Secure communications: Cryptographic protocols

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Context

Applications exchanging sensitive data over a public network:

- eBanking,
- eCommerce,
- eVoting,
- eHealth,
- Blockchains,
- Mobile phones,
- ...

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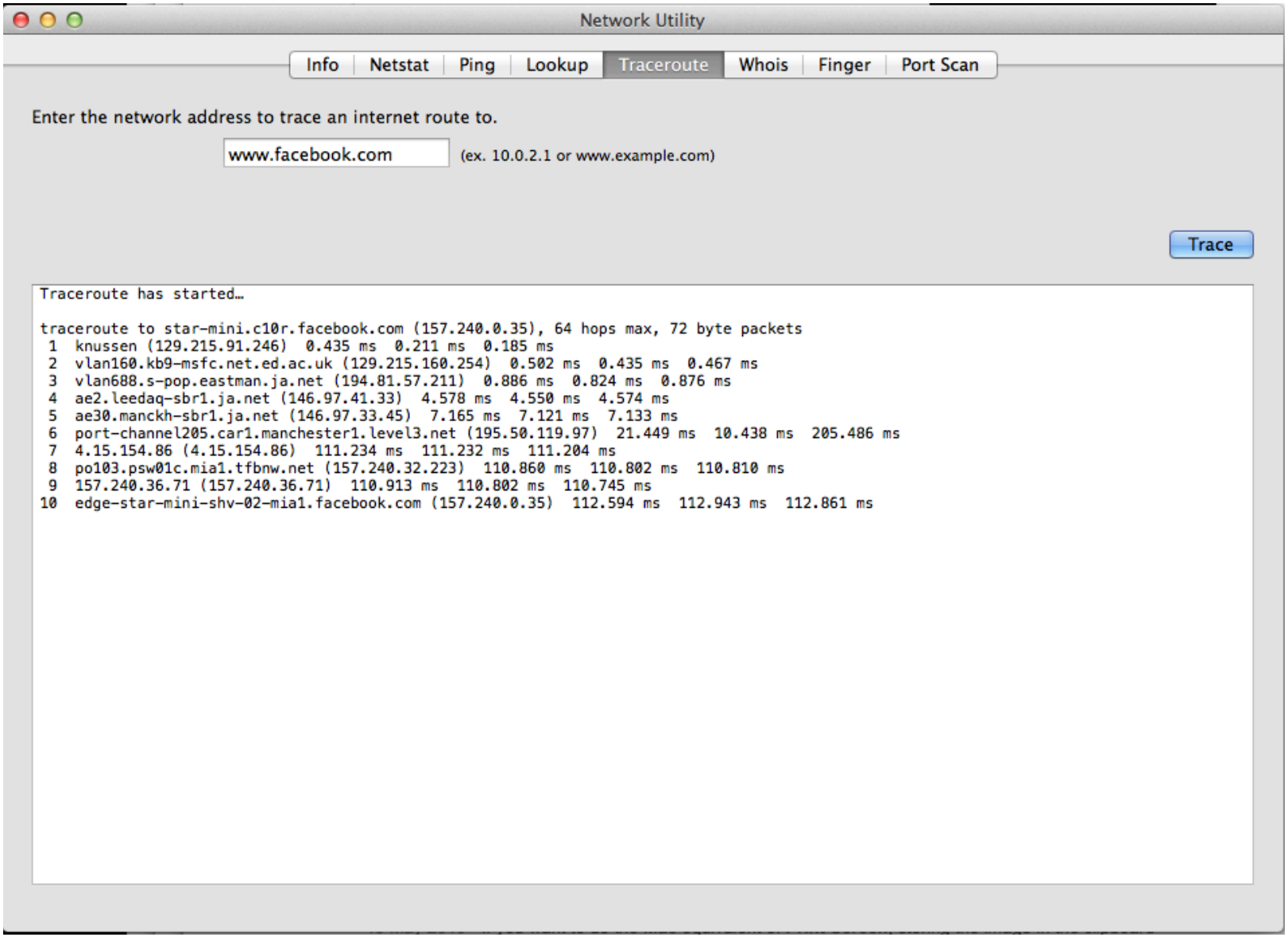
A malicious agent can:

- record, alter, delete, insert, redirect, reorder, and reuse past or current messages, and inject new messages
  $\longrightarrow$ the network is the attacker
- control dishonest participants

The attacker controls the network (1)



The attacker controls the network (2)

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DATA CENTRE SOFTWARE NETWORKS SECURITY TRANSFORMATION DEVOPS BUSINESS HARDWARE

Networks

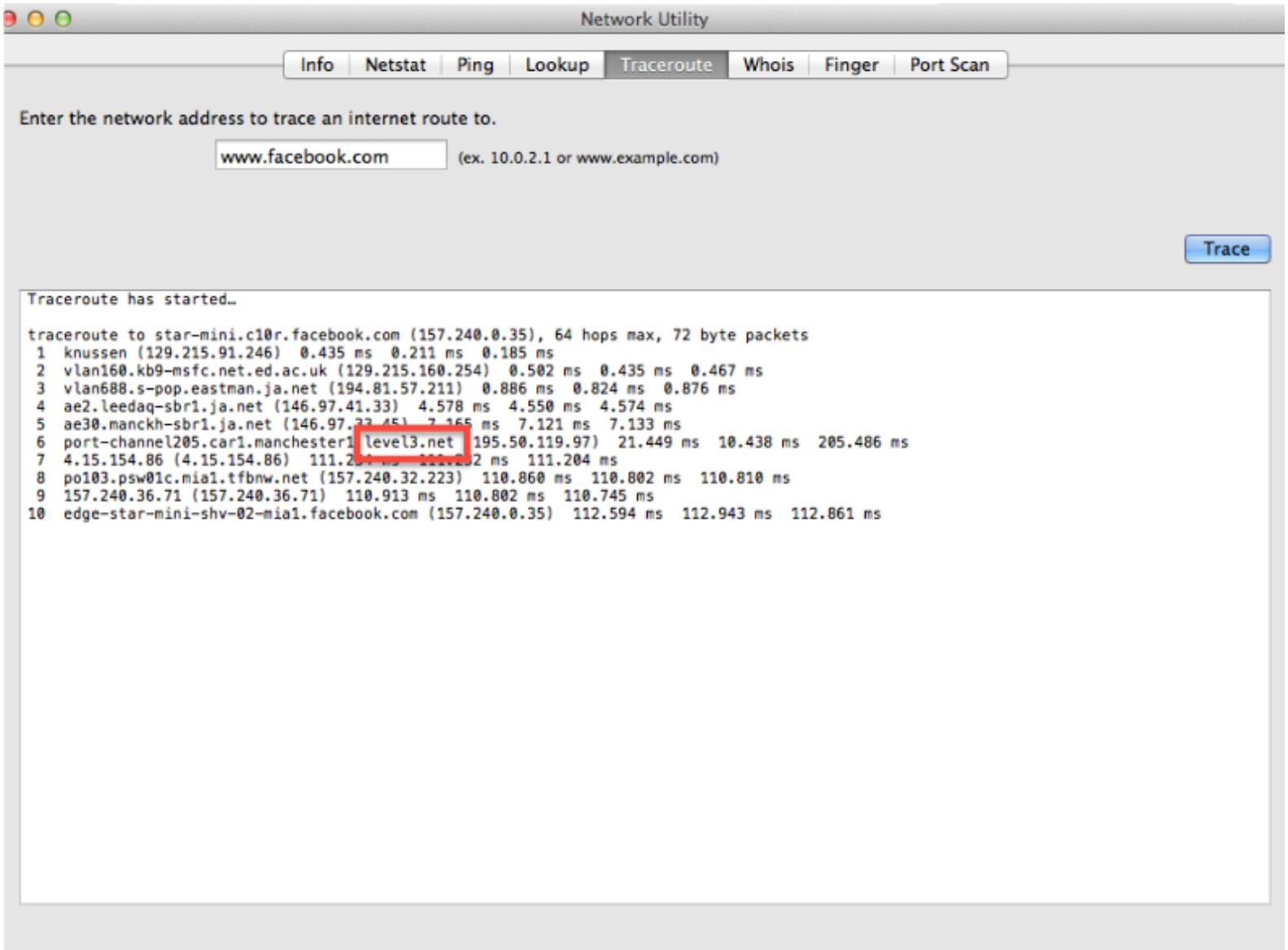
Verizon, BT, Vodafone, Level 3 'let NSA jack into Google, Yahoo! fiber'

Telcos cooperated with g-men in data slurp, claim sources

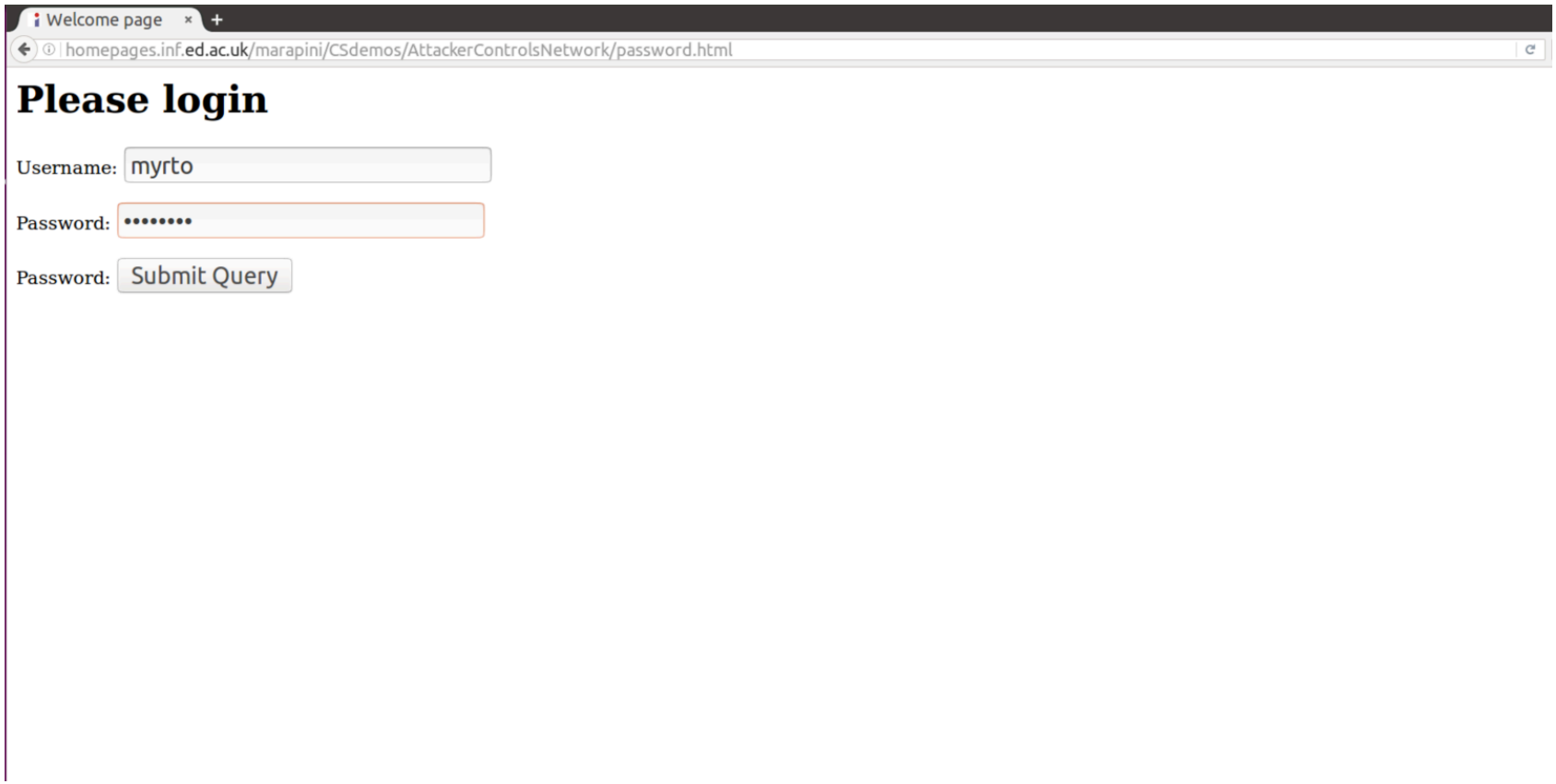
27 Nov 2013 at 02:19, Shaun Nichols 2

In October, NSA whistleblower Edward Snowden claimed Uncle Sam's spies tapped into the optic-fiber cables linking the data centers of Google and Yahoo!

The attacker controls the network (3)



All messages can be intercepted by an attacker (1)



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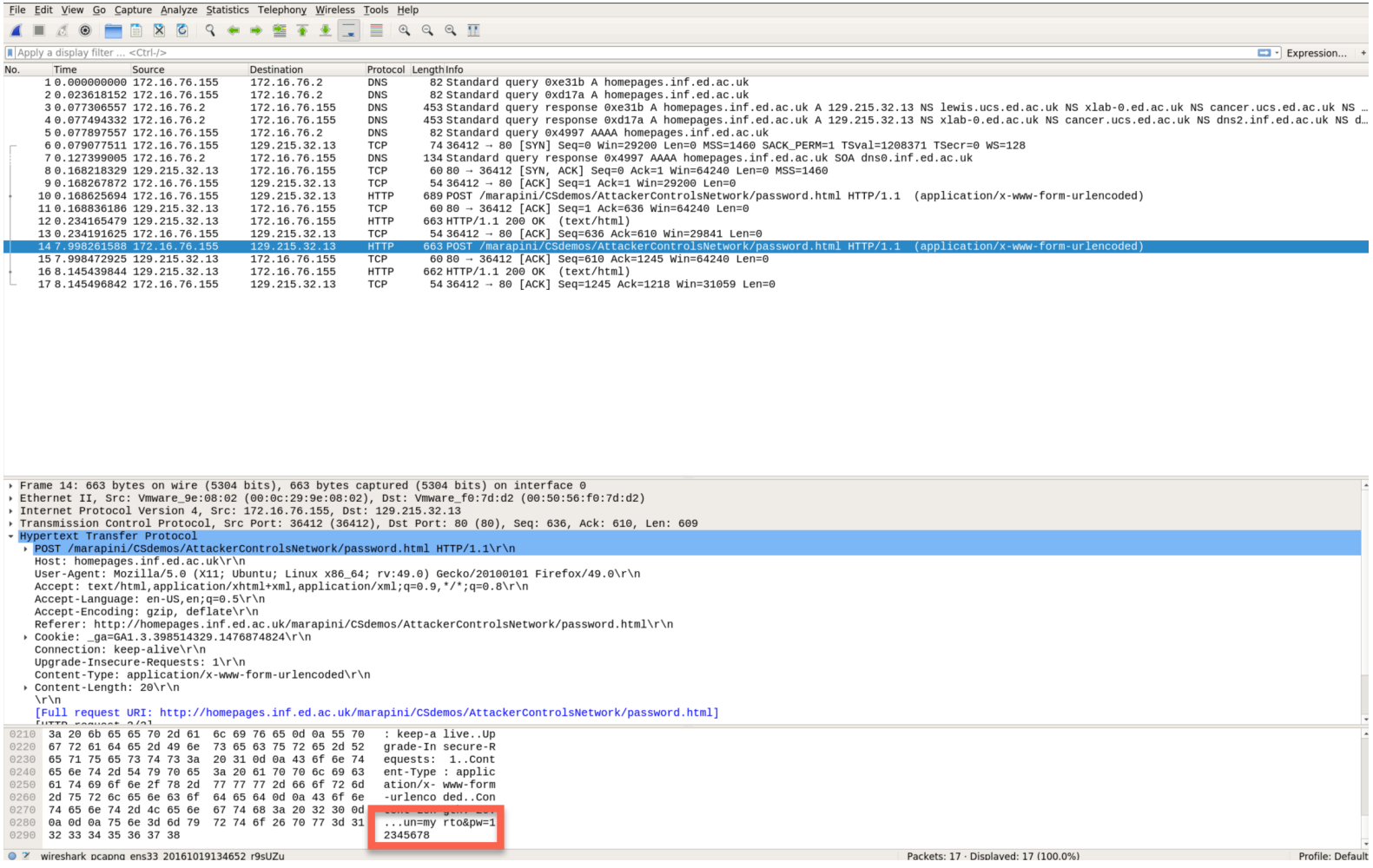

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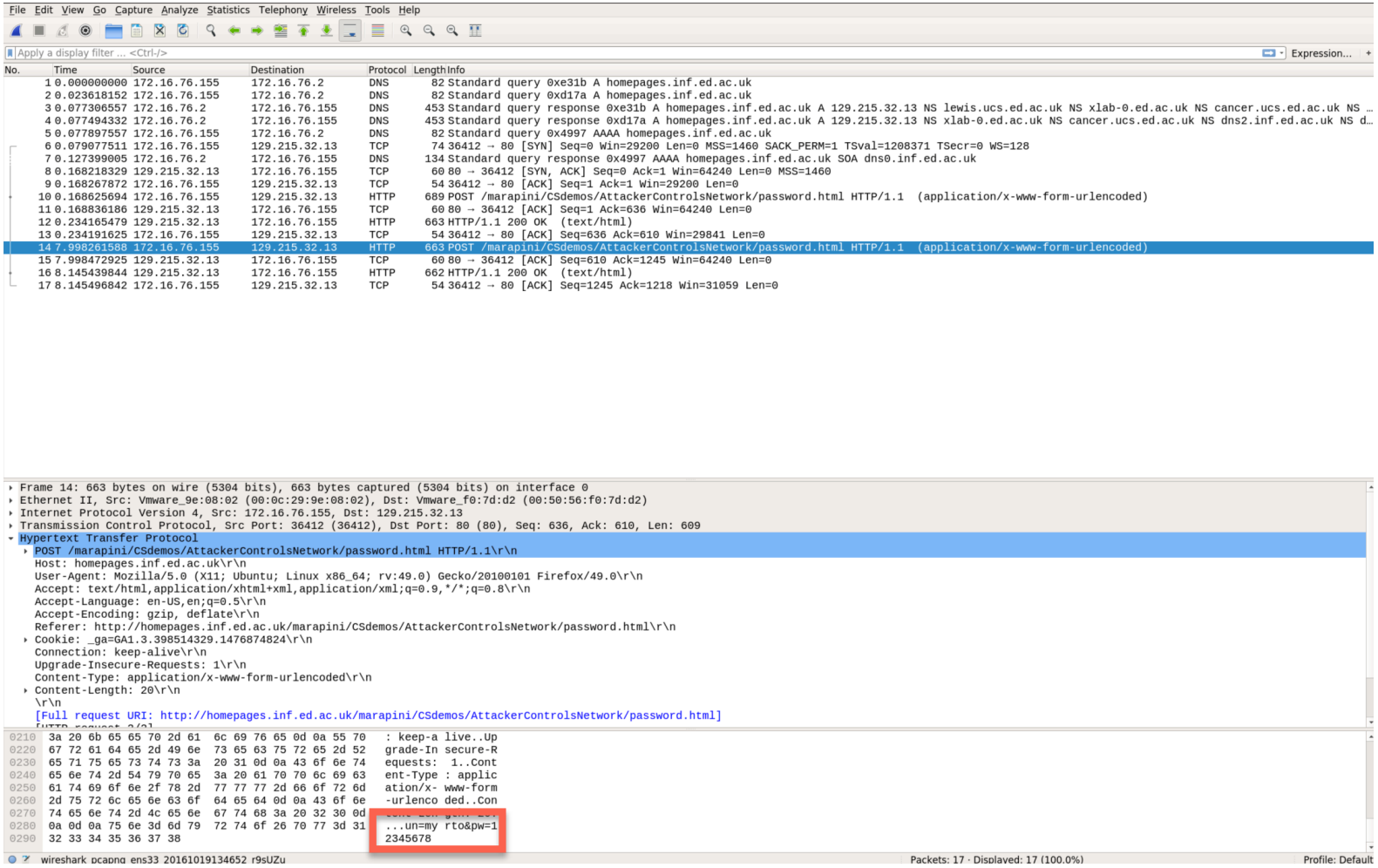

Man in the Middle (MitM) - An attacker can intercept packets, but also alter, forge new, and inject packets

More complex systems needed...

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$$\xrightarrow[m=MAC(K_M, E(K_E, \text{Transfer 100 € on Amazon's account}))]{e=E(K_E, \text{Transfer 100 € on Amazon's account})}$$

Royal Bank of Scotland

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Replay attack

$\xrightarrow{(e,m)}$

$\xrightarrow{(e,m)}$

$\vdots$

$\xrightarrow{(e,m)}$

Royal Bank of Scotland

... to achieve more complex properties

- Confidentiality: Some information should never be revealed to unauthorised entities.
- Integrity: Data should not be altered in an unauthorised manner since the time it was created, transmitted or stored by an authorised source.
- Authentication: Ability to know with certainty the identity of an communicating entity.
- Anonymity: The identity of the author of an action (*e.g.* sending a message) should not be revealed.
- Unlinkability: An attacker should not be able to deduce whether different services are delivered to the same user
- Non-repudiation: The author of an action should not be able to deny having triggered this action.
- ...

Cryptographic protocols

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Distributed programs relying on cryptographic primitives and whose goal is the establishment of "secure" communications.

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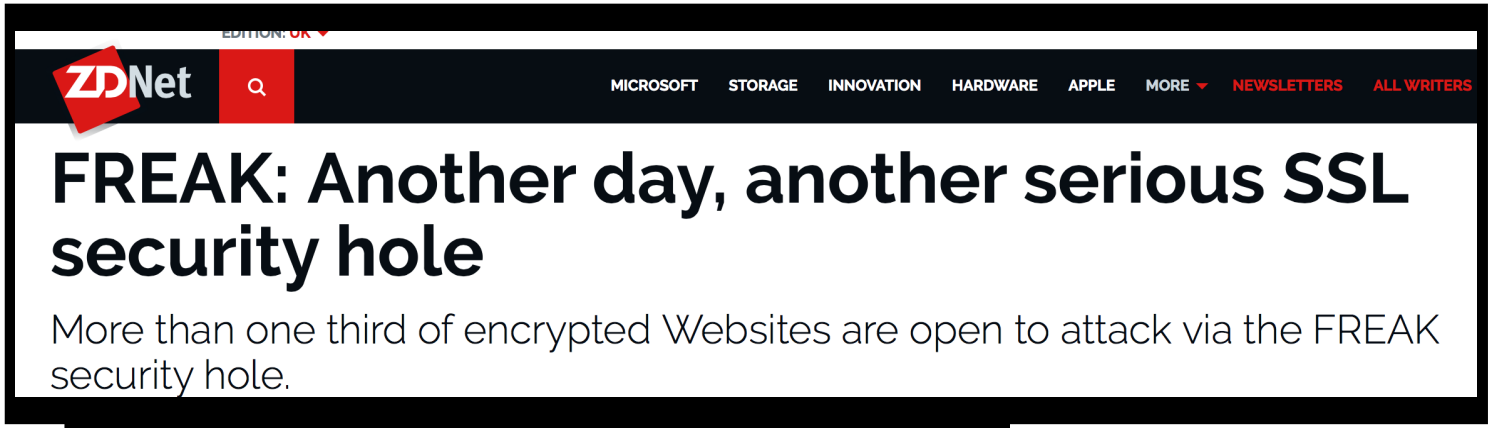
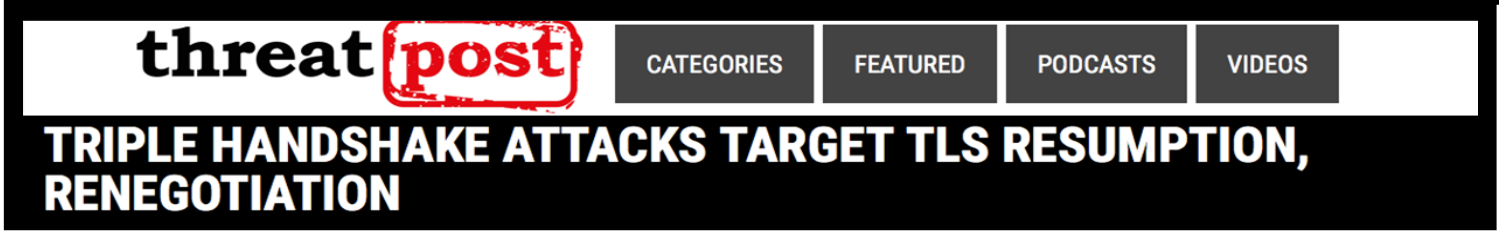
But!

Many exploitable errors are due not to design errors in the primitives, but to the way they are used, *i.e.* bad protocol design and buggy or not careful enough implementation

Numerous deployed protocols are flawed...

... and end up in the news :(





Logical attacks

Many of these attacks do not even break the crypto primitives!!

Example of a logical attack

Assume a commutative symmetric encryption scheme

$$\{\{m\}_{k_1}\}_{k_2} = \{\{m\}_{k_2}\}_{k_1}$$

where $\{m\}_k$ denotes the encryption of message m under the key k
Example: stream ciphers

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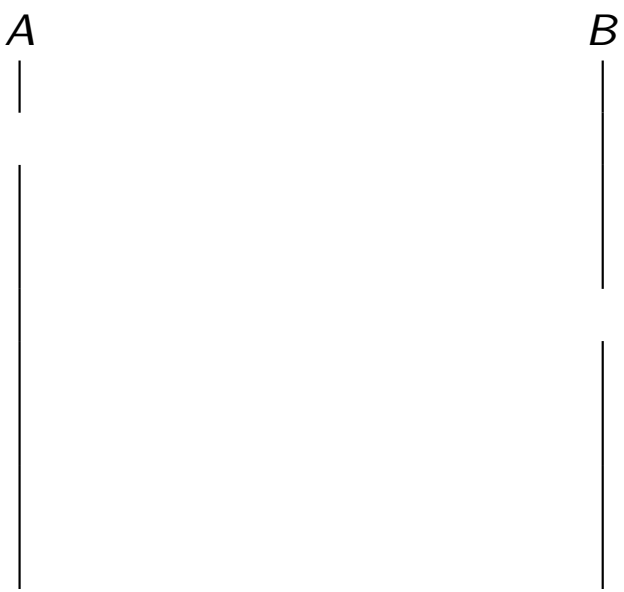

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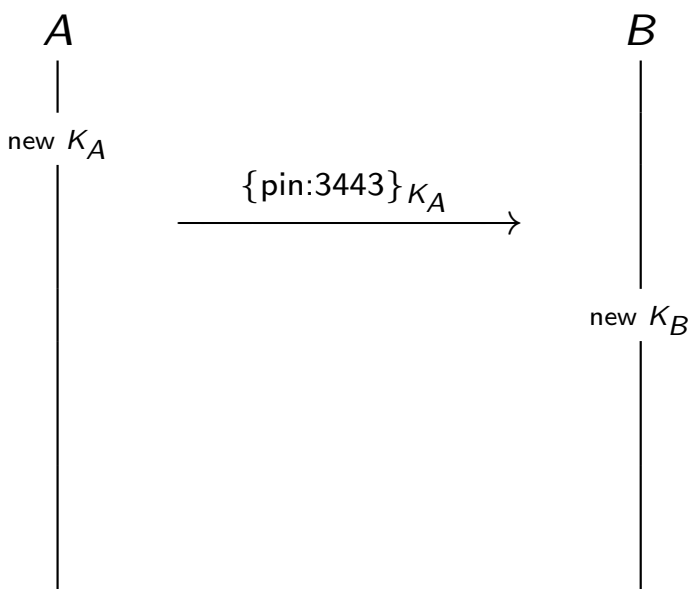

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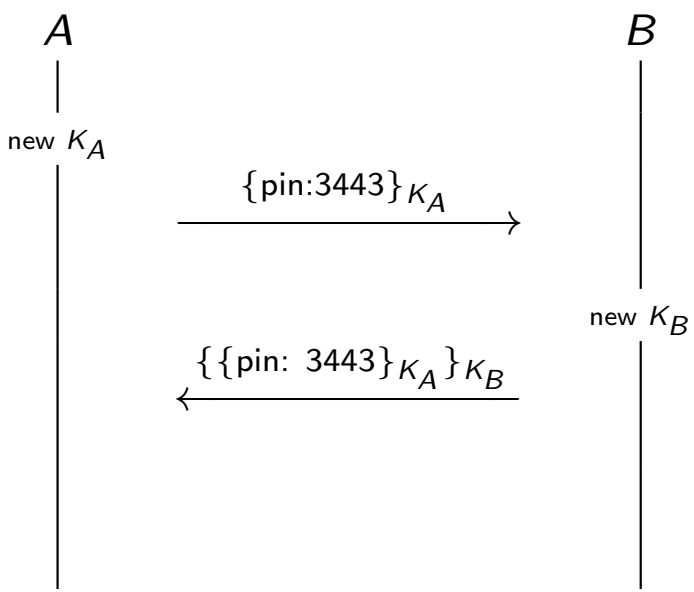

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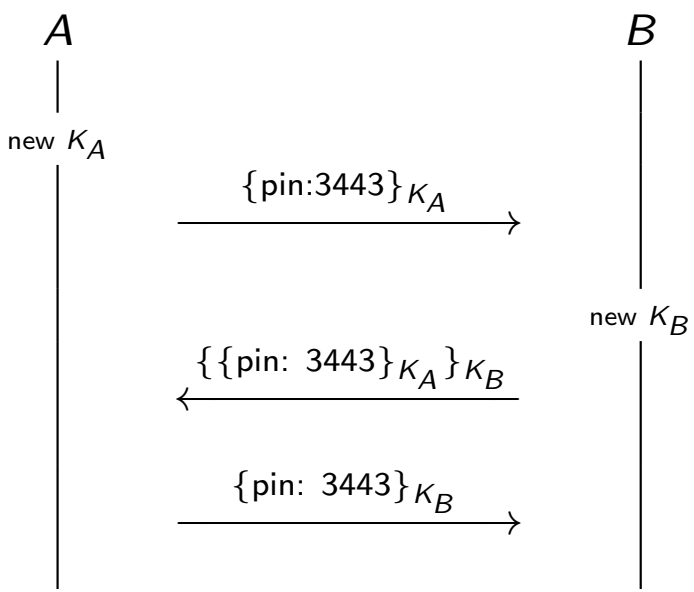

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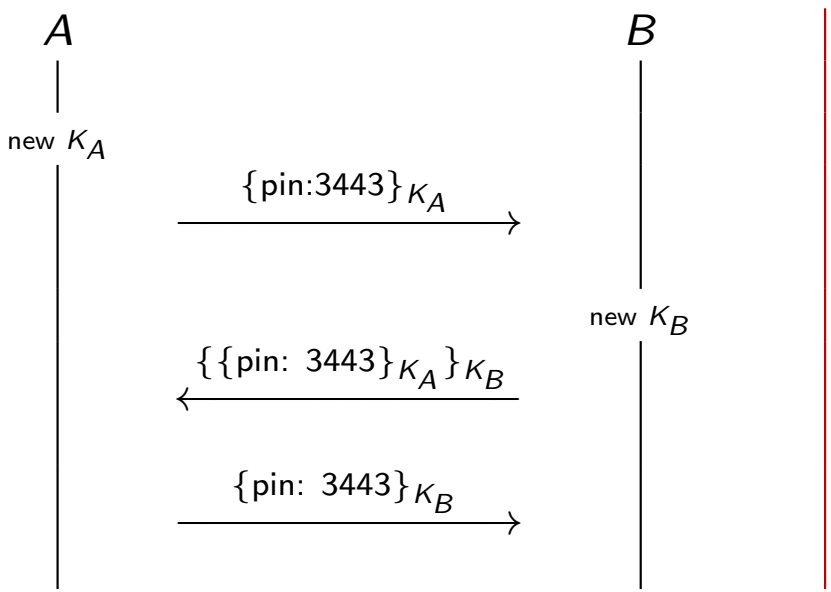

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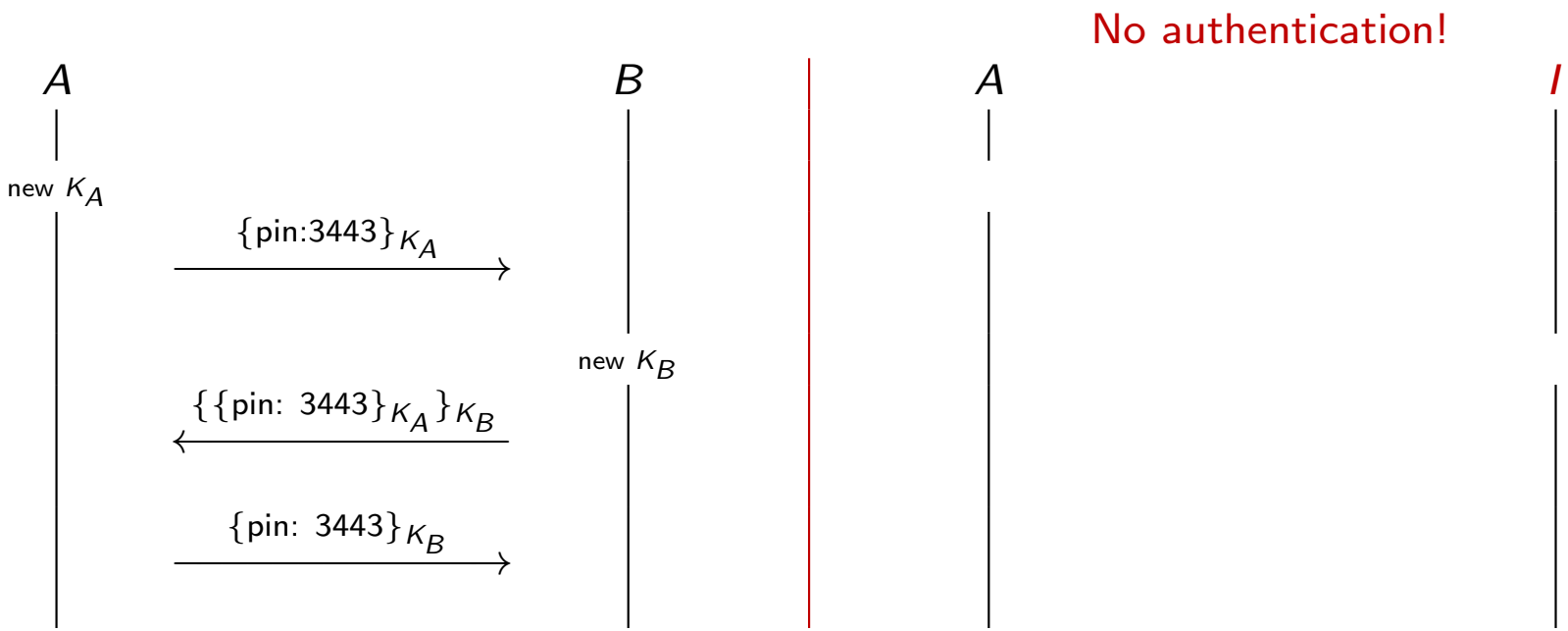

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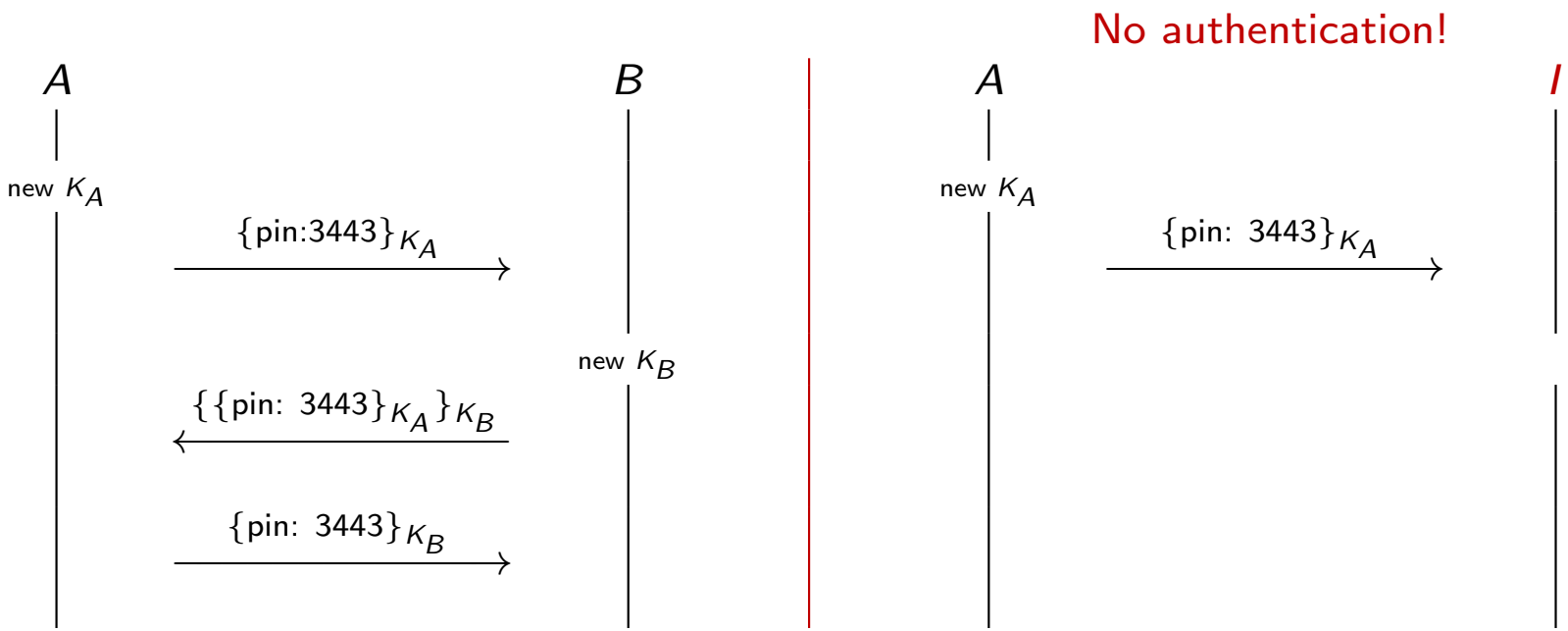

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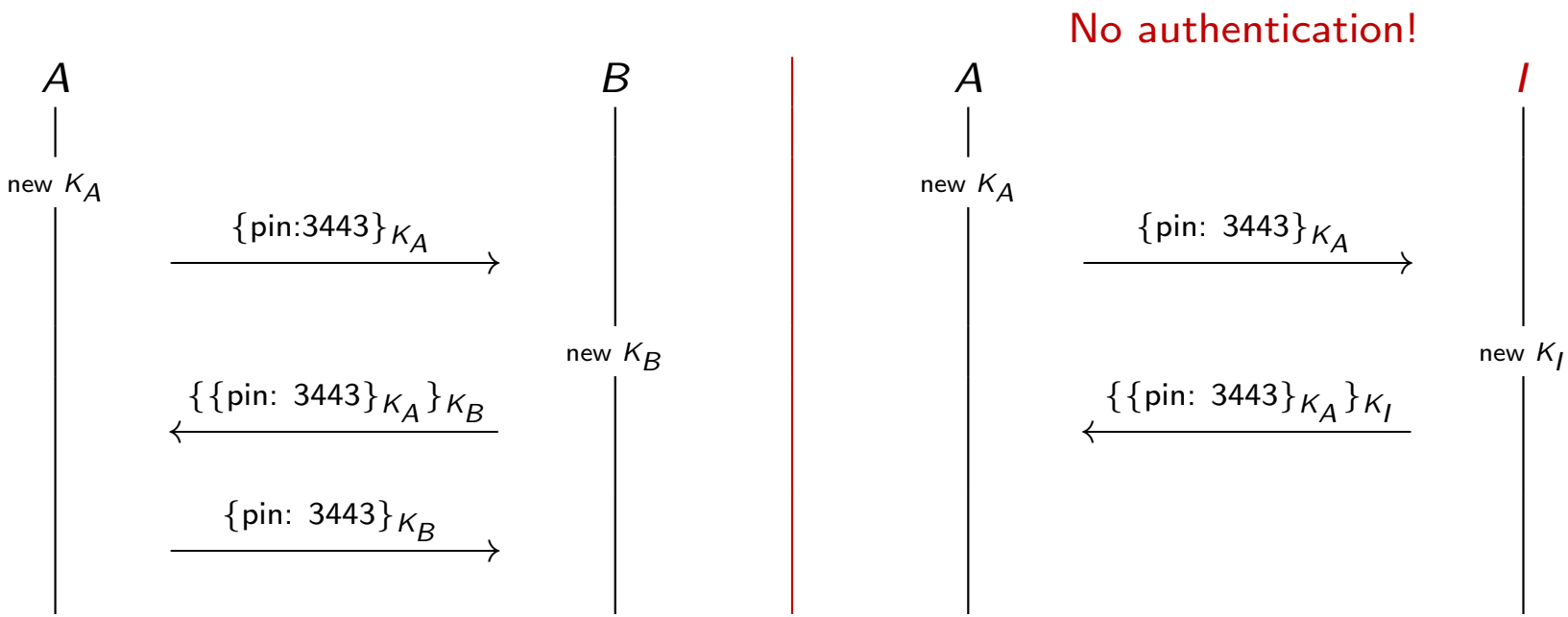

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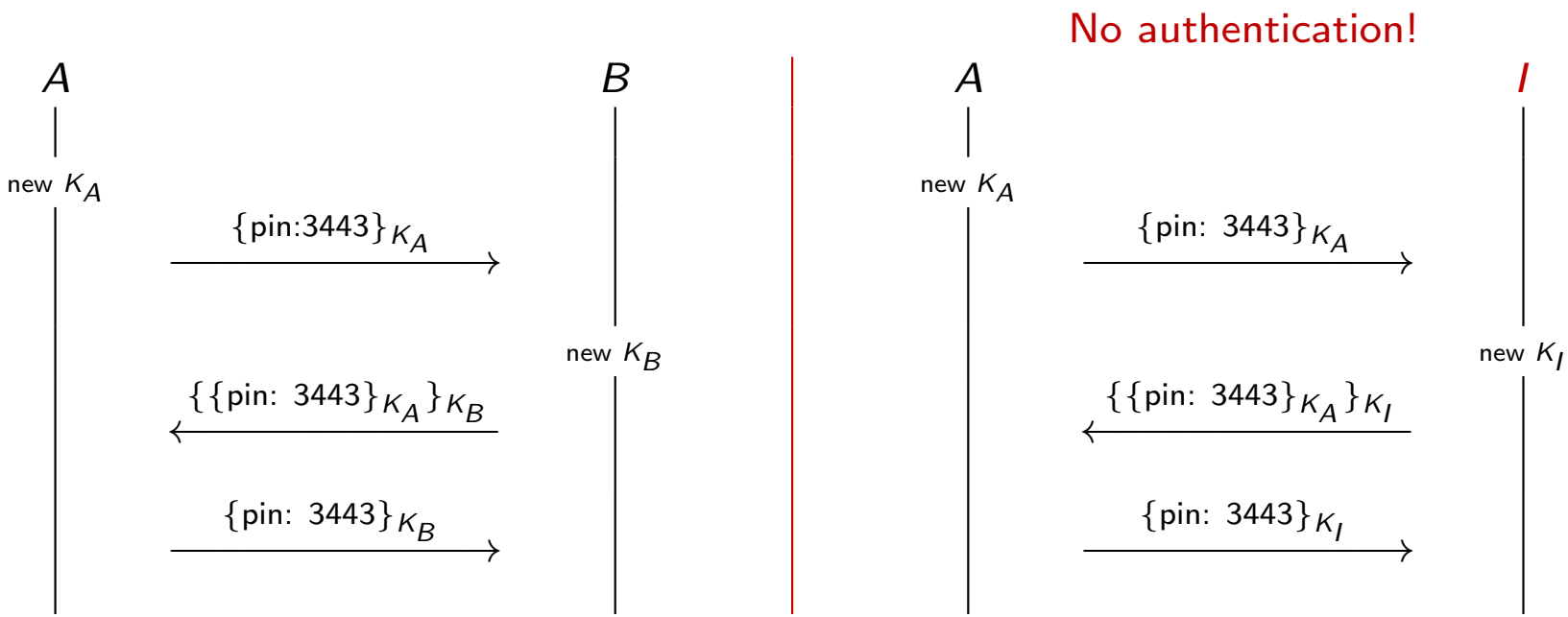

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Authentication and key agreement protocols

Authentication and key agreement

- Long-term keys should be used as little as possible to to reduce "attack-surface"
- The use of a key should be restricted to a specific purpose
  e.g. you shouldn't use the same RSA key both for encryption and signing
- Public key algorithms tend to be computationally more expensive than symmetric key algorithms

$\rightsquigarrow$ Long-term keys are used to establish short-term session keys
e.g. TLS over HTTP, AKA for 3G, BAC for epassports, *etc.*

Needham-Schroeder Public Key (NSPK)

NSPK: authentication and key agreement protocol

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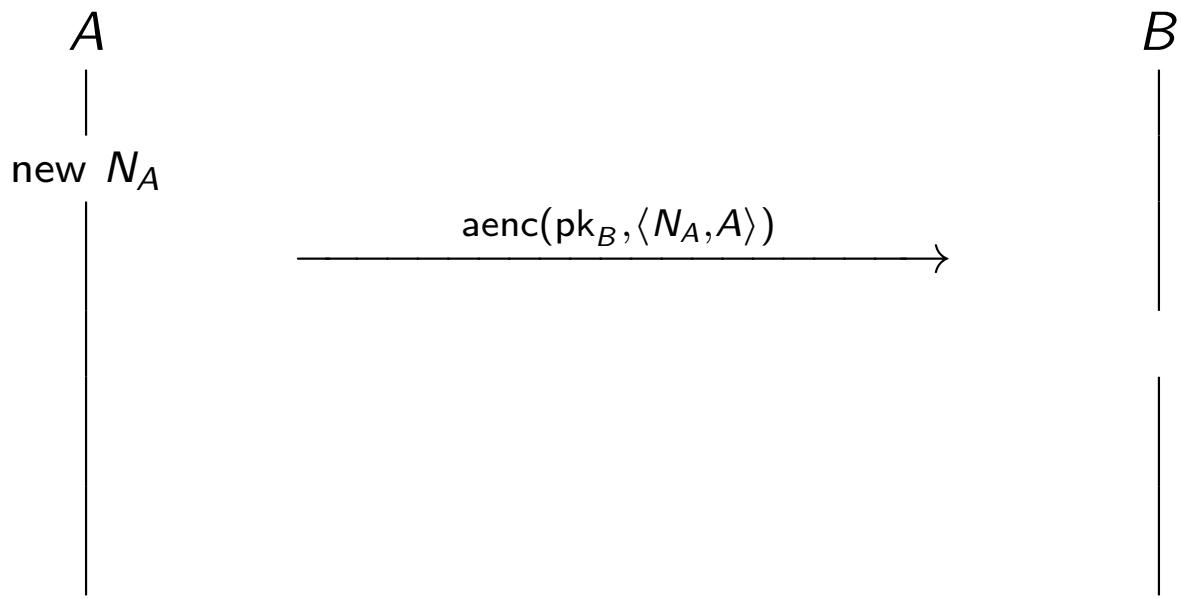

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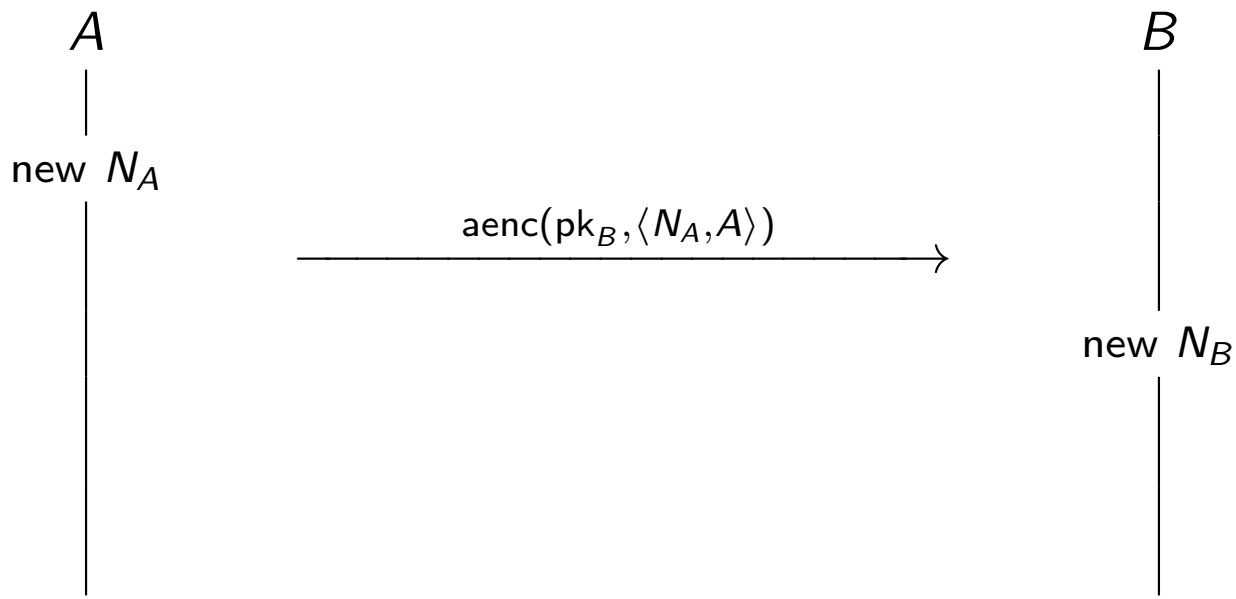

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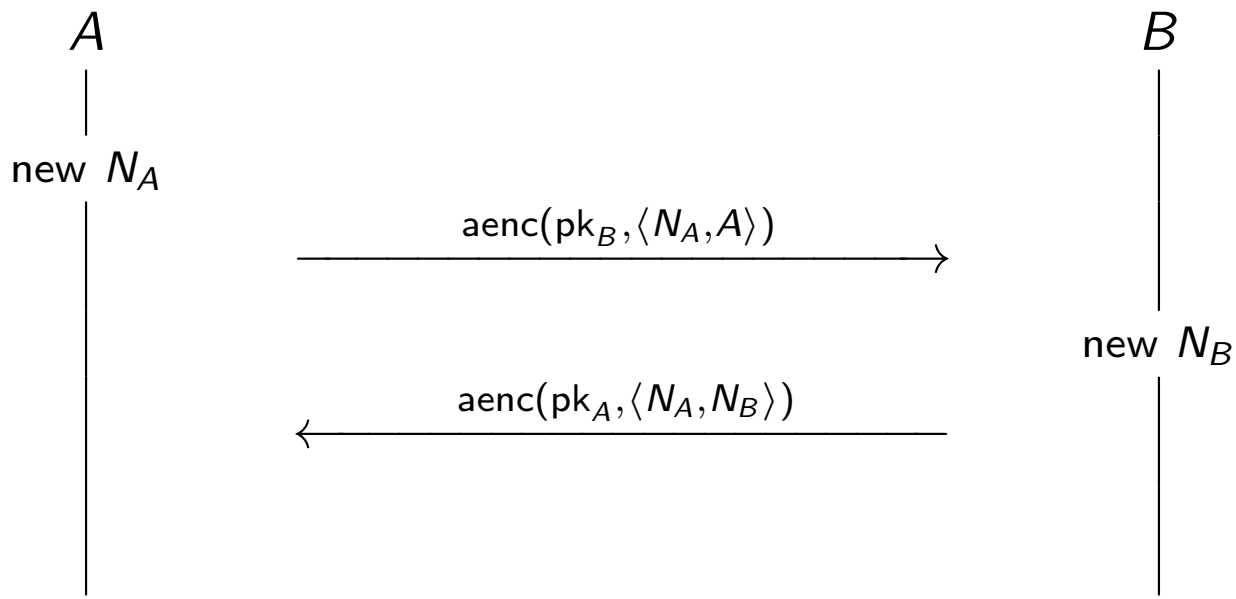

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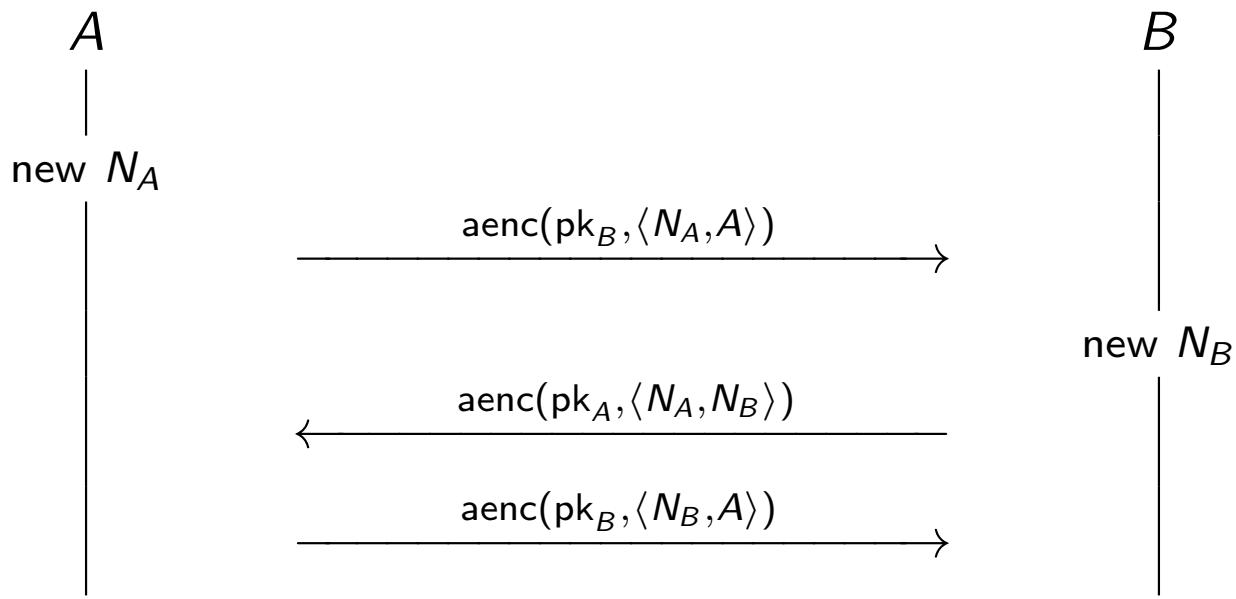

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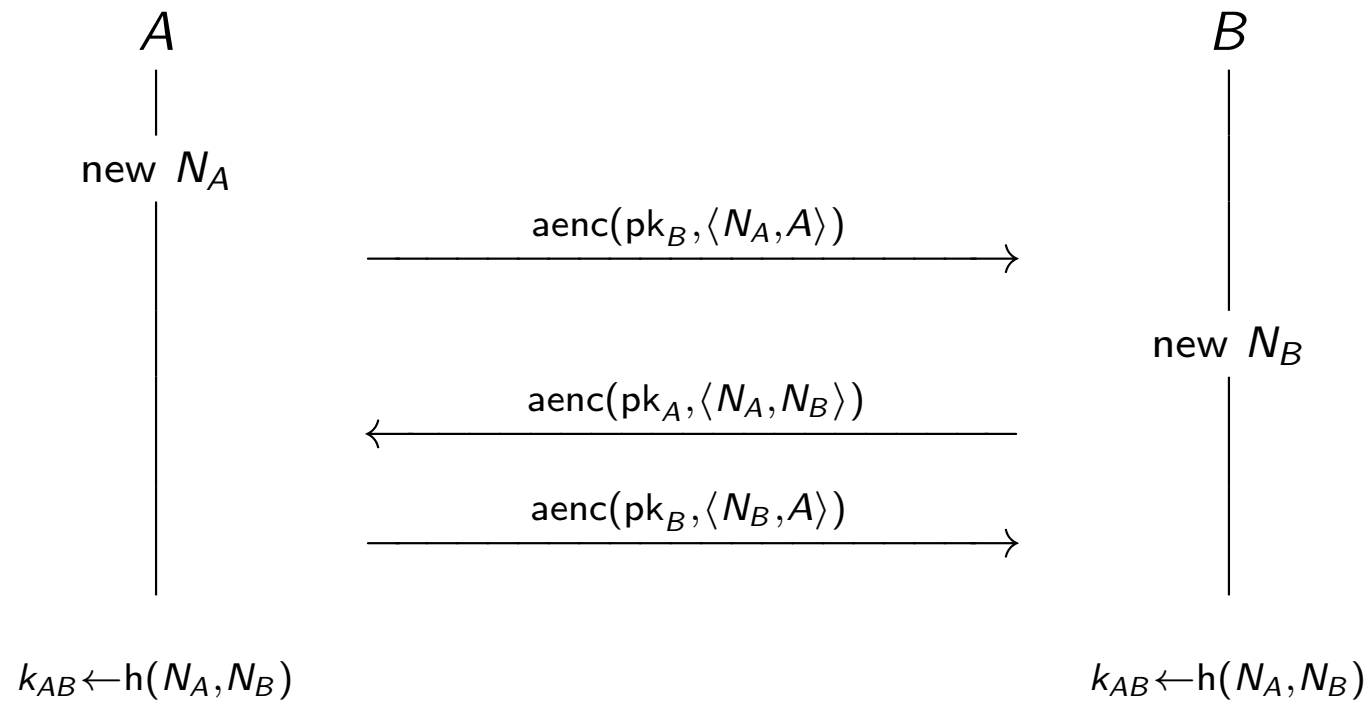

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NSPK: security requirements

- Authentication: if Alice has completed the protocol, apparently with Bob, then Bob must also have completed the protocol with Alice.
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- Confidentiality: Messages sent encrypted with the agreed key ($k \leftarrow \mathsf{h}(N_A, N_B)$) remain secret.

NSPK: Lowe's attack on authentication

Attack found 17 years after the publication of the NS protocol!!

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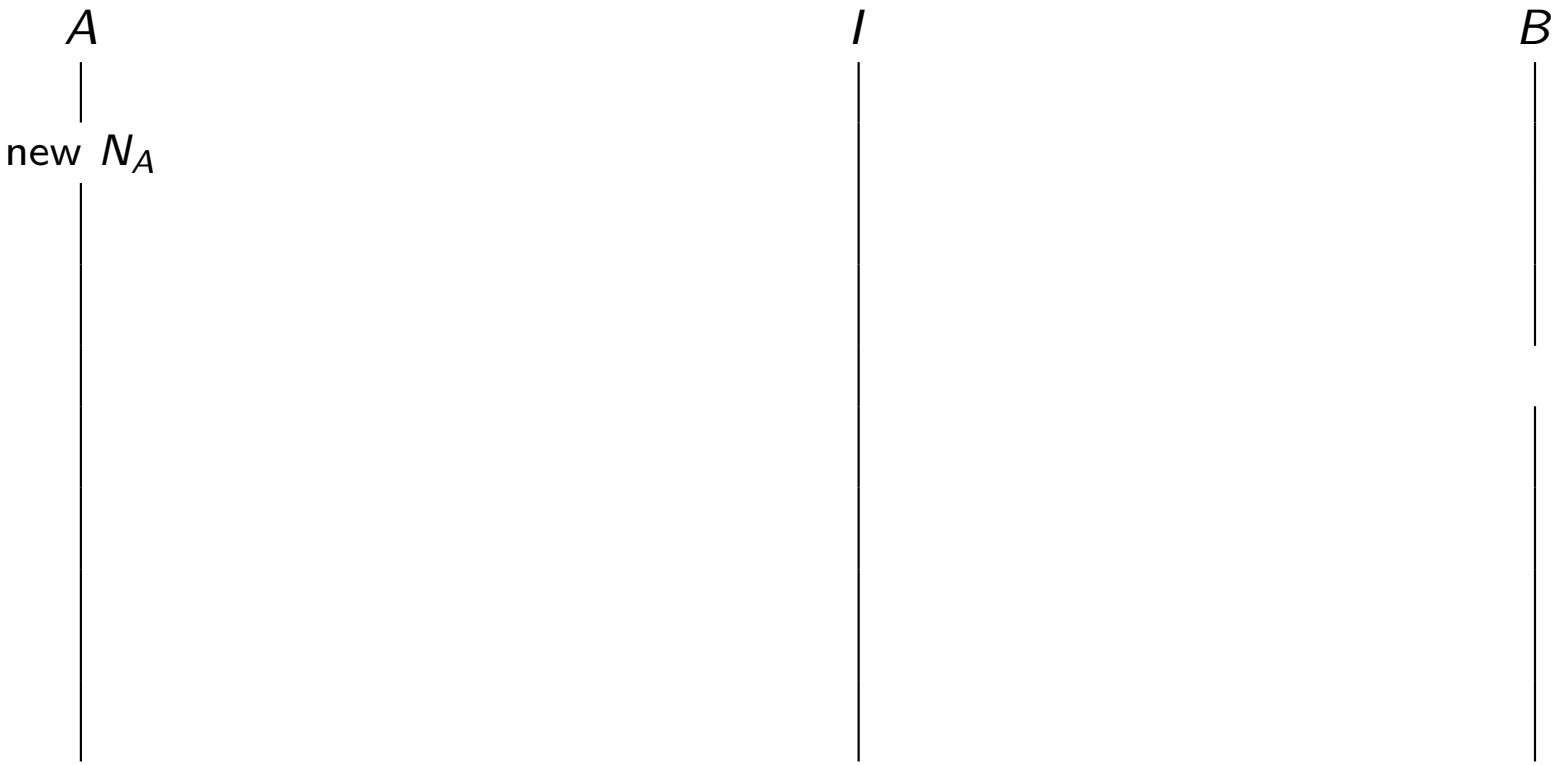

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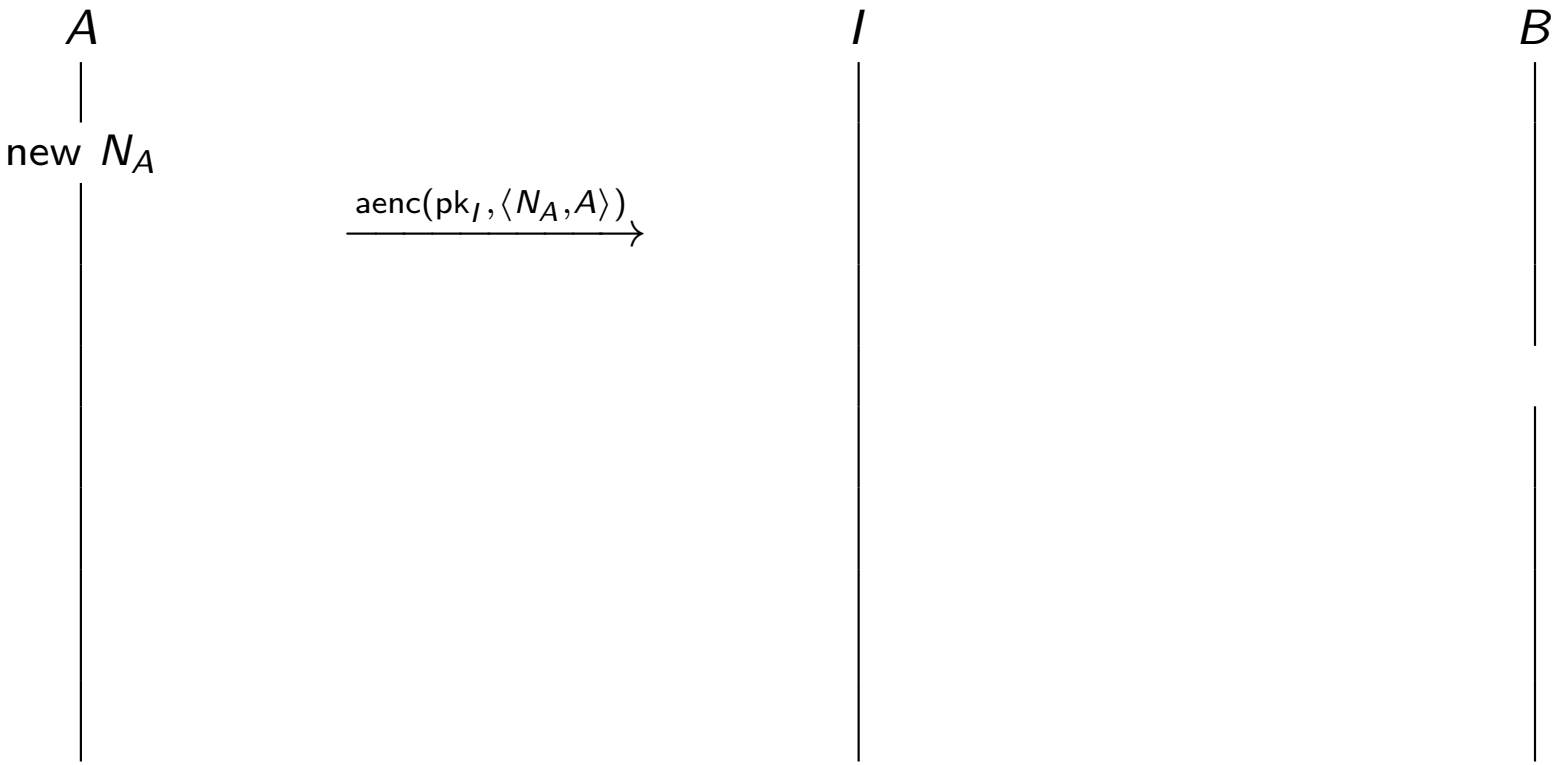

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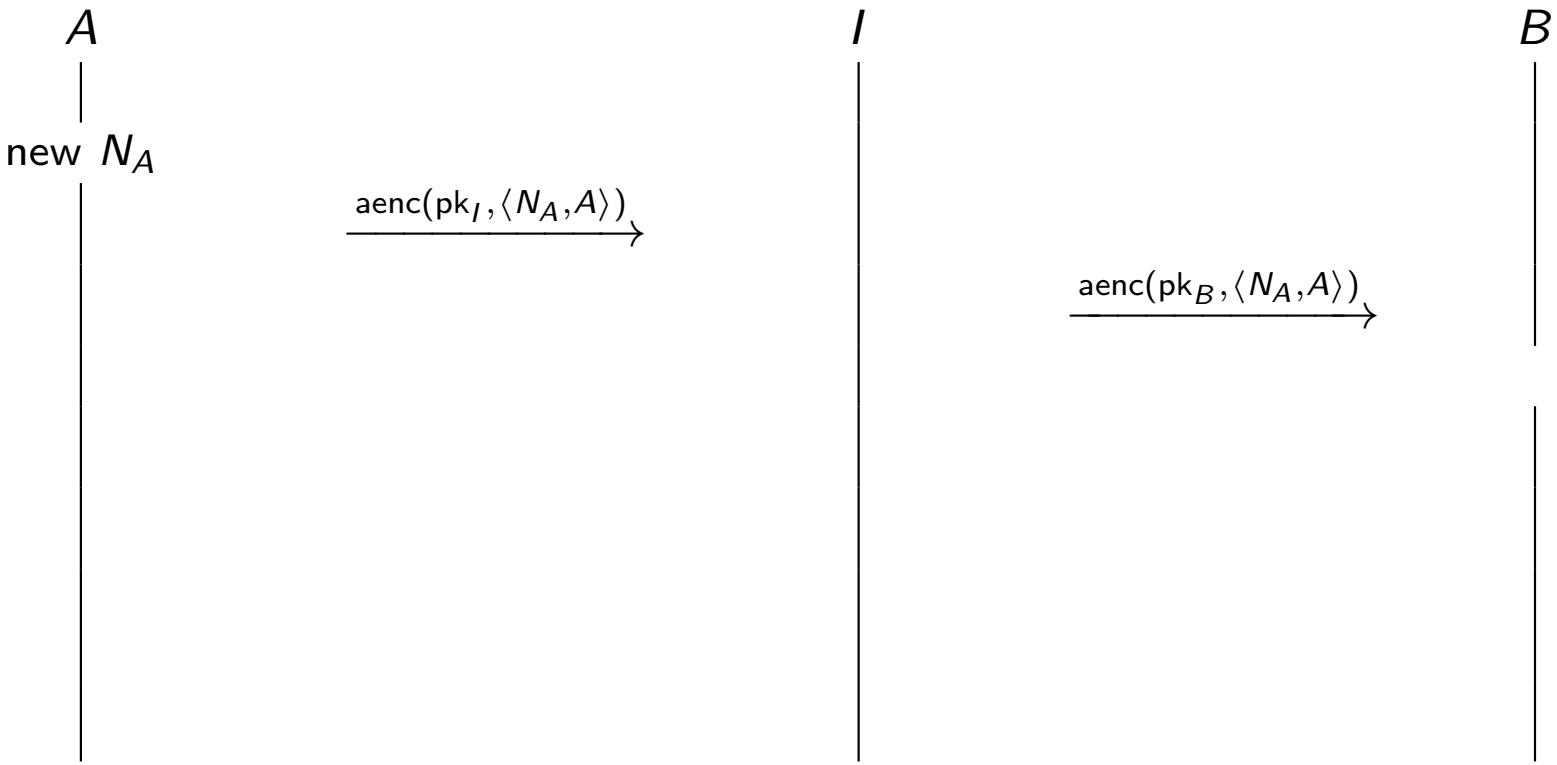

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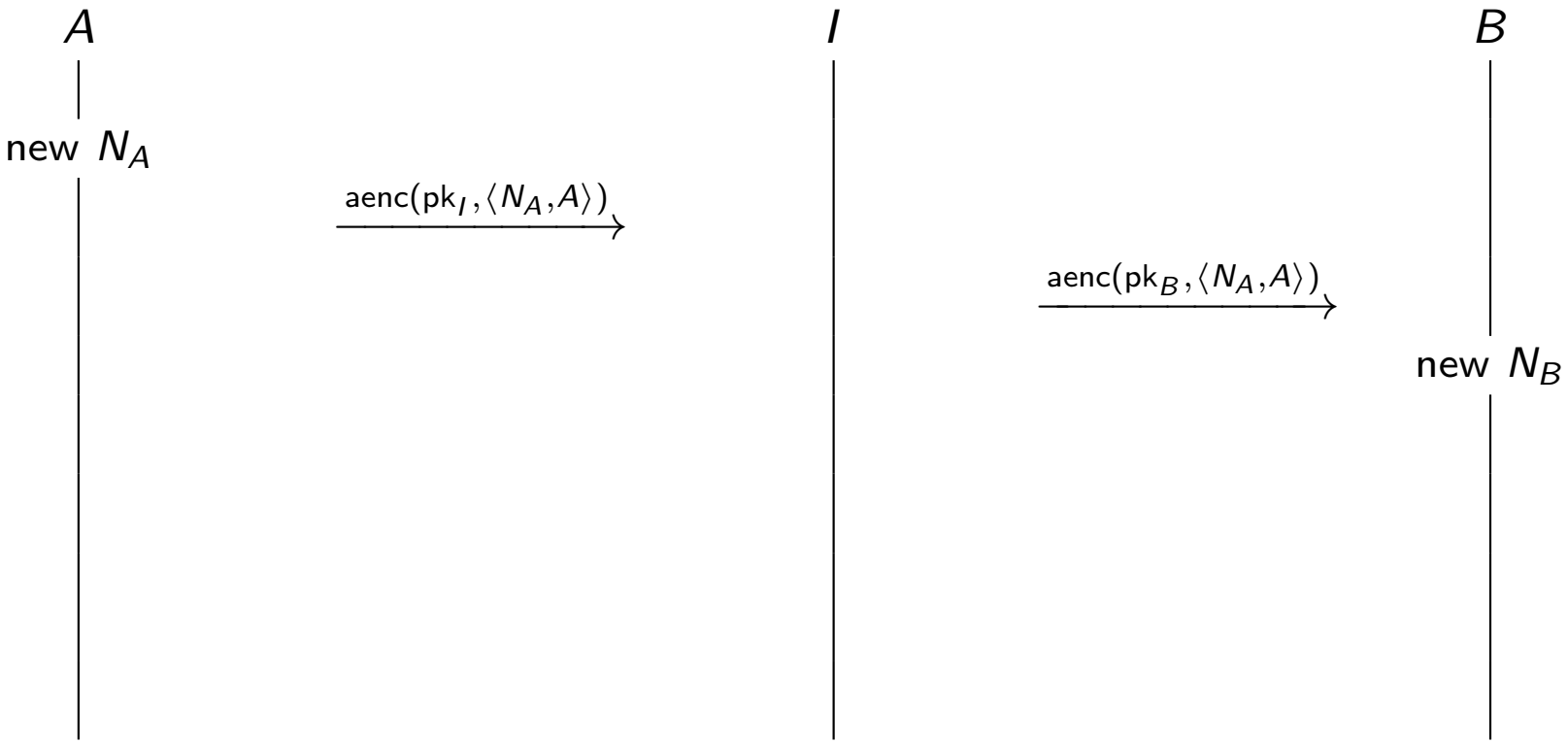

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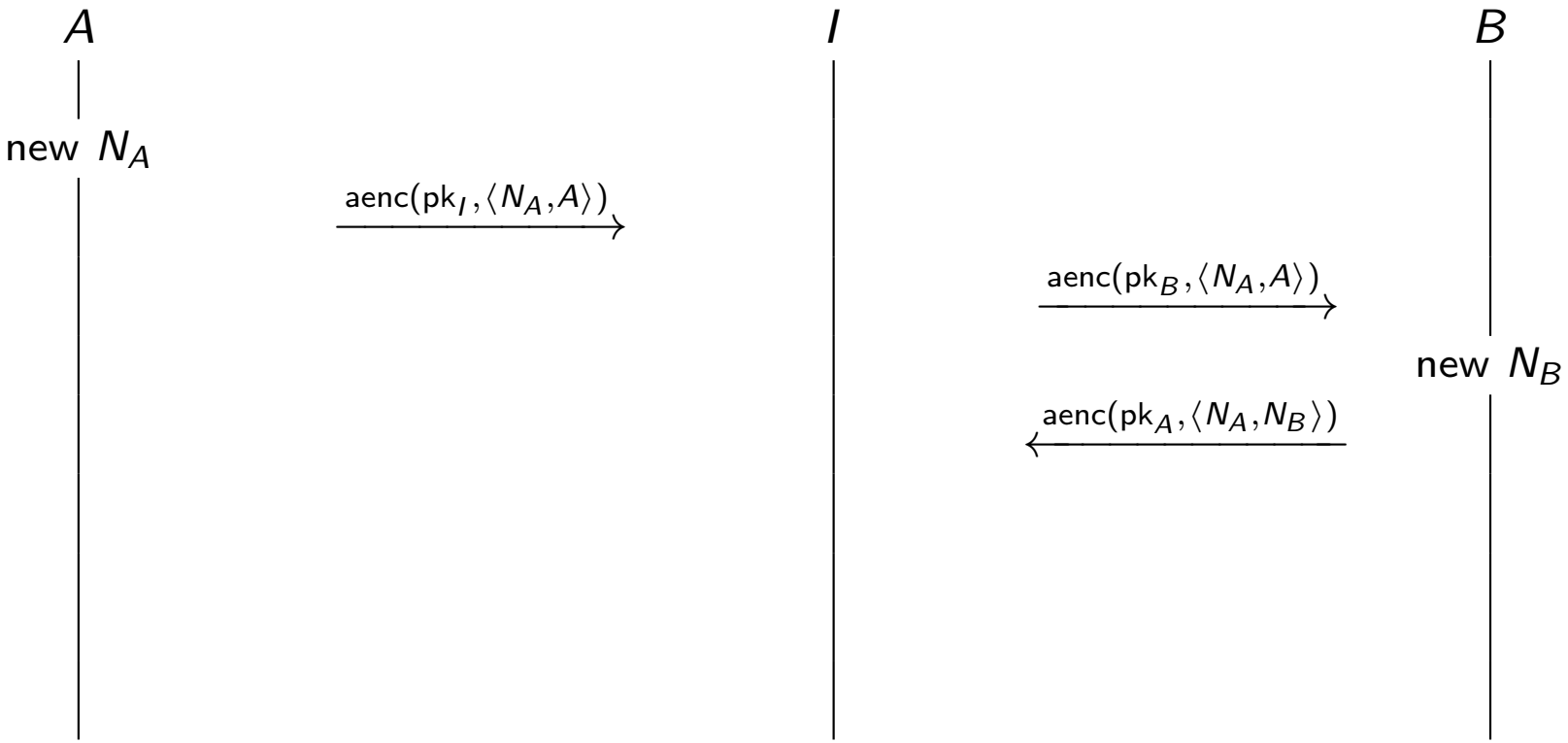

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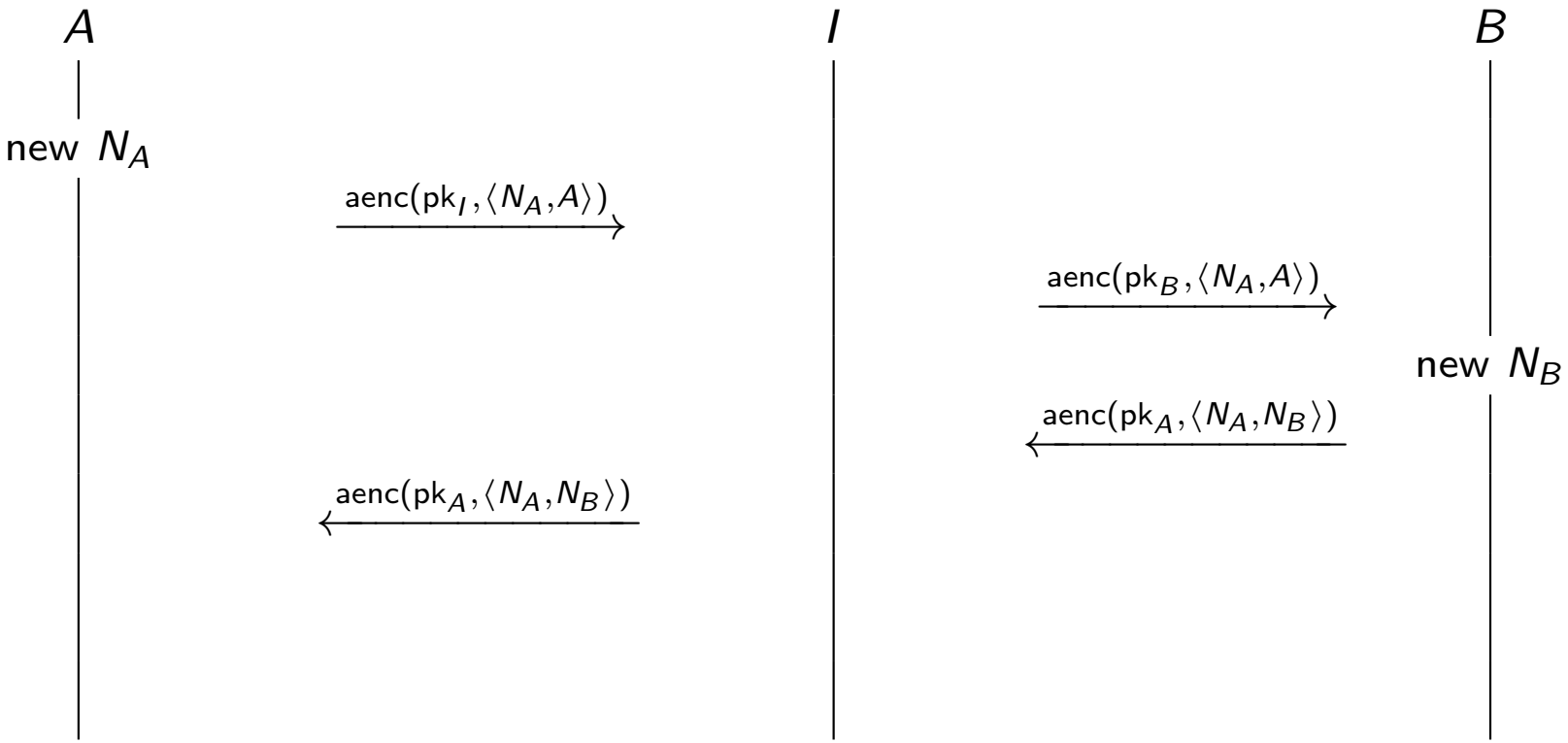

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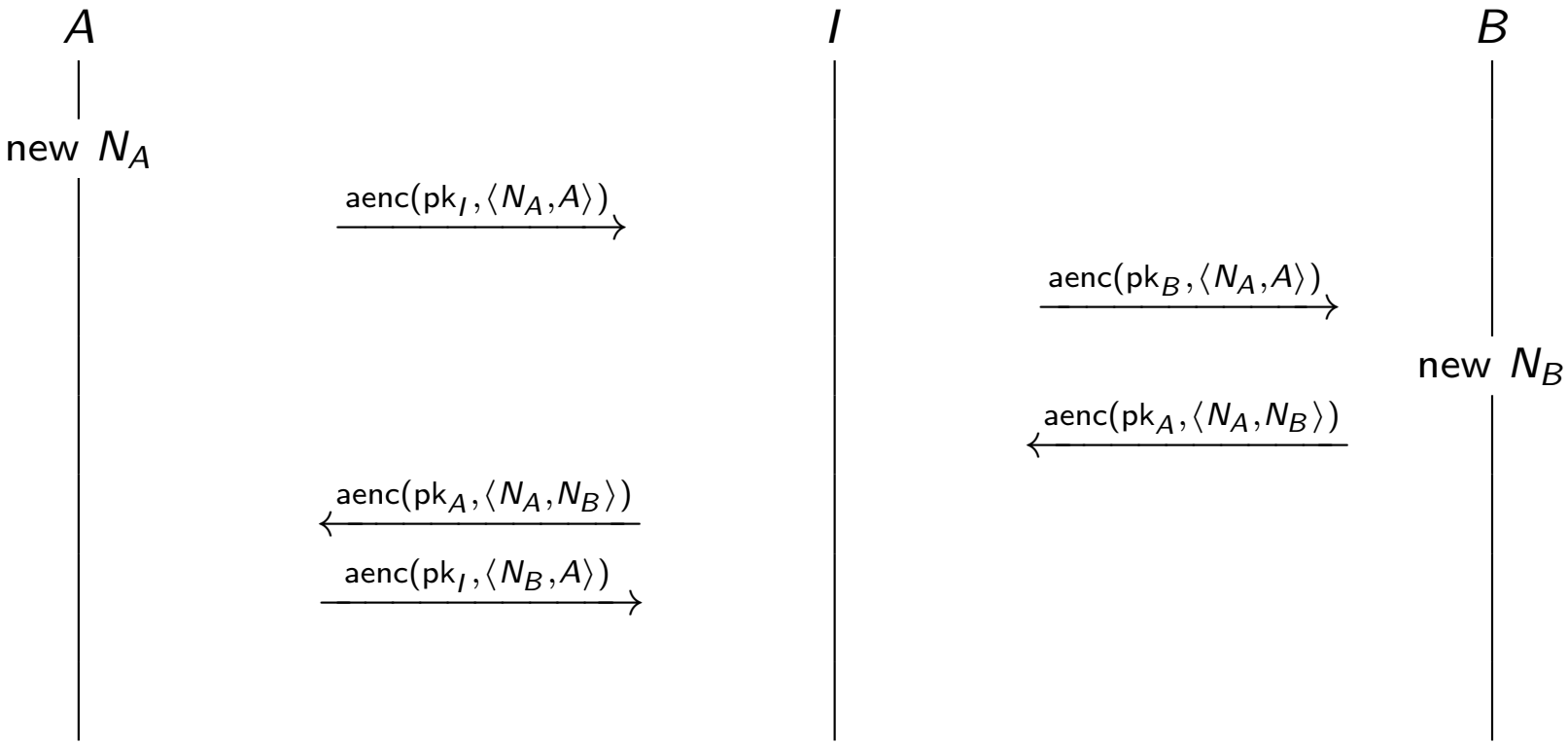

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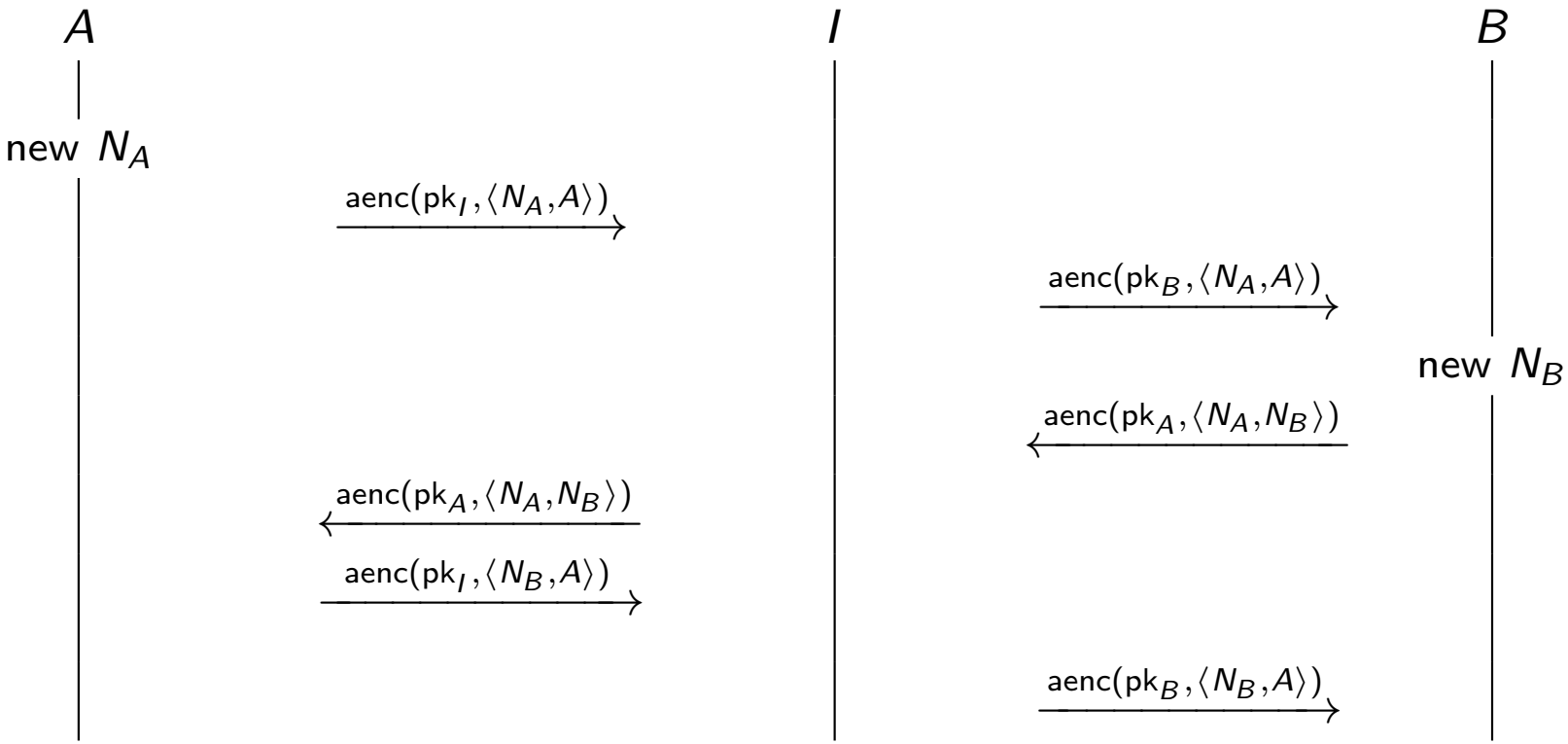

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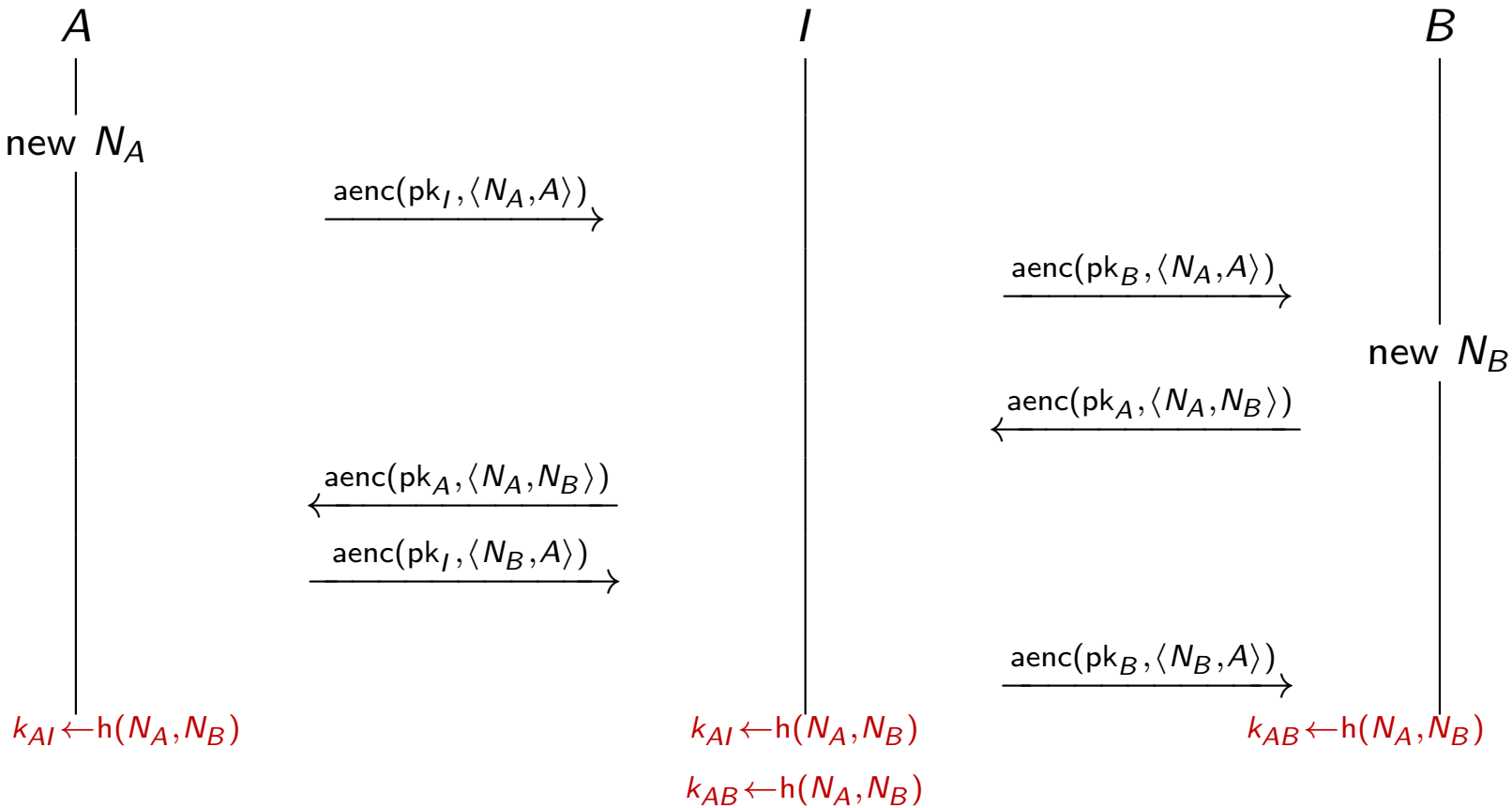

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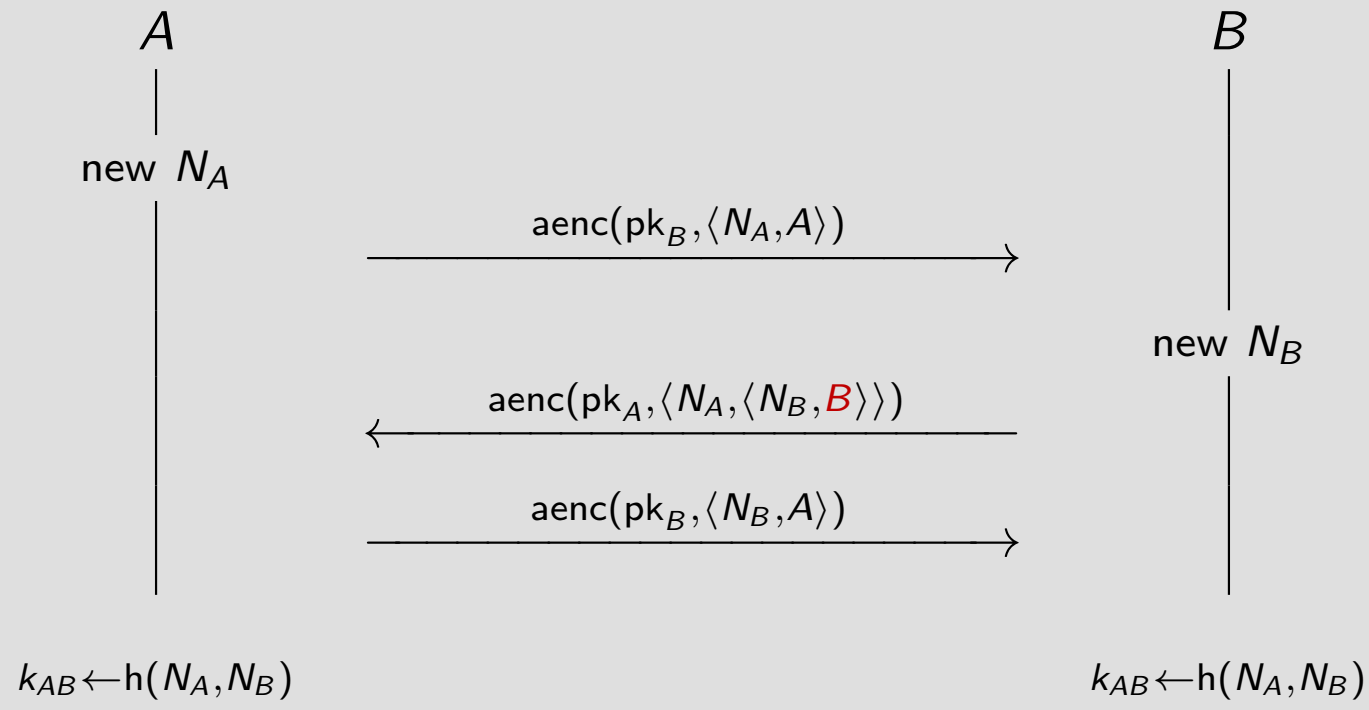
NSPK: Lowe's fix

The Needham-Schroeder-Lowe (NSL) protocol



Forward secrecy

- The NSL protocol is secure against an attacker that controls the network.
- What if the Alice's and Bob's private keys get compromised?
- What if the government forces Alice and Bob to reveal their private keys?
- Can we still protect confidentiality?

Forward secrecy

A protocol ensures forward secrecy, if even if long-term keys are compromised, past sessions of the protocol are still kept confidential, and this even if an attacker actively interferred.

The Station-to-Station (StS) protocol

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- where p is a large prime
- and g a generator of $\mathbb{Z}_p^*$

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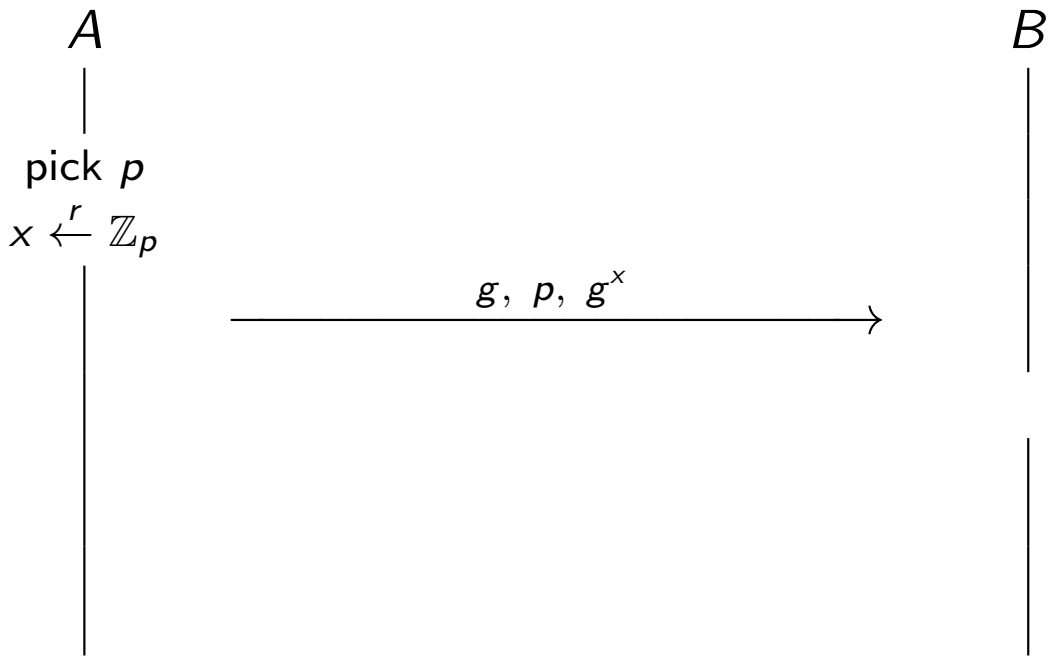

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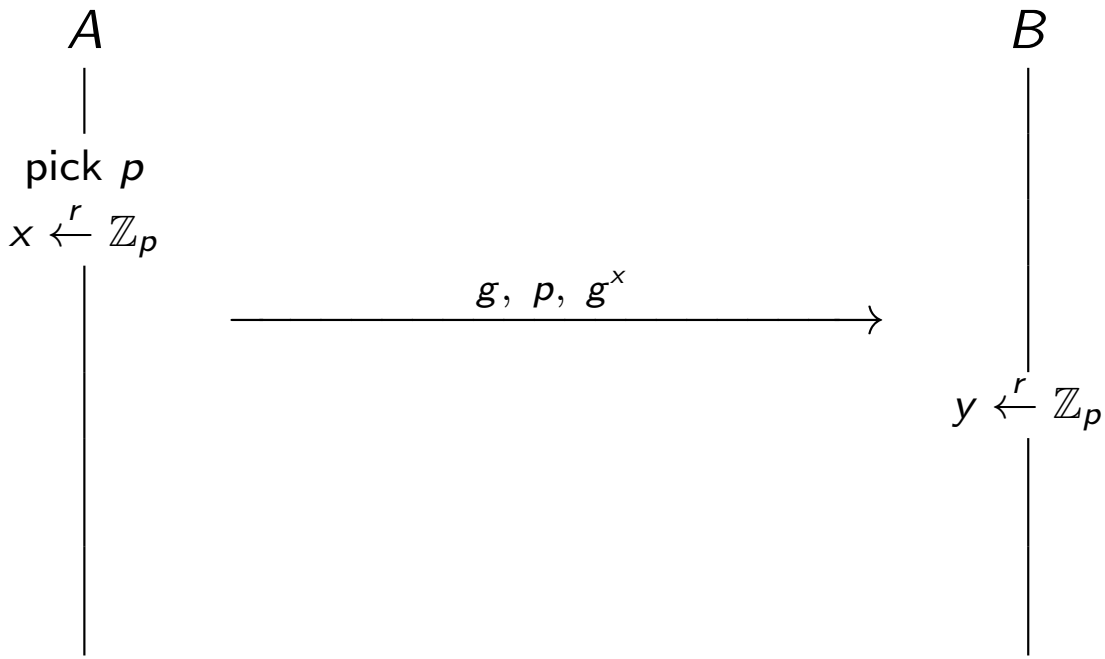

- where p is a large prime
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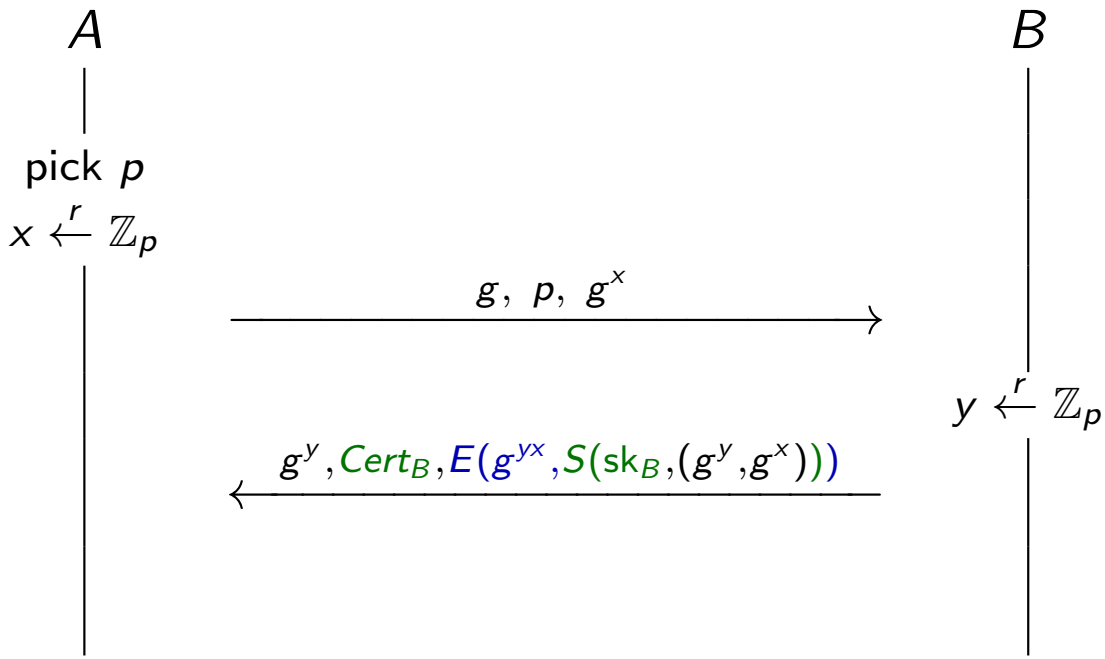

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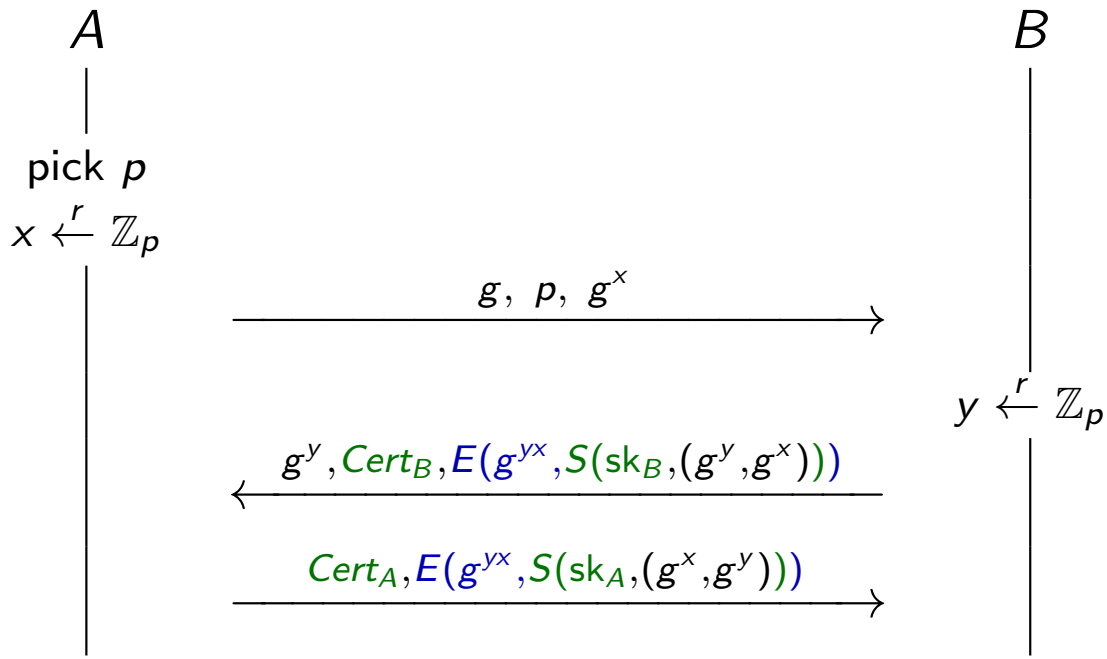

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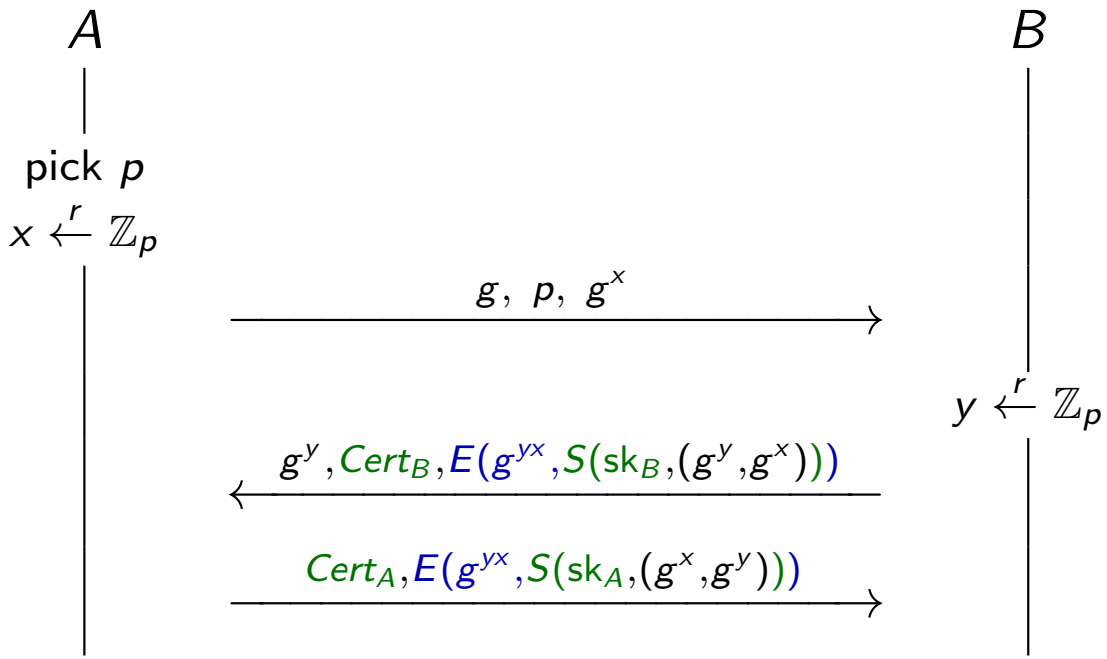

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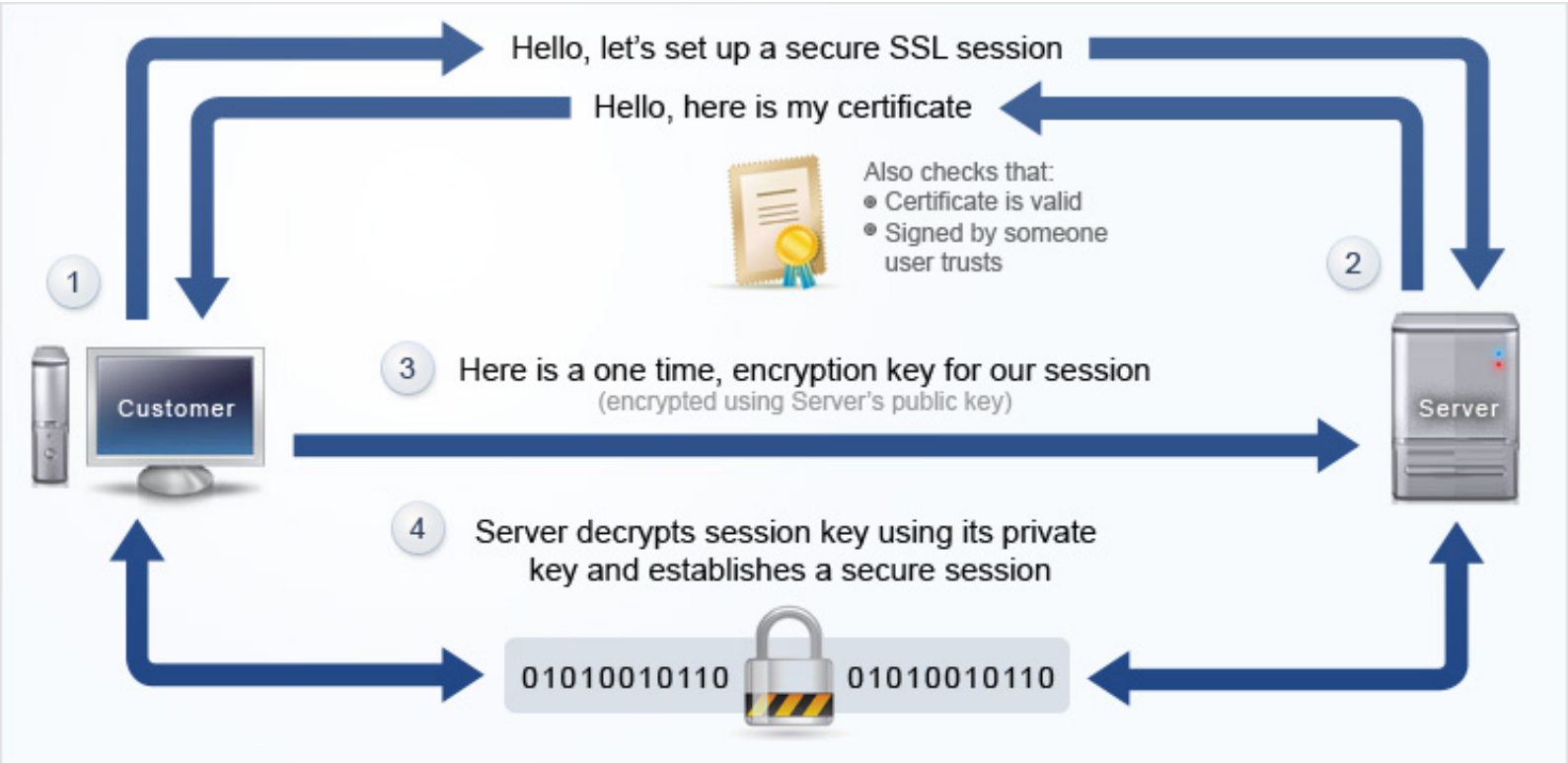
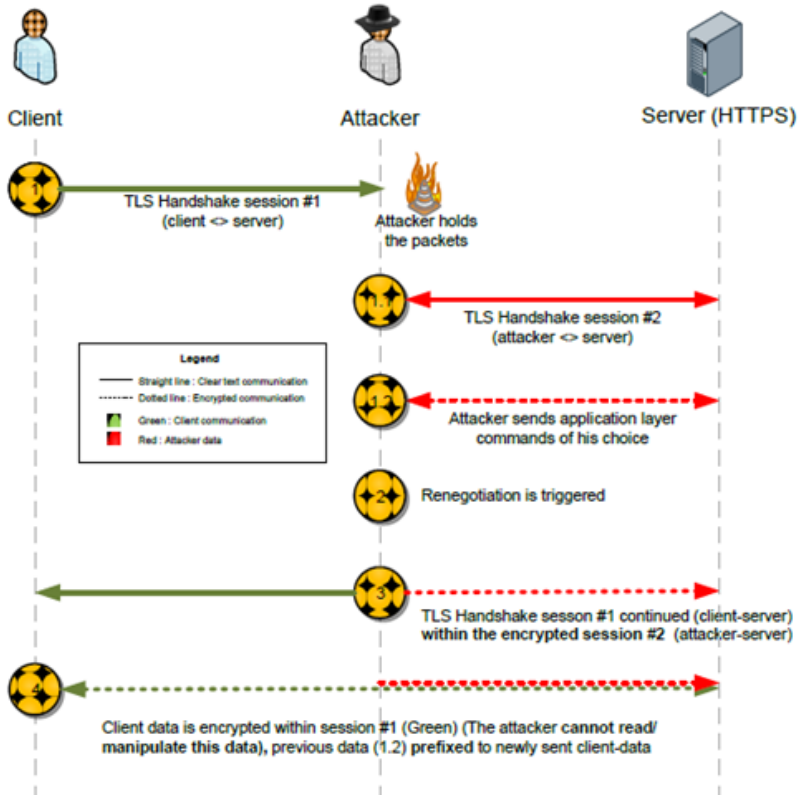
The StS ensures mutual authentication, key agreement, and forward secrecy

Old SSL/TLS handshake protocol



SSL/TLS renegotiation weaknesses

- Renegotiation has priority over application data!
- Renegotiation can take place in the middle of an application layer transaction!



Incorrect implicit assumtion: the client doesn't change through renegotiation

Marsh Ray's plaintext injection attack on HTTPS

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Attacker:

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$\Rightarrow$ **Server uses victim's account to send a pizza to attacker!**

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$\Rightarrow$ **the attacker gets the user name and password of the victim!**