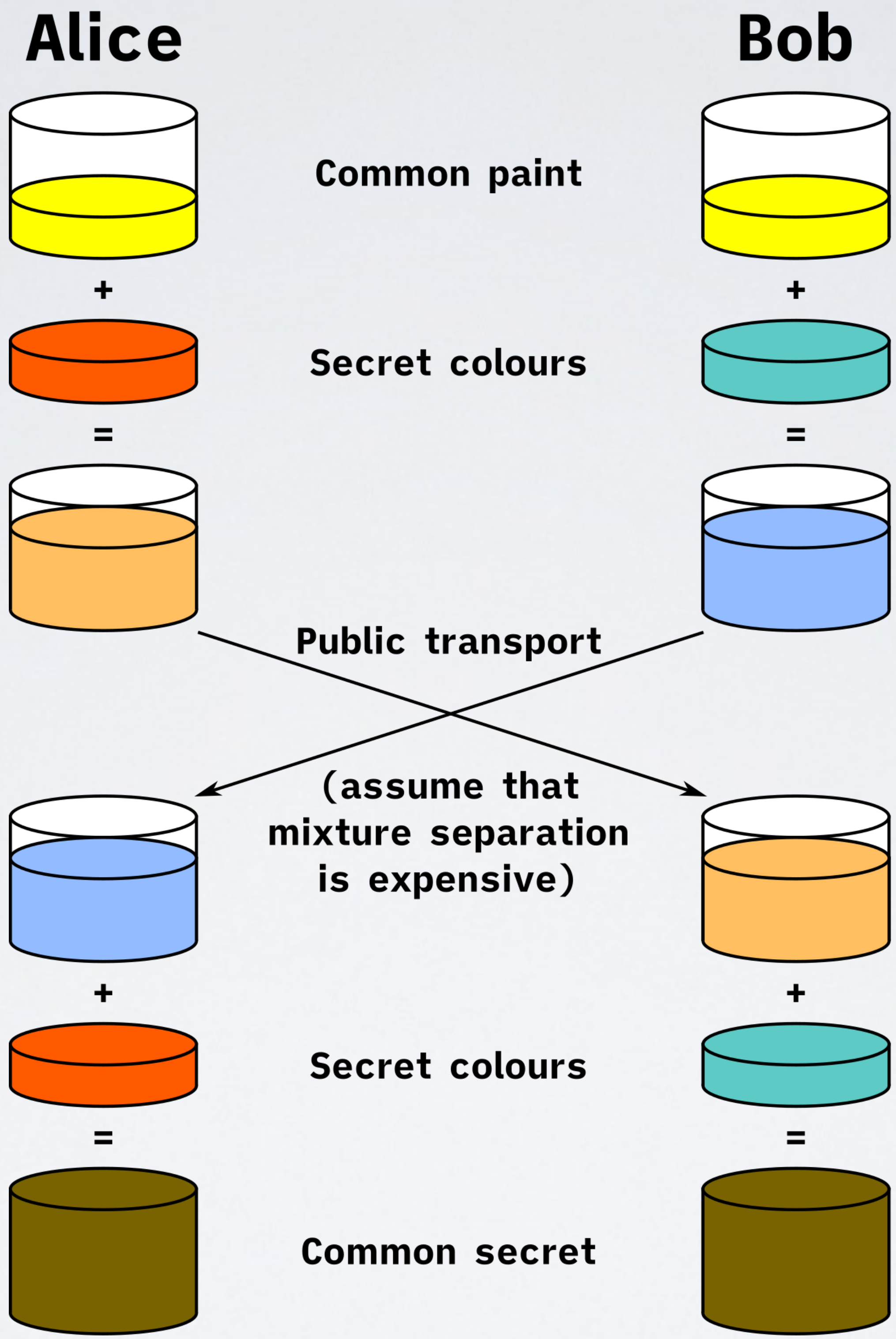
➡ Having a KDC does not offer "Perfect Forward Secrecy"

Can we avoid having a KDC ?

Could Alice and Bob could magically come up with a key without exchanging it over the network?

➡ The magic is called **Diffie-Hellman-Merkle Protocol**

The Diffie-Hellman-Merkel key exchange protocol



Alice: p, g ; a ; $A = g^a \bmod p$; $K = B^a \bmod p$

Bob: p, g ; b ; $B = g^b \bmod p$; $K = A^b \bmod p$

$$K = g^{ab} \bmod p = (g^a \bmod p)^b \bmod p = (g^b \bmod p)^a \bmod p$$

The Diffie-Hellman-Merkel key exchange protocol

1. Generates public numbers **p** and **g** such that **g** if co-prime to **p-1**
2. Generates a secret number **a**
3. Sends $\mathbf{A = g^a \bmod p}$ to Bob

A, p, g

1. Generates a secret number **b**
2. Sends $\mathbf{B = g^b \bmod p}$ back to Alice
3. Calculates the key $\mathbf{K = A^b \bmod p}$

B

4. Calculates the key $\mathbf{K = B^a \bmod p}$

Diffie-Hellman-Merkle in practice

- $\mathbf{g}$ is small (either 3, 5 or 7 and fixed in practice)
- $\mathbf{p}$ is at least 2048 bits (and fixed in practice)
- private keys $\mathbf{a}$ and $\mathbf{b}$ are 2048 bits as well

➡ So the public values $\mathbf{A}$ and $\mathbf{B}$
and the master key $\mathbf{k}$ are 2048 bits

➡ Use $\mathbf{k}$ to derive an AES key using a Key Derivation Function
(usually HKDF - the HMAC-based Extract-and-Expand key derivation function)

A widely used key exchange protocol

Diffie-Hellman-Merkle is in many protocols

- SSH
- TLS (used by HTTPS)
- Signal (used by most messaging apps like Whatsapp)
- and so on . . .

✓ It is fast and requires two exchanges only

✓ Solves the problem of having a key distribution server

✓ Ensures Perfect Forward Secrecy

◉ But how to make sure Alice is talking to Bob and vice-versa?
Diffie-Hellman-Merkle alone **does not ensure authentication**

Implementation Flaws

Home / Business Software

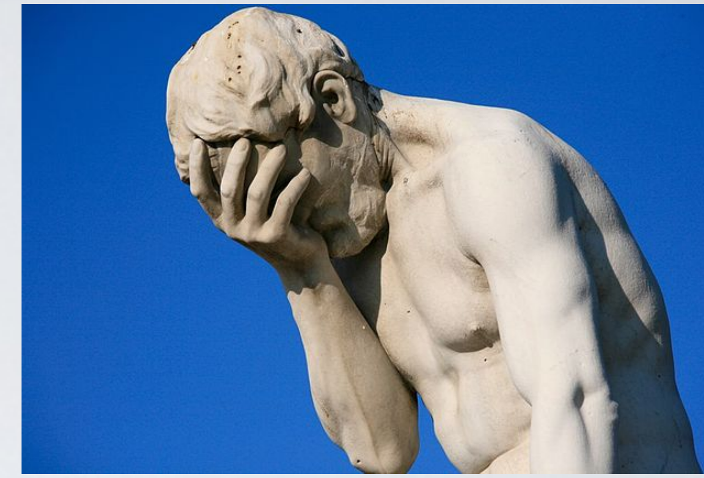
'Serious' Microsoft Office Encryption Flaw Uncovered

COMMENTS

By John E. Dunn, IDG News Service
Jan 27, 2005 4:00 PM

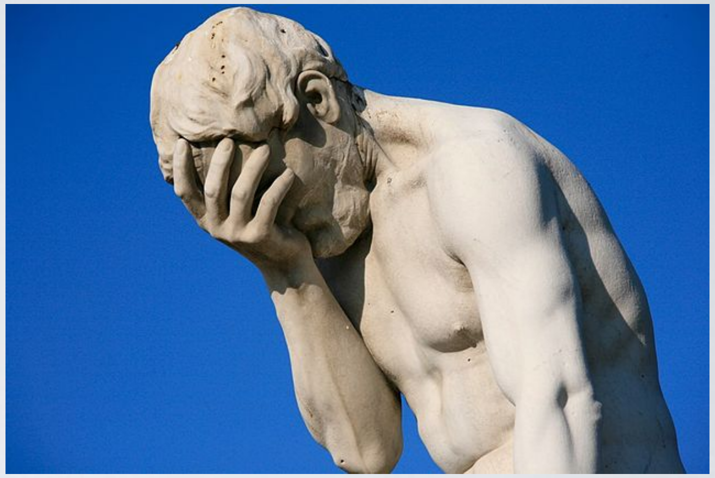
Cryptography expert Phil Zimmermann says he believes a flaw recently discovered in Microsoft Office's Word and Excel encryption is serious and warrants immediate attention.

"I think this is a serious flaw--it is highly exploitable. It is not a theoretical attack," says Zimmermann, referring to a flaw in Microsoft's use of RC4 document encryption unearthed recently by a researcher in Singapore.



MS Word and Excel 2003 used the same key to re-encrypt documents after editing changes

WEP - Wired Equivalent Privacy



- ➡ A random number IV (24 bits only) transmitted in clear between the clients and the base station

RC4_key = IV + SSID_password

- ◉ 50% chance the same IV will be used again after 5000 packets