Cryptographic protocols

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University of Edinburgh

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Context

Applications exchanging sensitive data over a public network:

- eBanking,
- eCommerce,
- eVoting,
- ePassports,
- 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

More complex systems needed...

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

BNP PARIBAS

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BNP PARIBAS

Replay attack

$\xrightarrow{(e,m)}$

$\xrightarrow{(e,m)}$

$\vdots$

$\xrightarrow{(e,m)}$

BNP PARIBAS

… 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.
- …

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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!!!

Needham-Schroeder protocol - G. Lowe, "An attack on the Needham-Schroeder public-key authentication protocol"

Kerberos protocol - I. Cervesato, A. D. Jaggard, A. Scedrov, J. Tsay, and C. Walstad, "Breaking and fixing public-key kerberos"

Single-Sign-On protocol - A. Armando, R. Carbone, L. Compagna, J. Cuellar, and M. L. Tobarra, "Formal analysis of SAML 2.0 web browser single sign-on: breaking the SAML-based single sign-on for google apps"

PKCS#11 API - M. Bortolozzo, M. Centenaro, R. Focardi, and G. Steel, "Attacking and fixing PKCS#11 security tokens"

BAC protocol - T. Chothia, and V. Smirnov, "A traceability attack against e-passports"

AKA protocol - M. Arapinis, L. Mancini, E. Ritter, and M. Ryan, "New privacy issues in mobile telephony: fix and verification"

. . .

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: RSA

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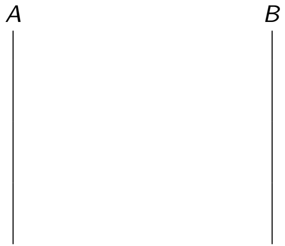

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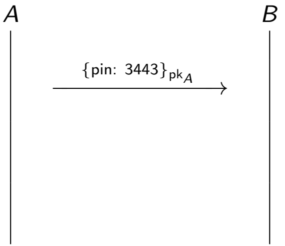

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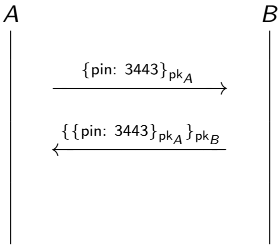

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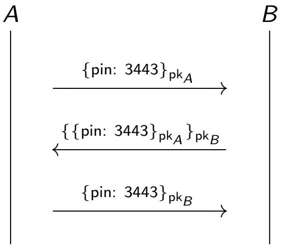

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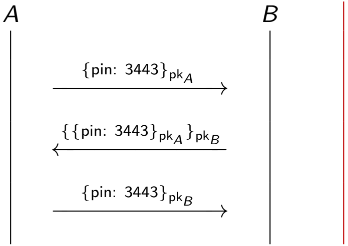
No authentication!



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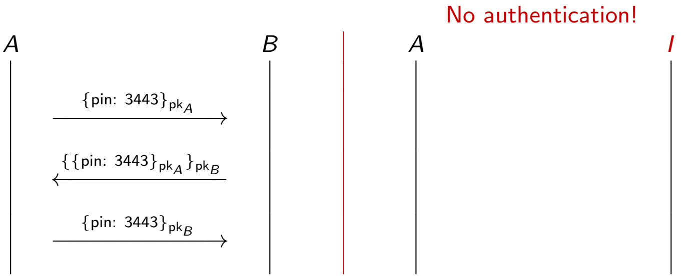

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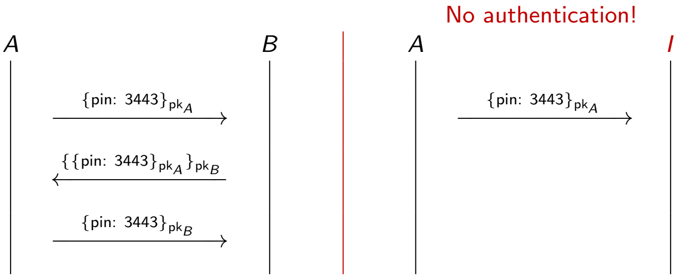

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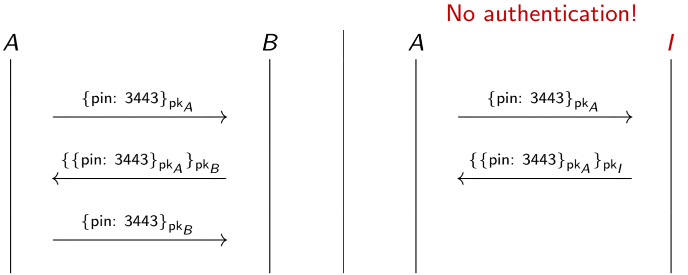

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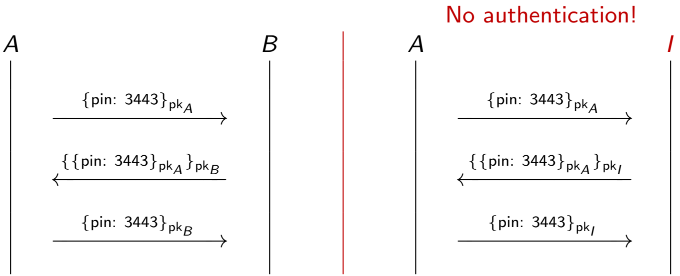

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Needham-Schroeder Public Key (NSPK)

NSPK: authentication and key agreement protocol

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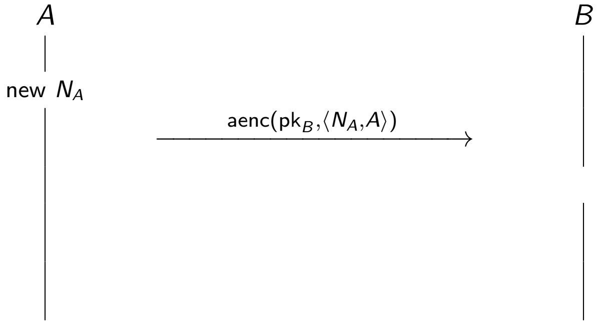

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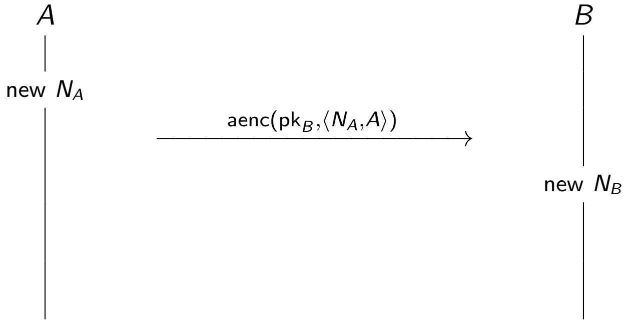

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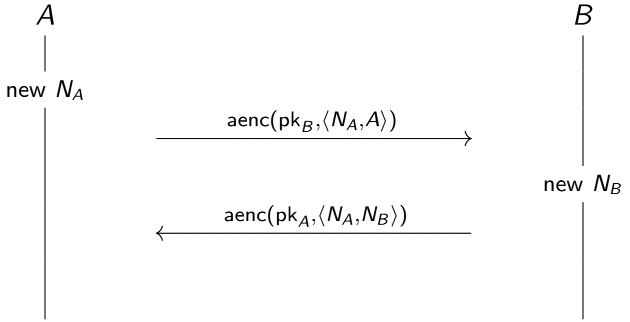

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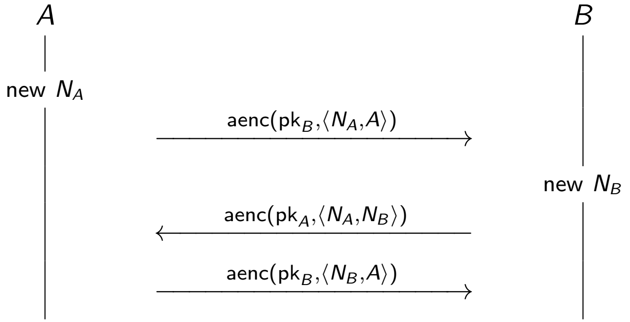

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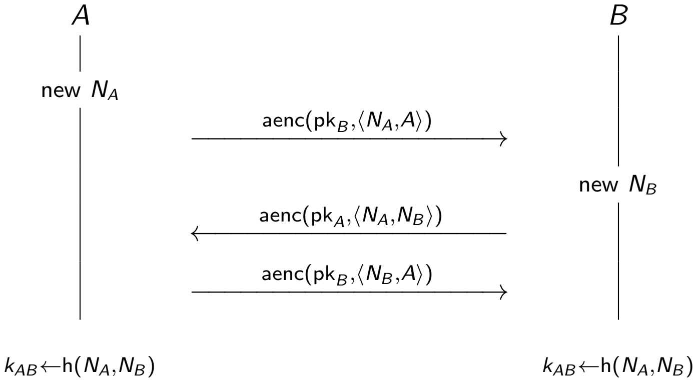

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NSPK: security requirements

- 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 ($k \leftarrow \mathrm{h}(N_A, NB)$) remain secret.

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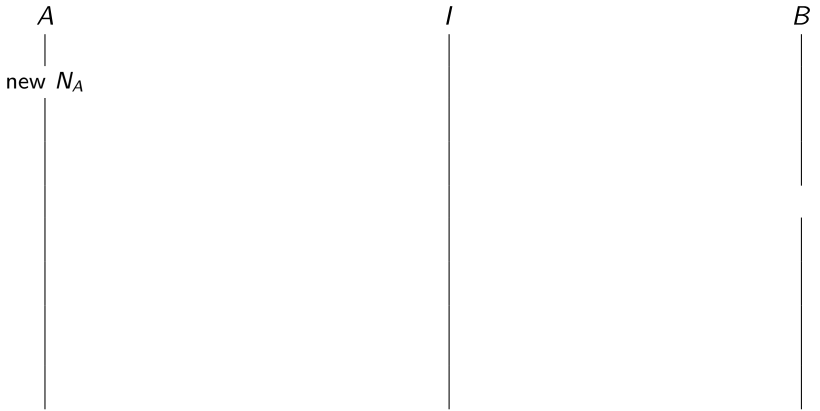

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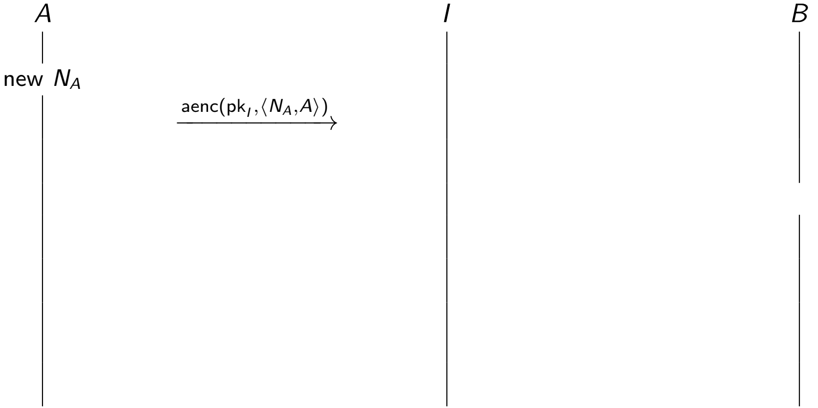

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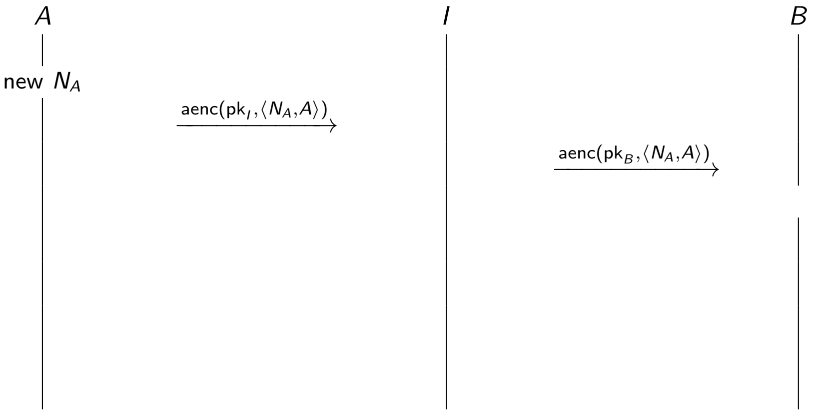

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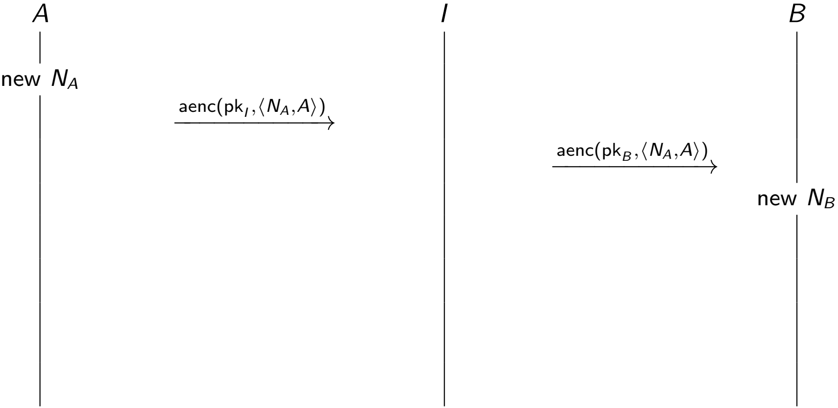

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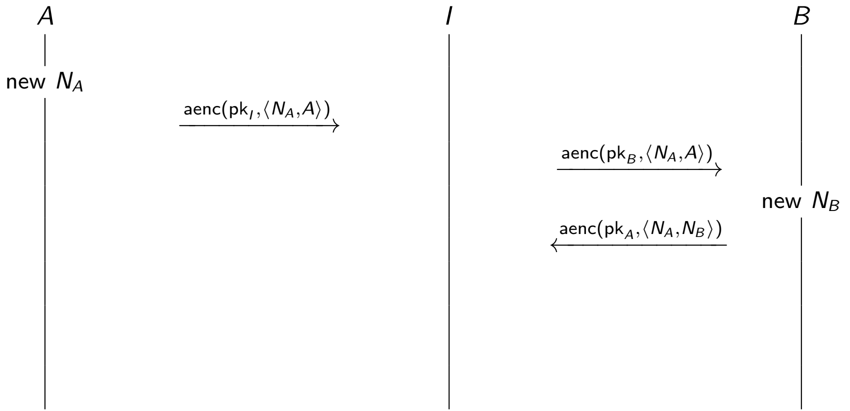

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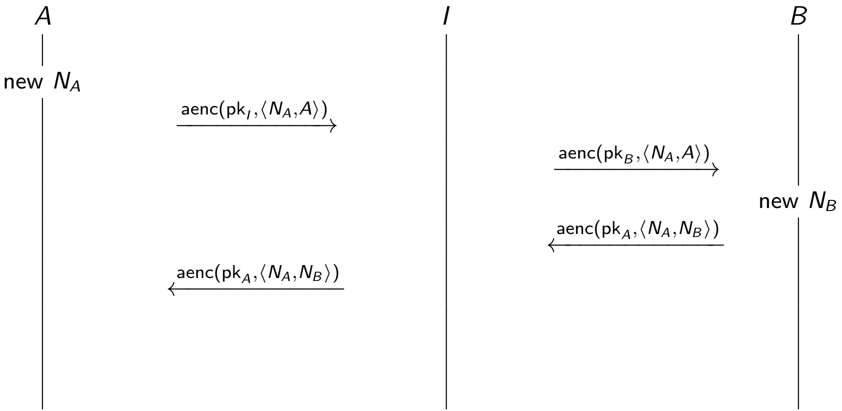

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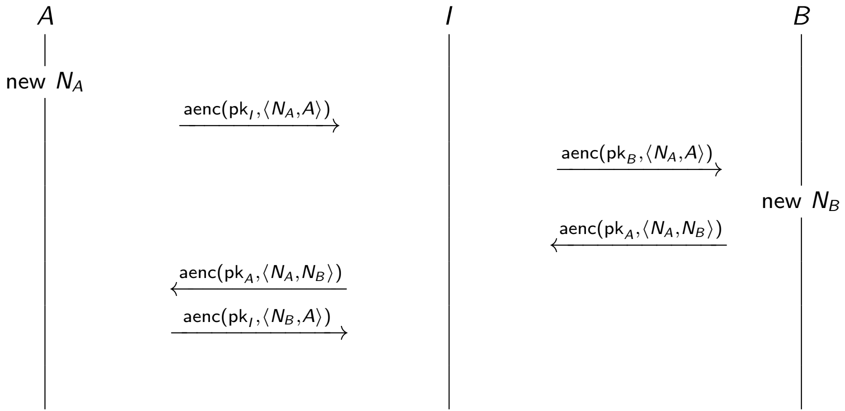

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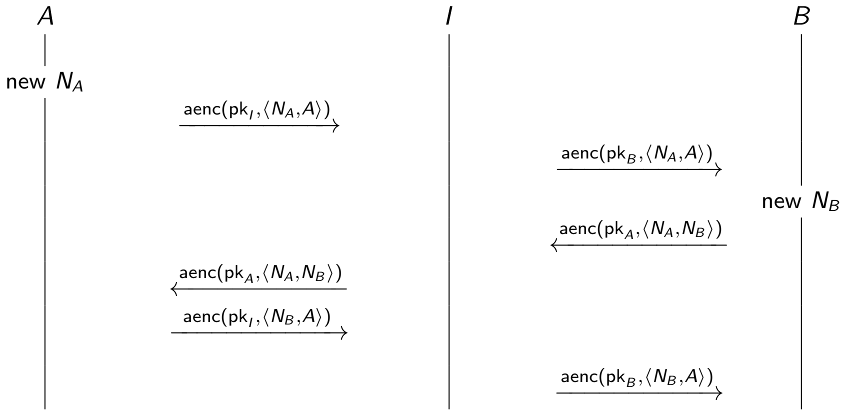

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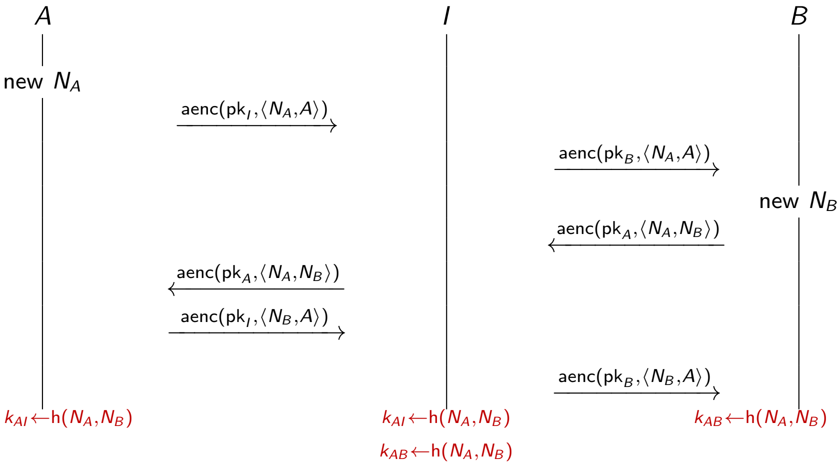

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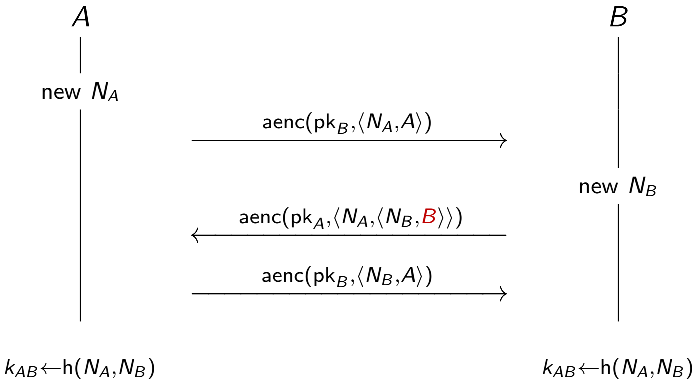
NSPK: Lowe's fix



Public Key Kerberos PKINIT-26 (very abstract)

Goals: client authentication, key agreement, TGT delivery

- $\{m\}^s_k$: message m symmetrically encrypted under key k
- $\{m\}^a_k$: message m asymmetrically encrypted under key k
- $[m]_k$: message m digitally signed with key k
- t_C, t_K: timestamps
- $TGT = \{AK, C, t_K\}^s_{k_T}$

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C | KAS

new n_1, n_2

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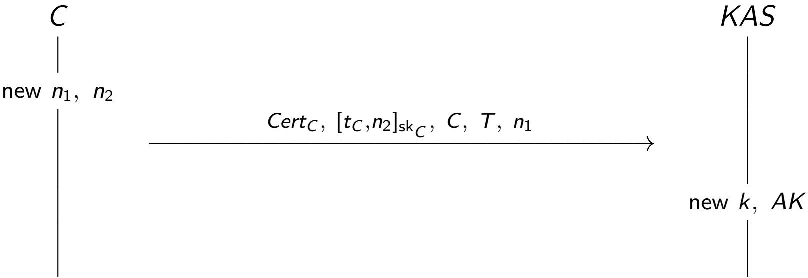

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C $\qquad\qquad\qquad\qquad\qquad\qquad$ KAS

new $n_1,\ n_2$

$C \xrightarrow{\ Cert_C,\ [t_C, n_2]_{\mathrm{sk}_C},\ C,\ T,\ n_1\ } KAS$

new $k,\ AK$

$C \xleftarrow{\ \{Cert_K,\ [k, n_2]_{\mathrm{sk}_K}\}^a_{\mathrm{pk}_C},\ C,\ TGT,\ \{AK,\ n_1,\ t_K, T\}^s_k\ } KAS$

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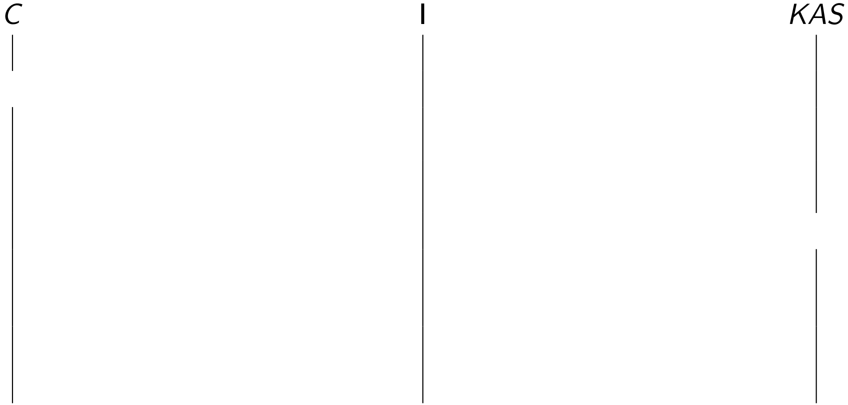
PKINIT-26: attack



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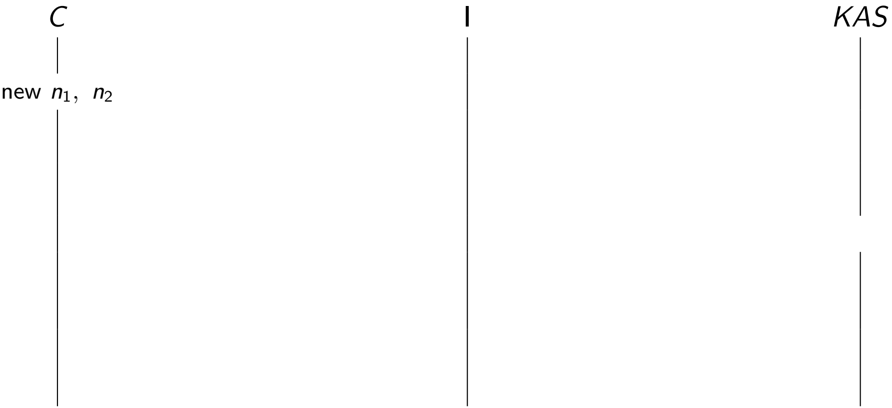

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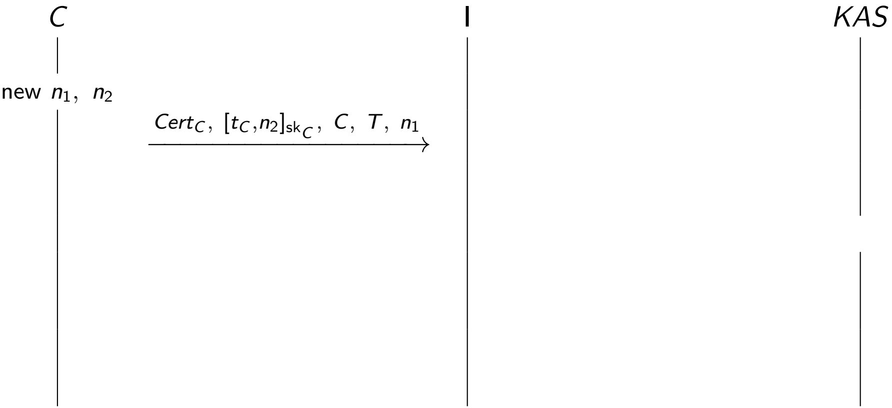

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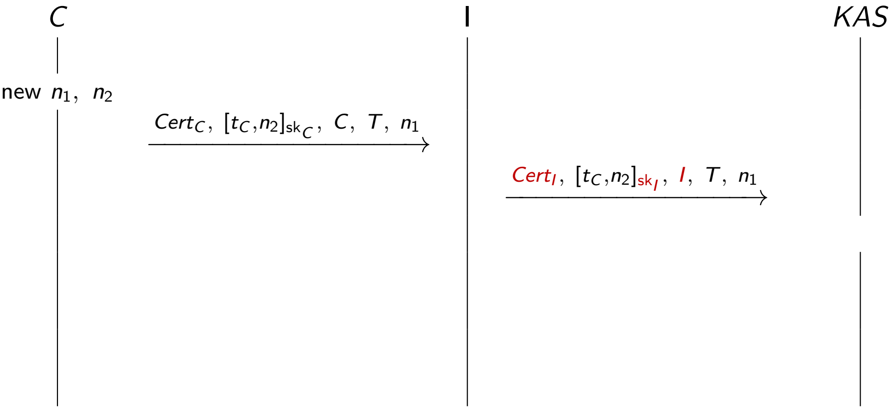

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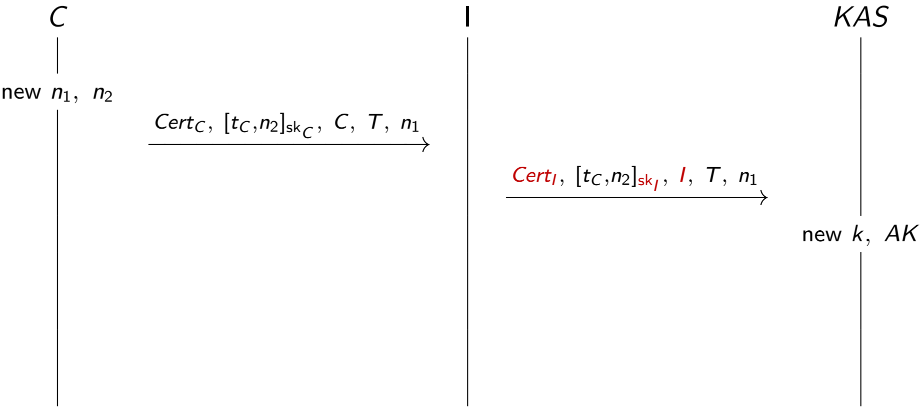

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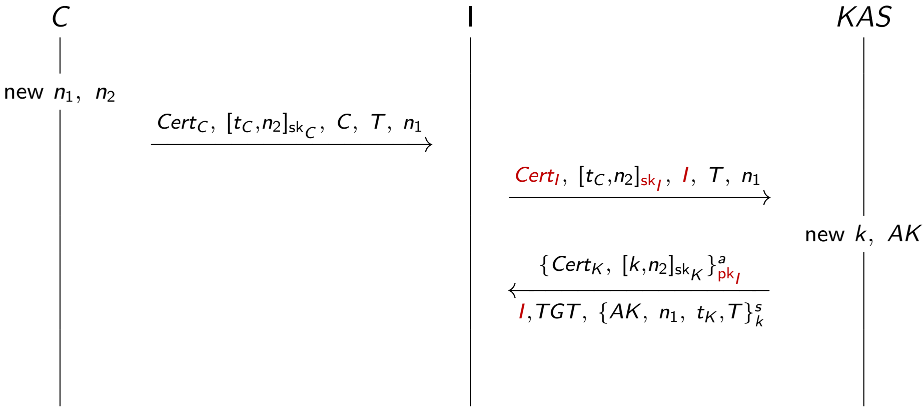

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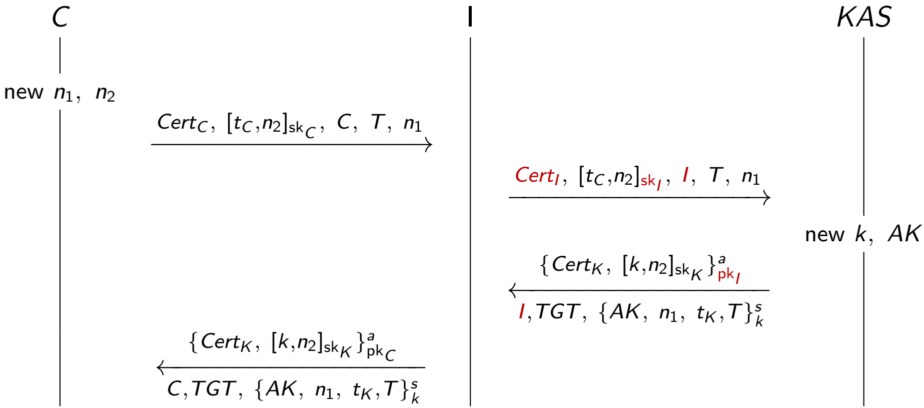

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