Needham Schroeder Protocol

Software Security

Steffen Helke
Chair of Software Engineering

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Brandenburgische
Technische Universität
Cottbus - Senftenberg

Objectives of today's lecture

- ➜ Getting to know different variants of the famous *Needham-Schroeder protocol*
- ➜ Understanding attack types like *Man-in-the-Middle* and *Replay* attack and possible countermeasures

Needham-Schroeder Protocol

– Introduction –

Needham-Schroeder Protocols (NSP)

- ➜ Developed by Rodger Needham and Michael Schroeder at the Xerox Palo Alto Research Center (MIT) in 1978
- ➜ Protocol family to support secure data exchange

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- ➜ Development of different variants for *symmetric and asymmetric encryption systems*

Needham-Schroeder Protocols (NSP)

Why is it so important to use secure protocols in addition to secure encryption algorithms?

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- ➜ Protocol family to support secure data exchange
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- ➜ Development of different variants for *symmetric and asymmetric encryption systems*

Variants: a form or version of something that differs in some respect from other forms of the same thing or from a standard

Remarks

- The NSP family is not only interesting for historical reasons, but also forms the basis for modern security protocols
- Note that the asymmetric encryption variant had a design flaw that was found 17 years later

Attack Types

Man-in-the-Middle Attack

- The attacker places himself between the communication partners Alice and Bob
- He has full control over the data traffic between Alice and Bob
- He can see/modify any information
- Attack is not detectable

Replay Attack

- Assumption: The attacker has found old keys and/or old tickets
- Attacker reuses old tickets from a previous session to manipulate the current communication

Needham-Schroeder Protocol

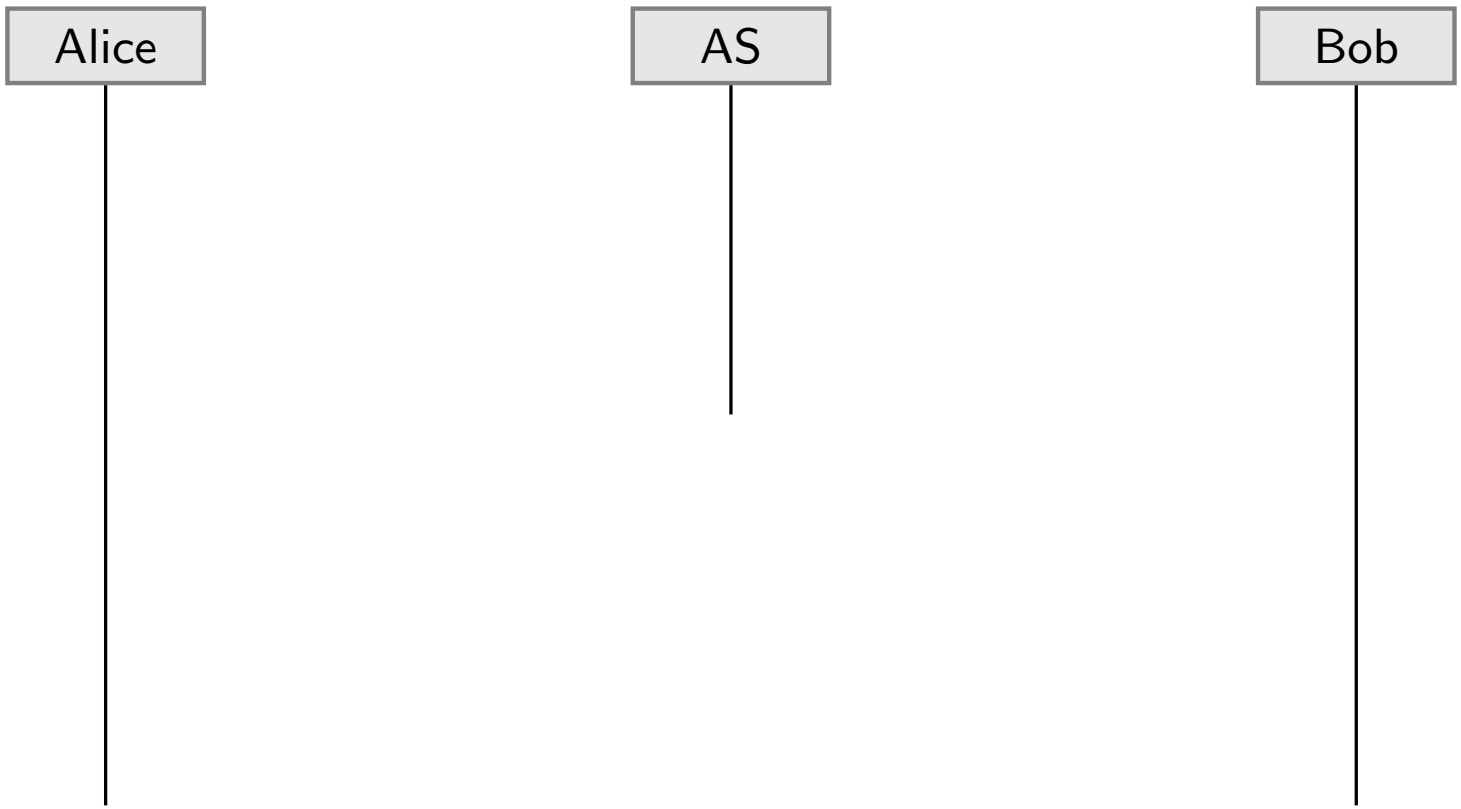
– Symmetric Encryption Variant –

Preliminary Specifications

Which notation is usually used to specify a security protocol?

- A: Identity of Alice
- B: Identity of Bob
- K_{AB}: Symmetric session key of Alice and Bob
- AS: Authentication server, is trustworthy, generates and distributes the session key K_{AB}
- K_A: Symmetric key between AS and A
- K_B: Symmetric key between AS and B
- N_A and N_B: Nonces (*number used one* or *number once*), random numbers used for only one protocol session

Naive Variant of the Symmetric NSP



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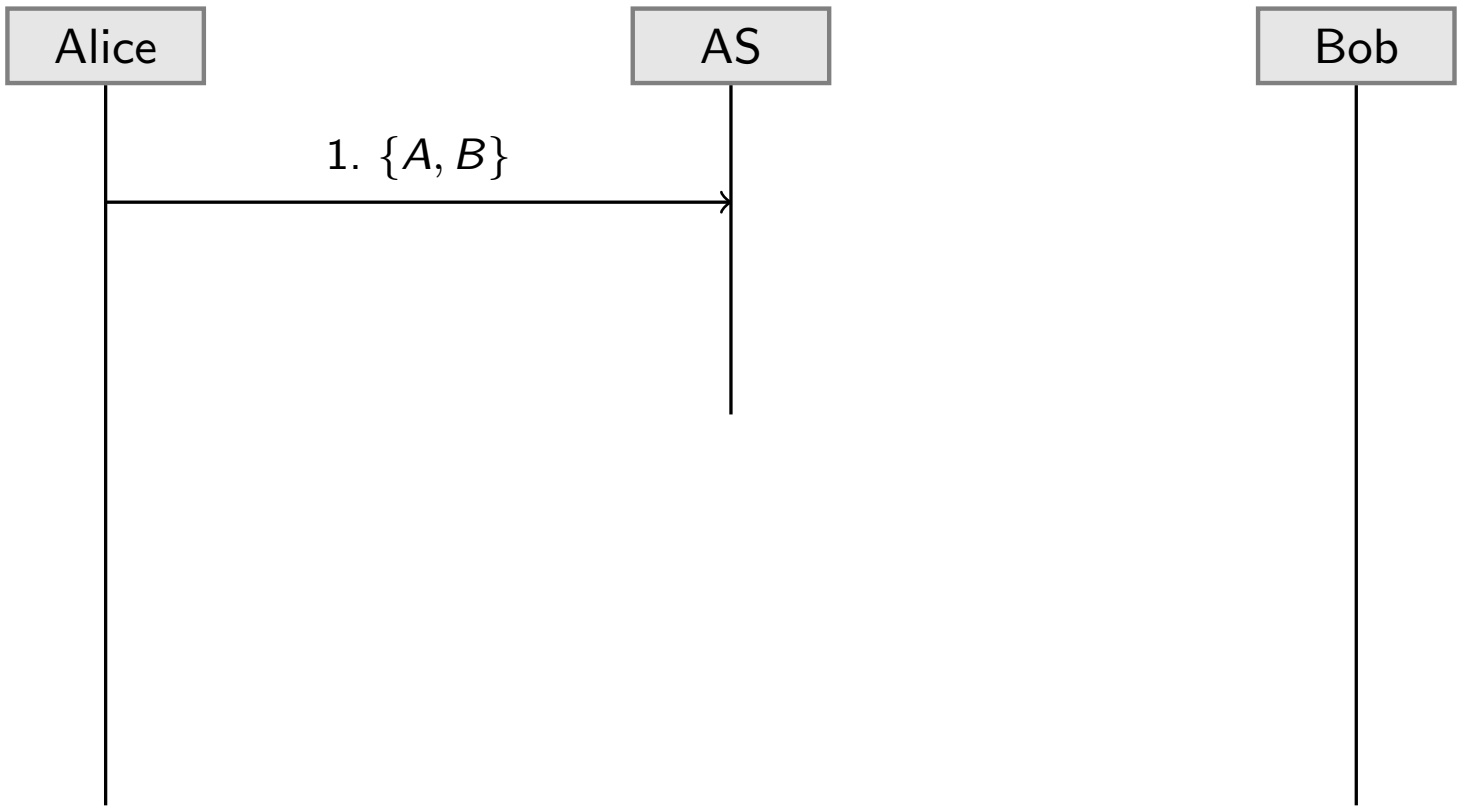

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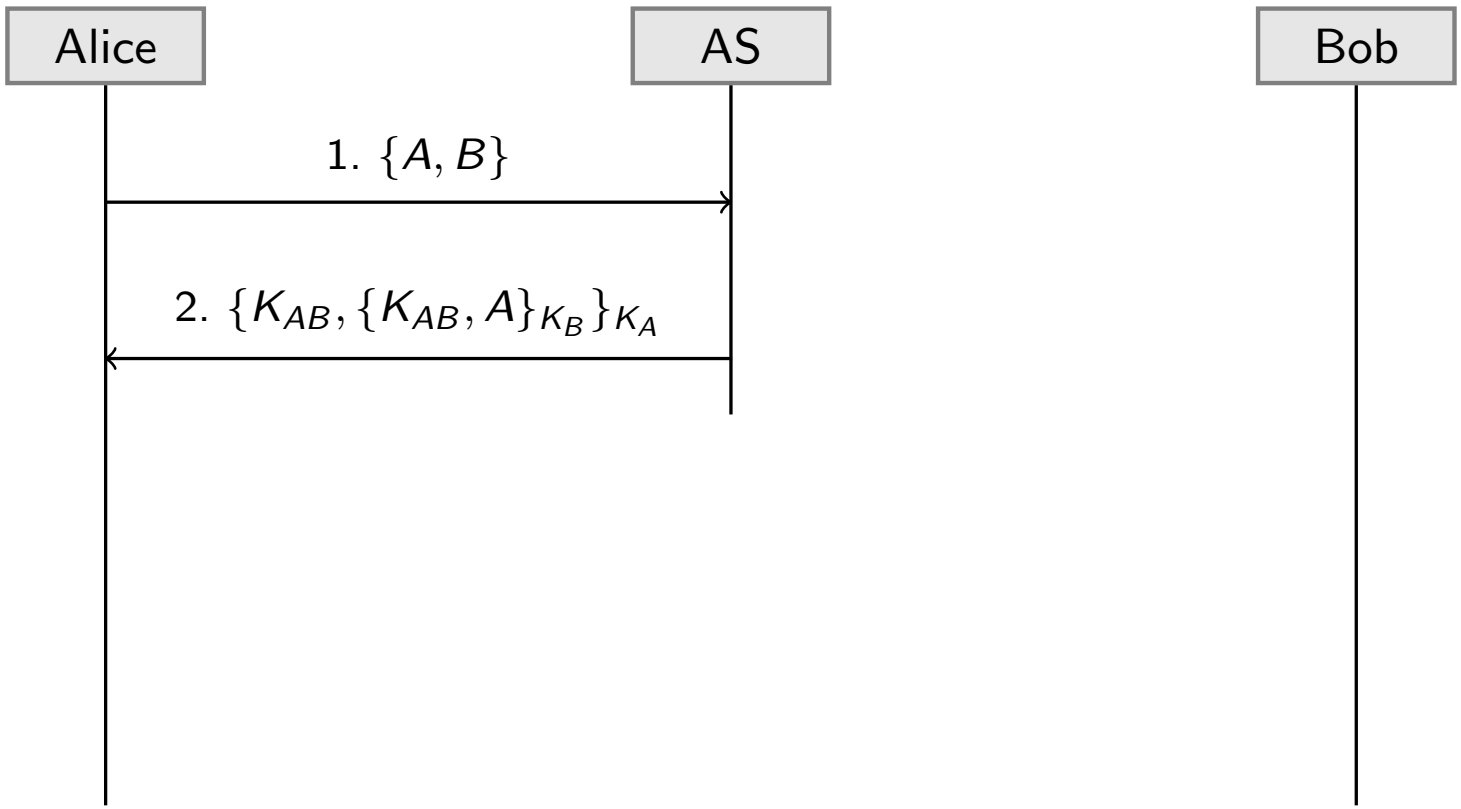

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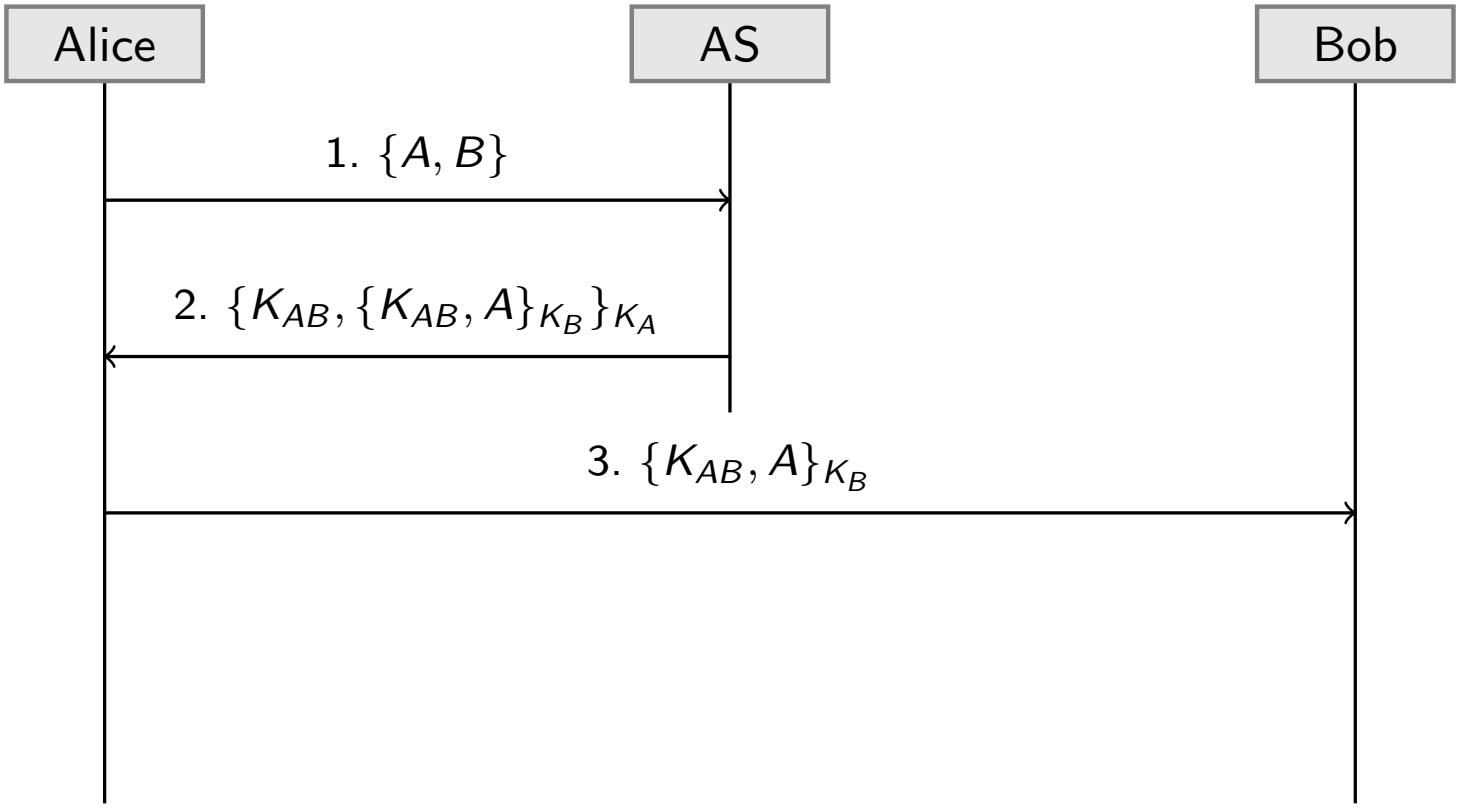

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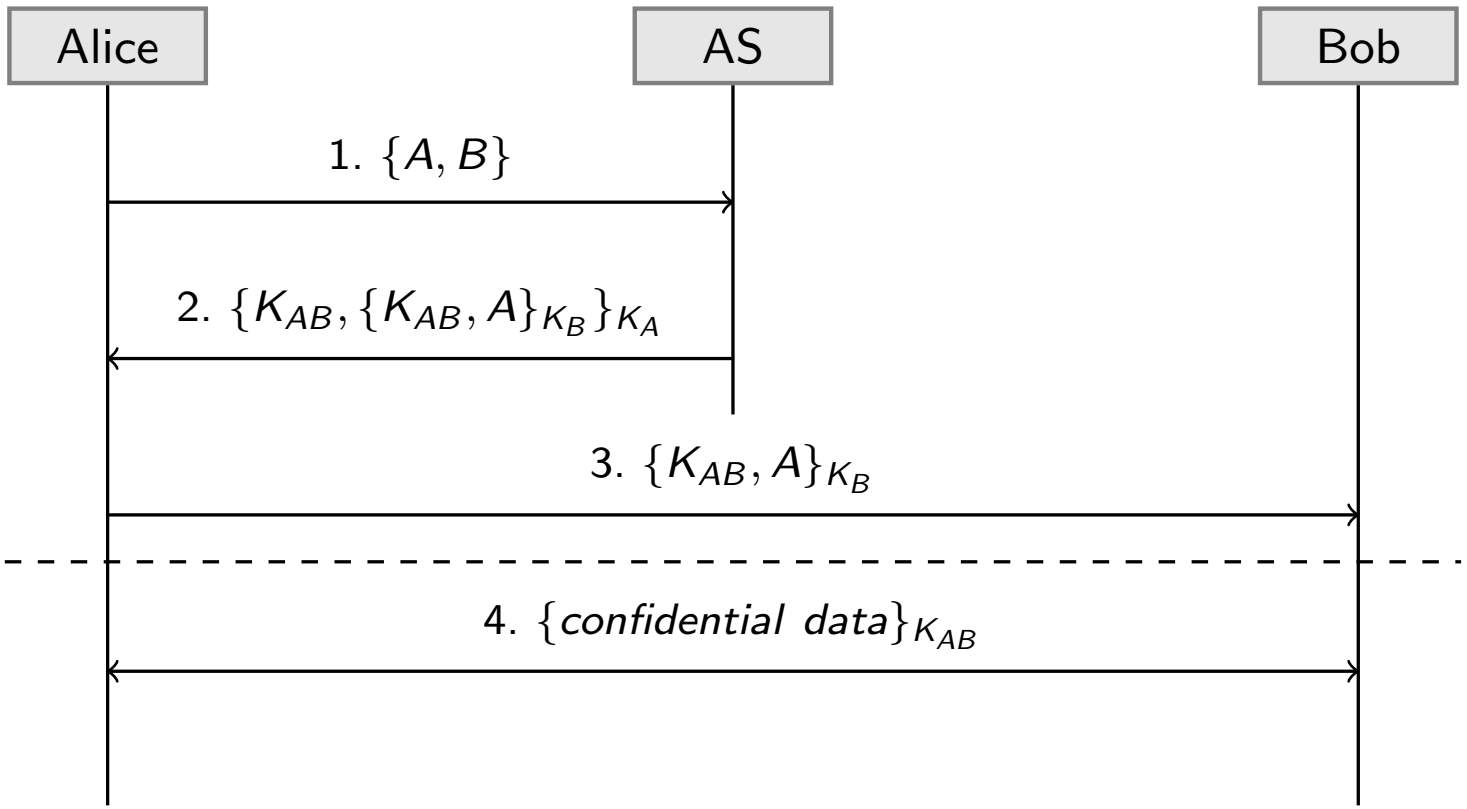

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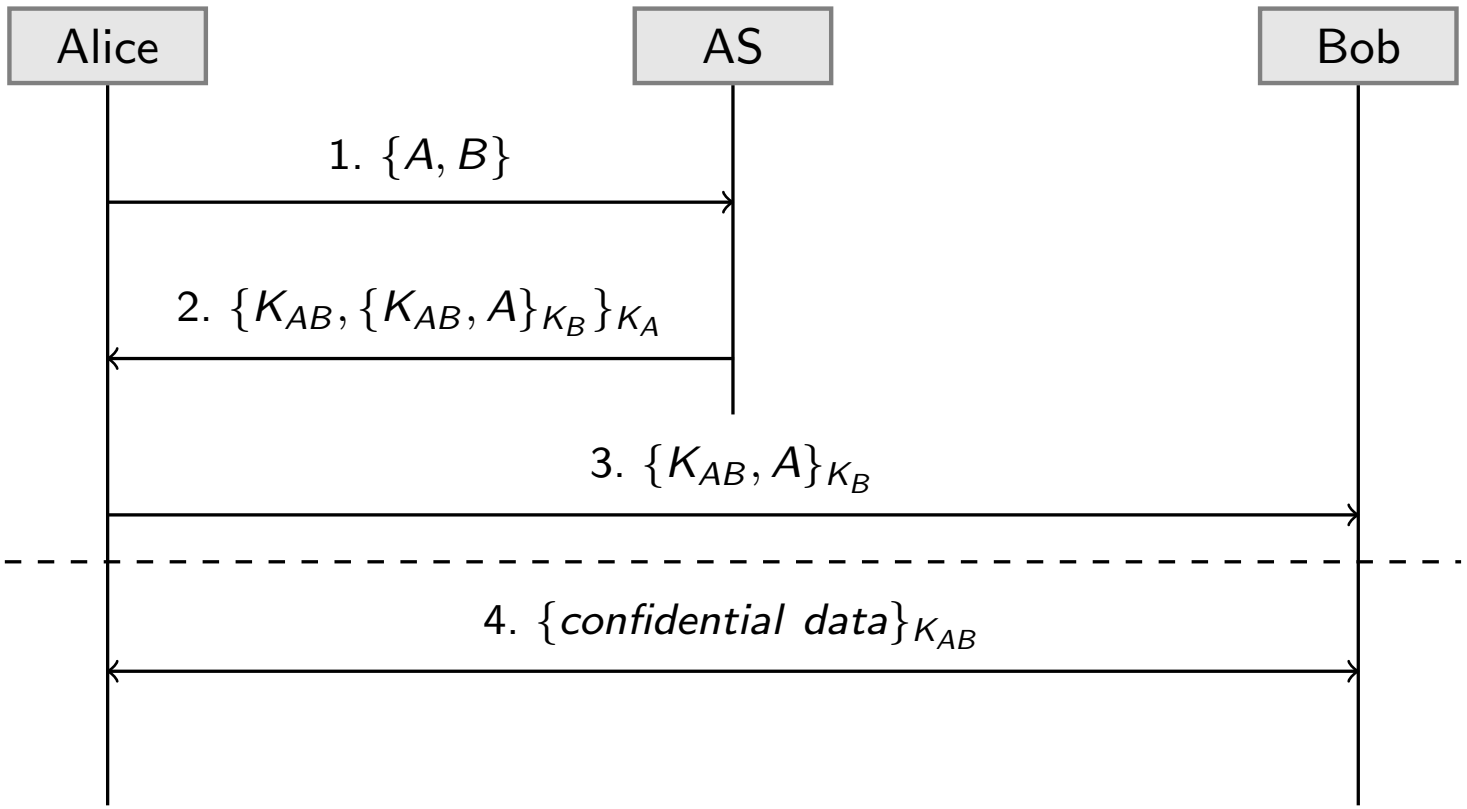
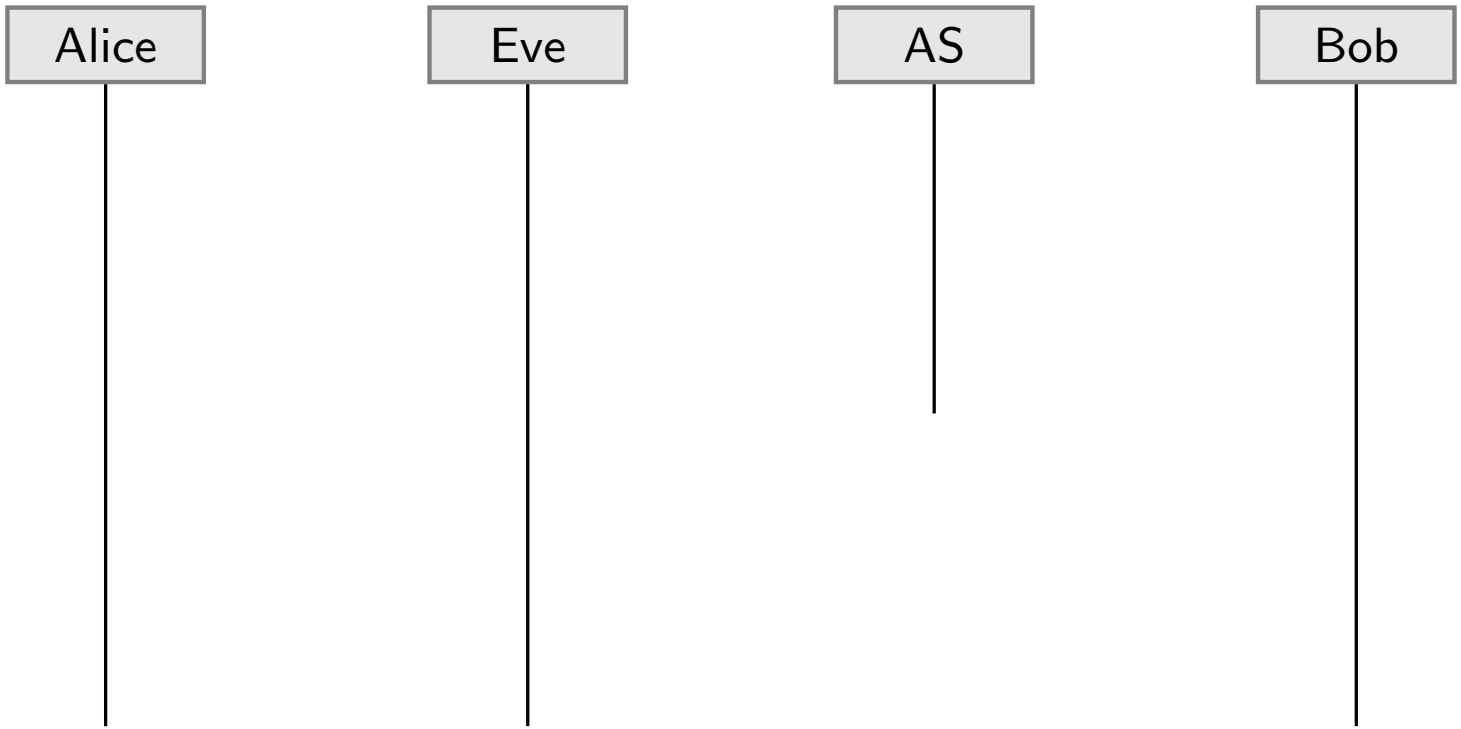


The naive variant of the NSP is not secure! Why?

Specify the steps of the traditional Needham-Schroeder protocol (symmetric variant)? Why is this protocol vulnerable?

Attack for the naive Symmetric NSP



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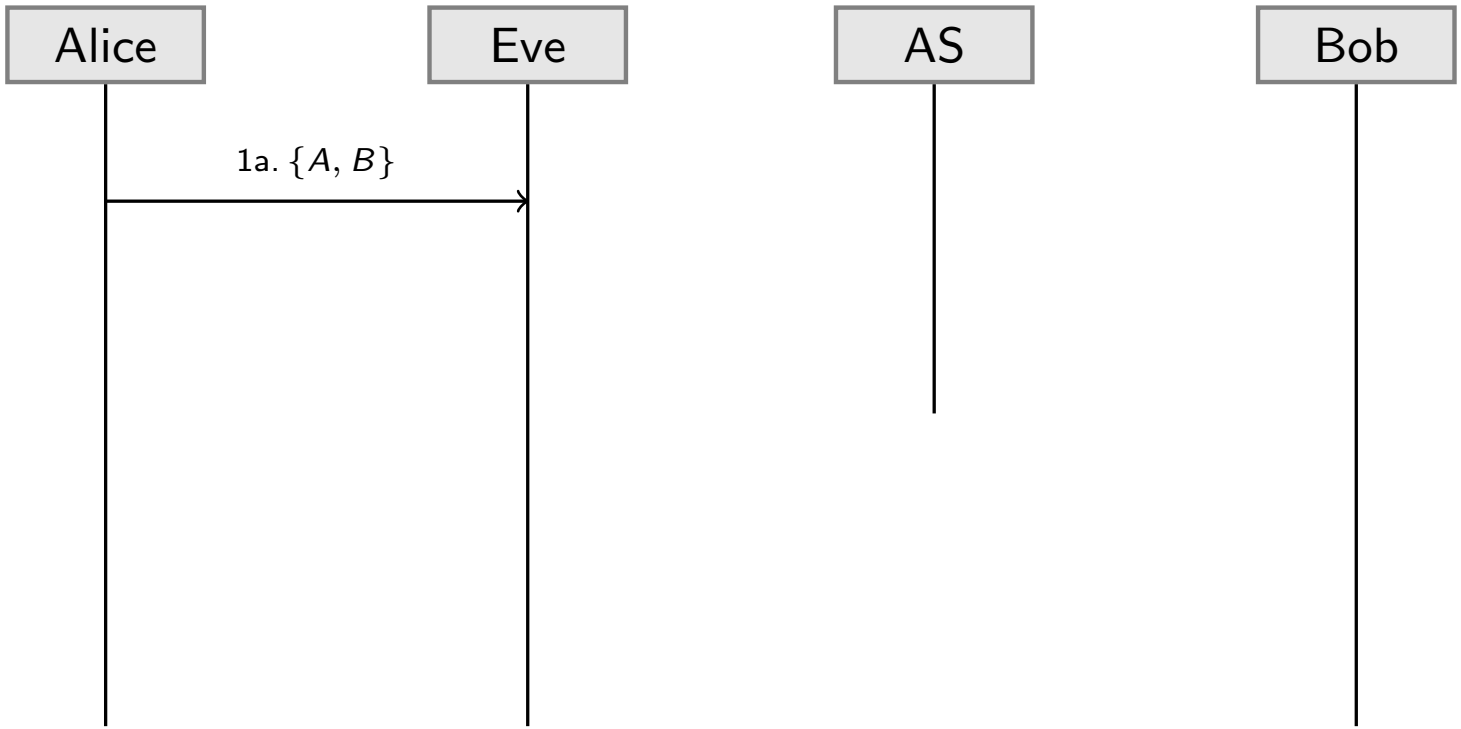

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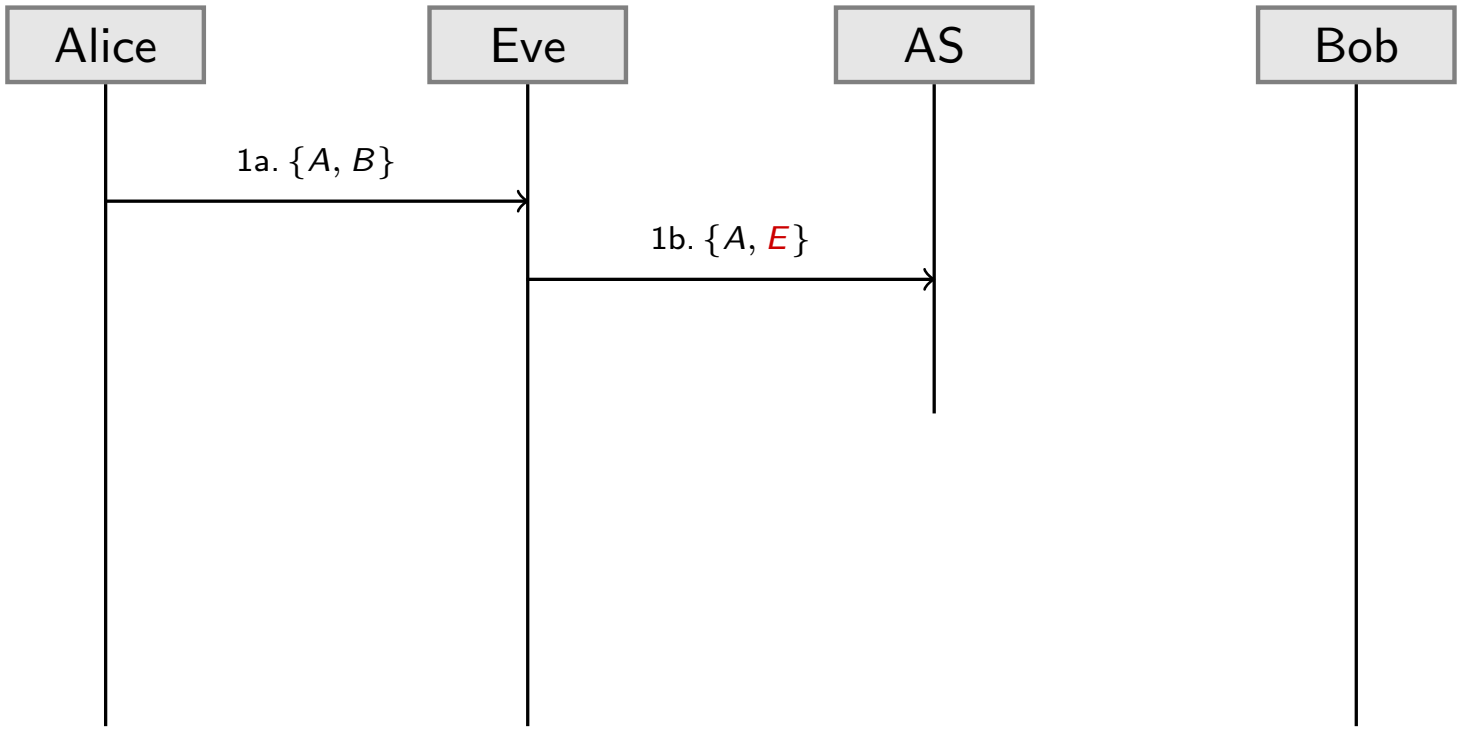

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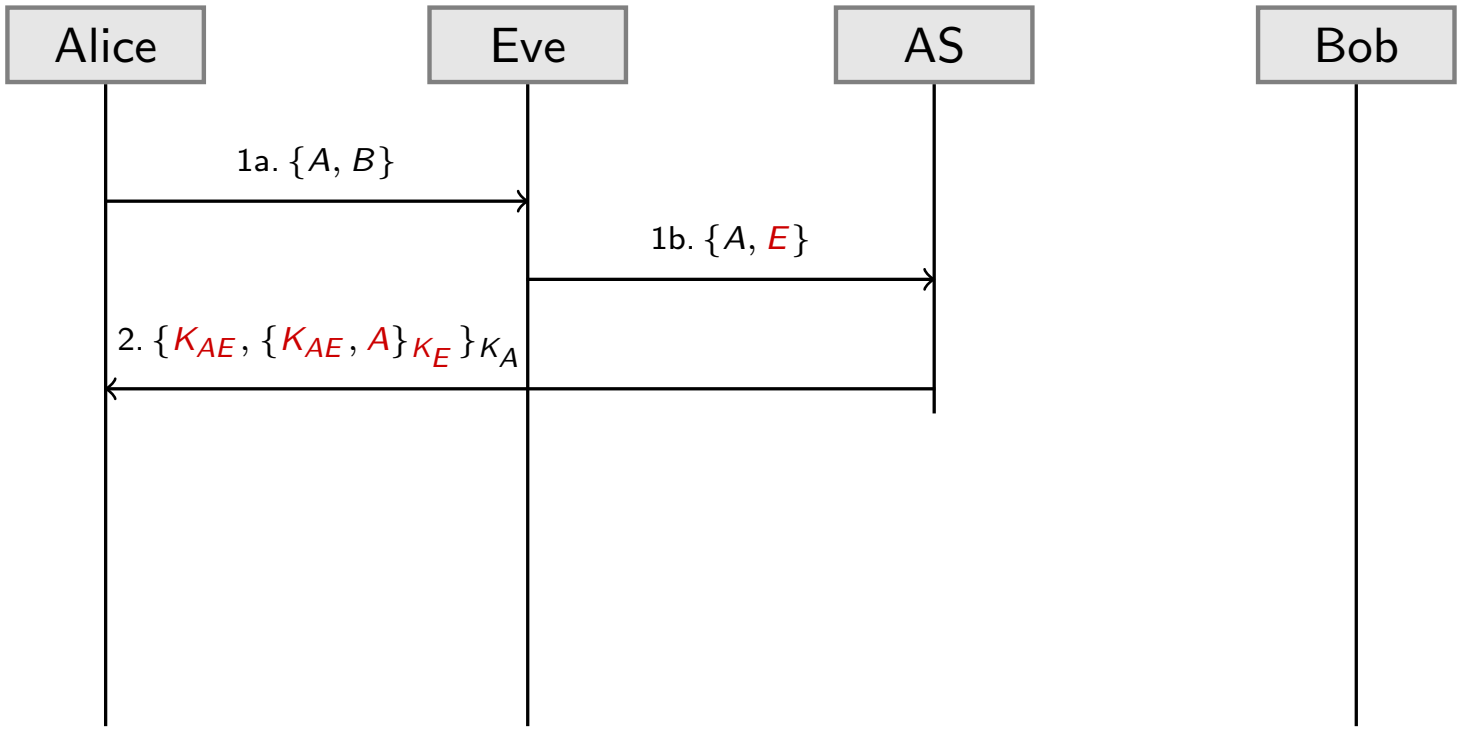

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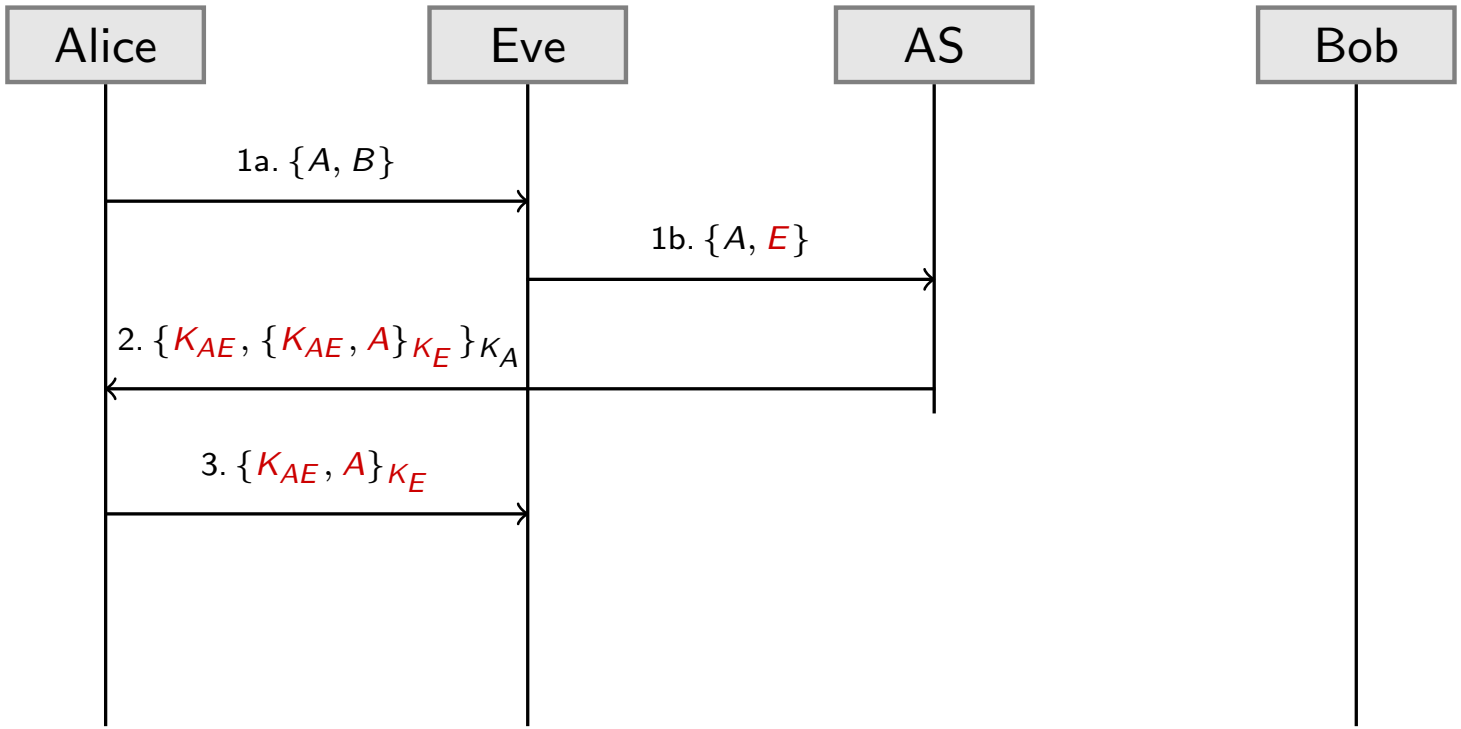

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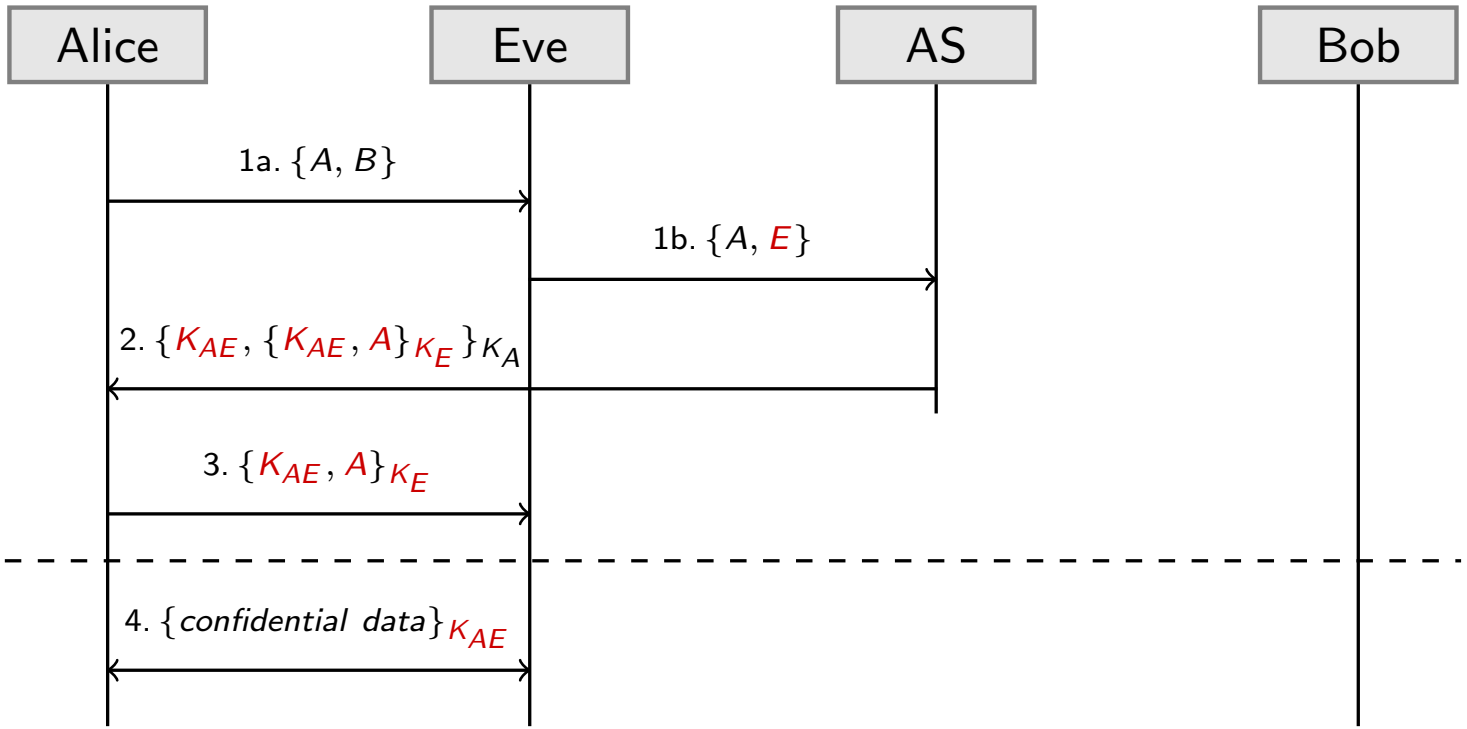

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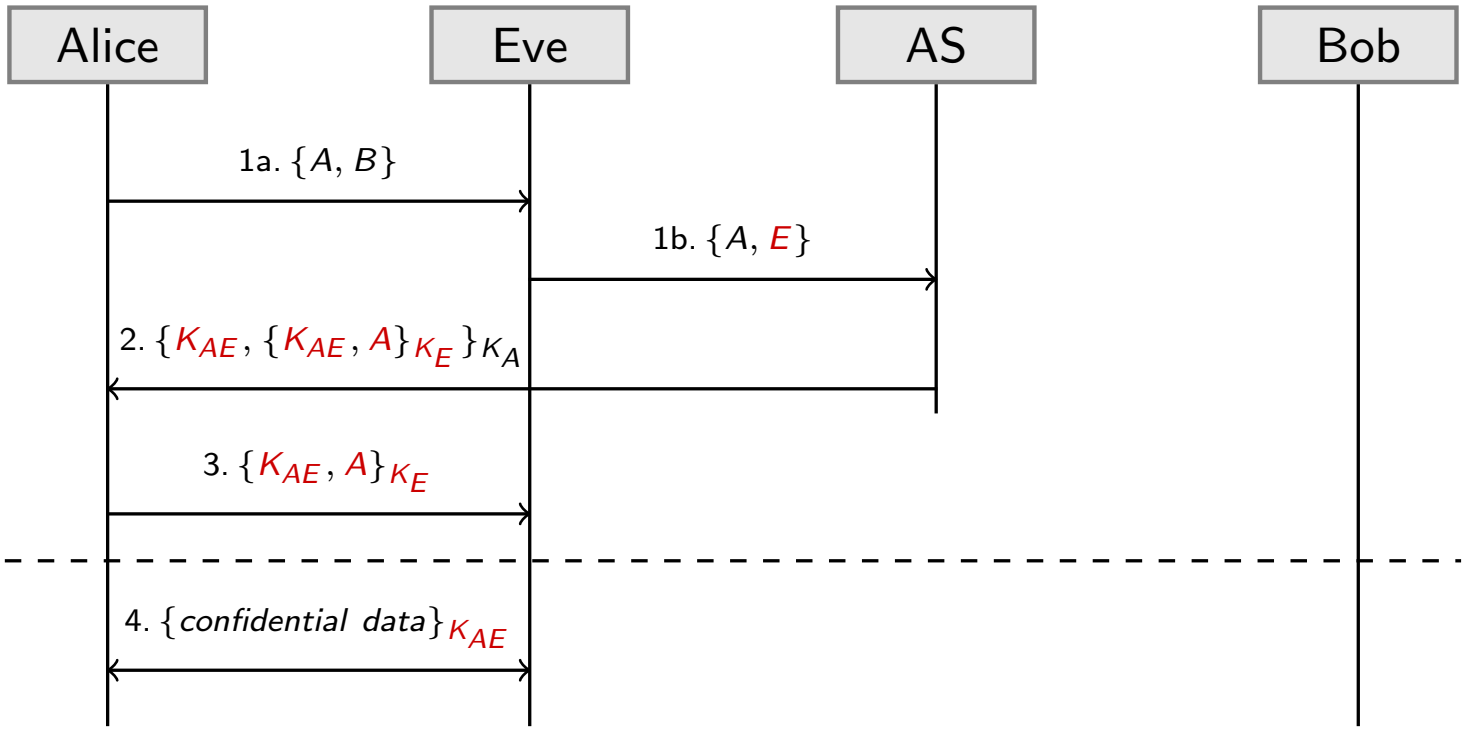

Eve is pretending to Alice to be Bob! Countermeasures?

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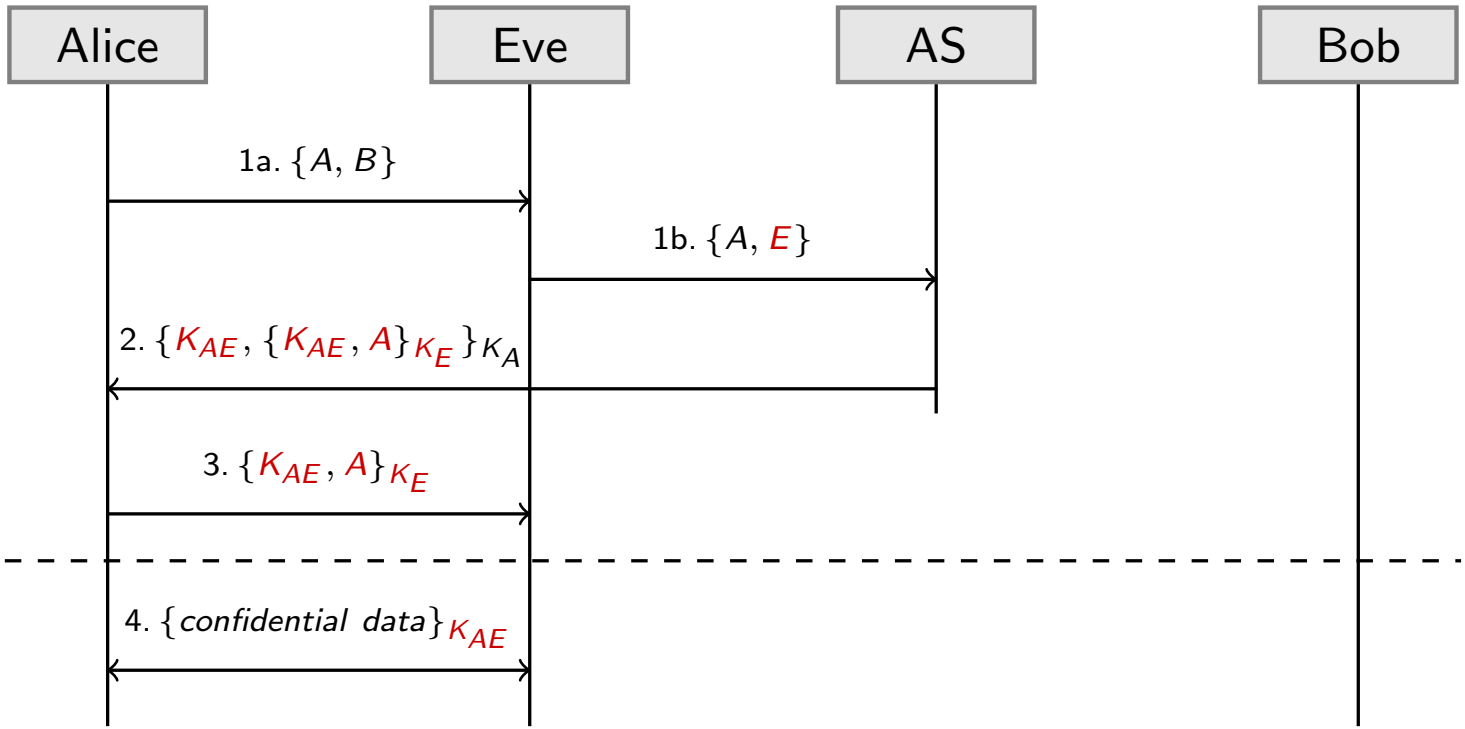
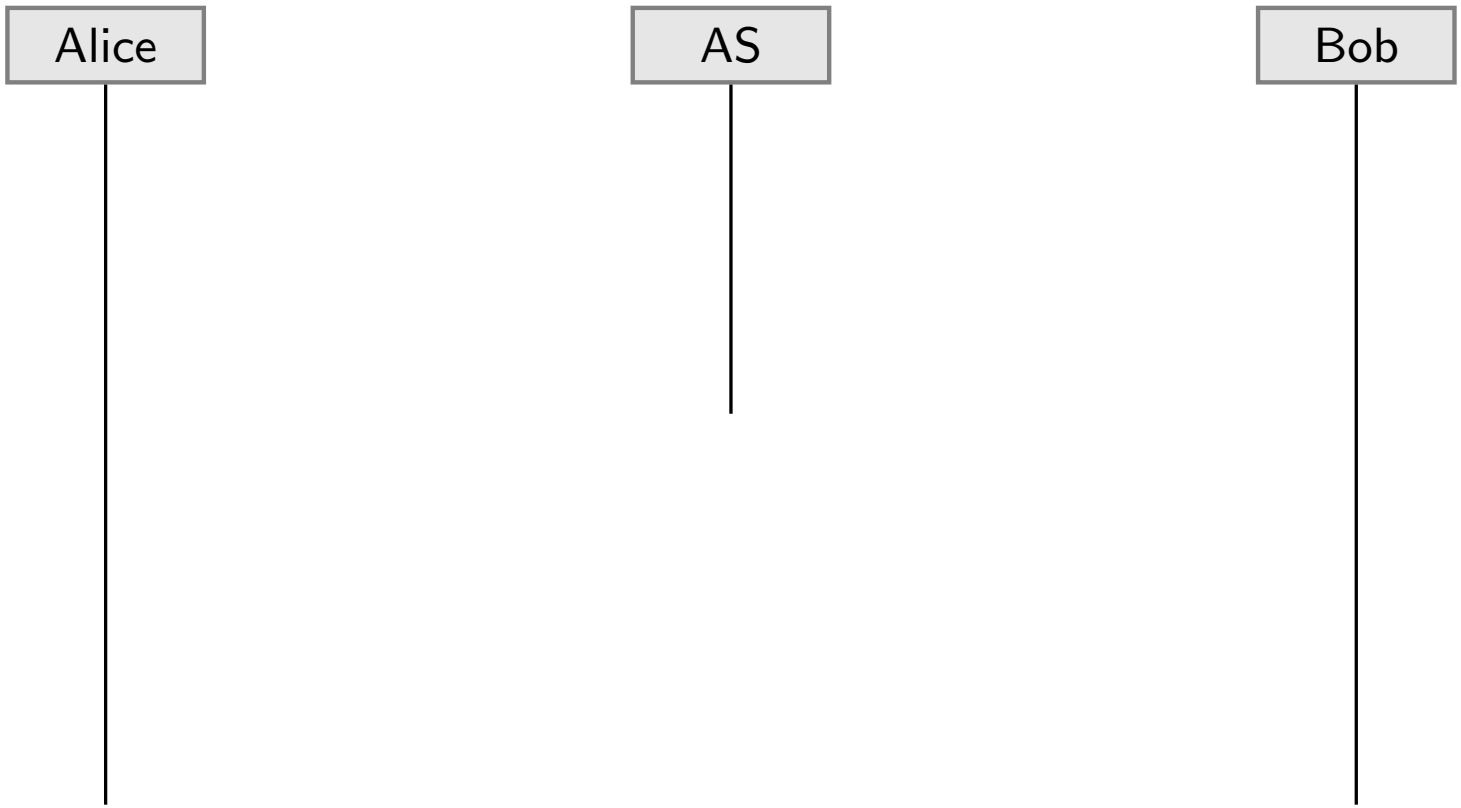


Eve is pretending to Alice to be Bob! Countermeasures?

➜ Man-in-the-middle attacks can be prevented by sending identities inside the tickets!

Specify a man-in-the-middle and a replay attack for the NSP example

Variant 2 for the Symmetric NSP



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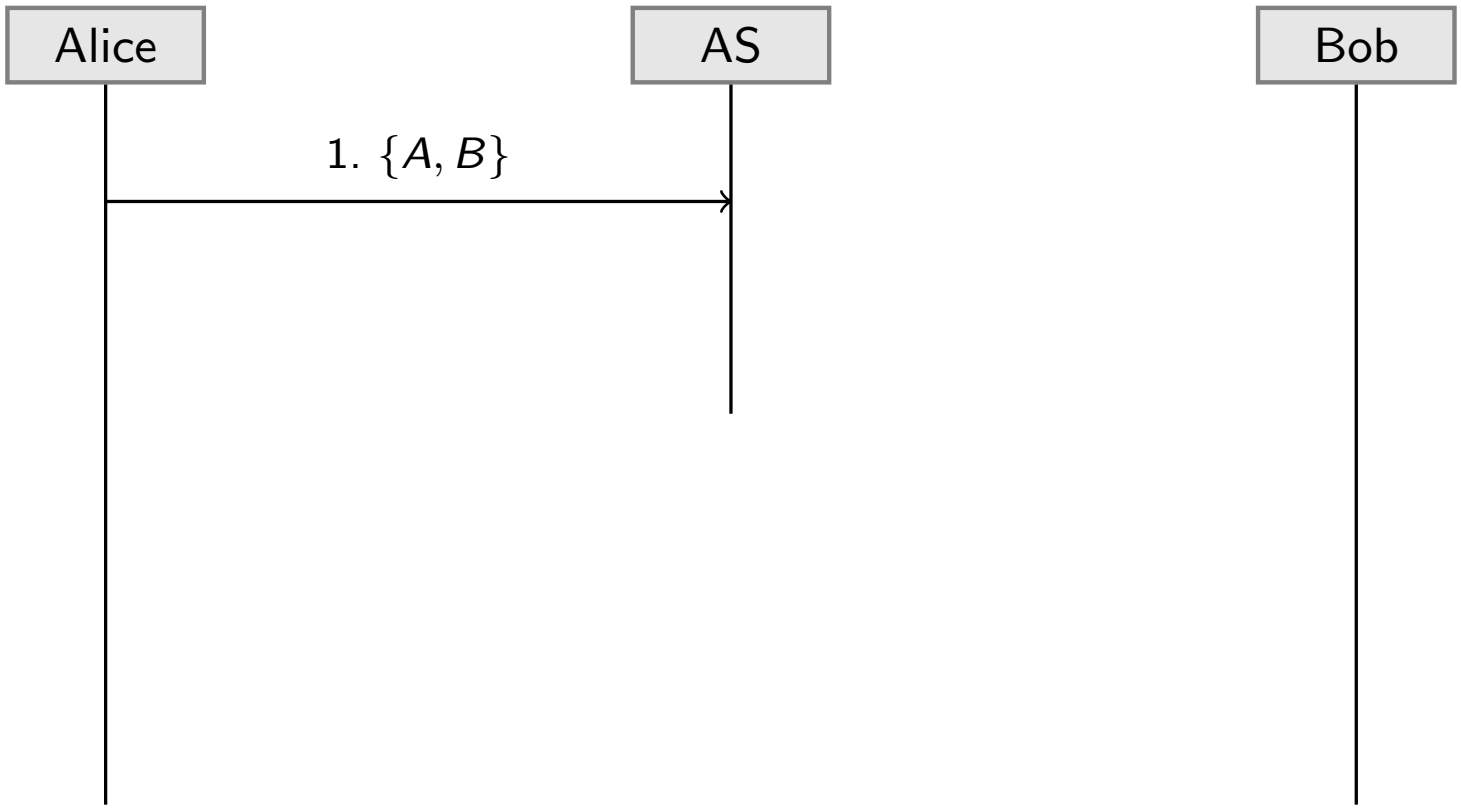

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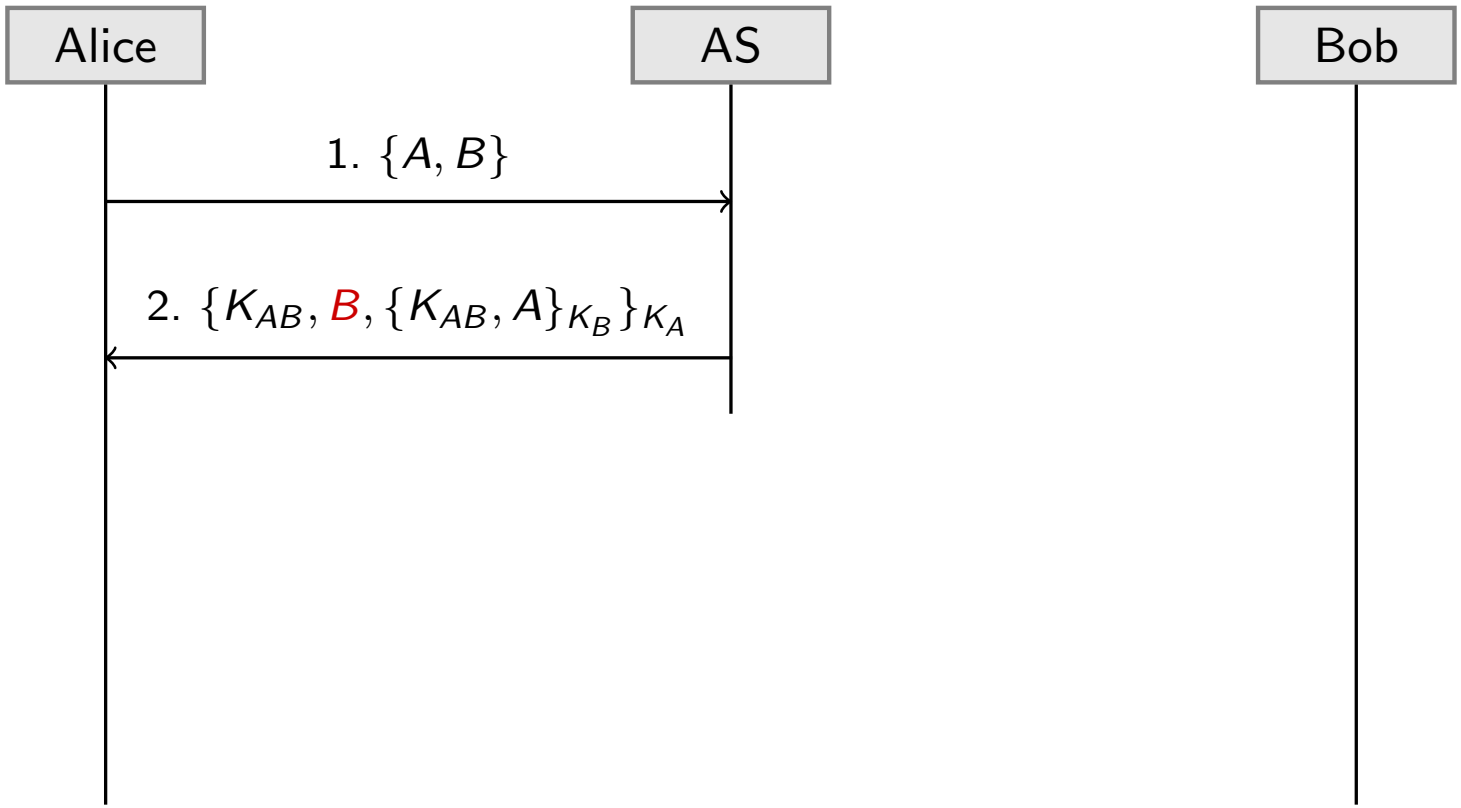

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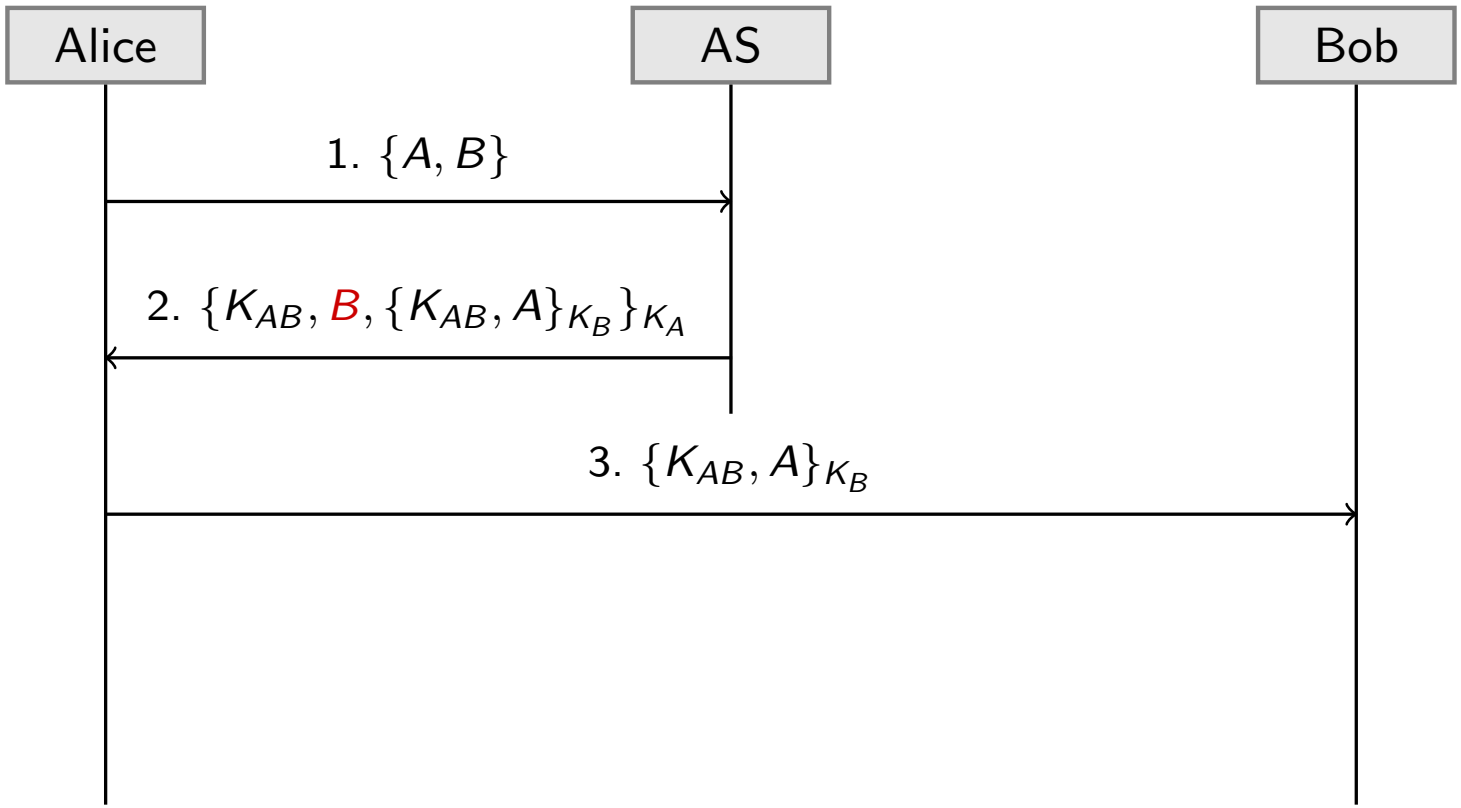

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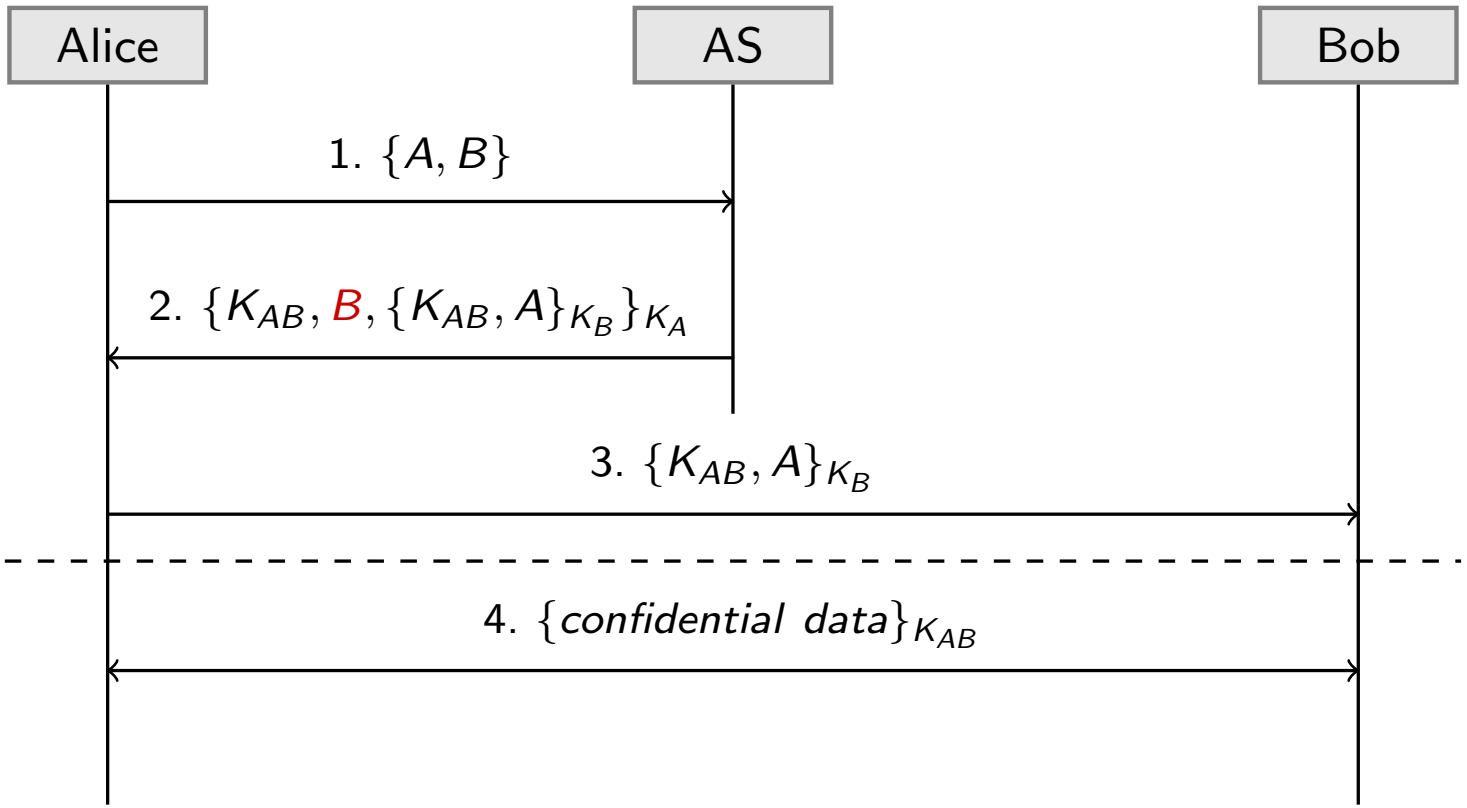

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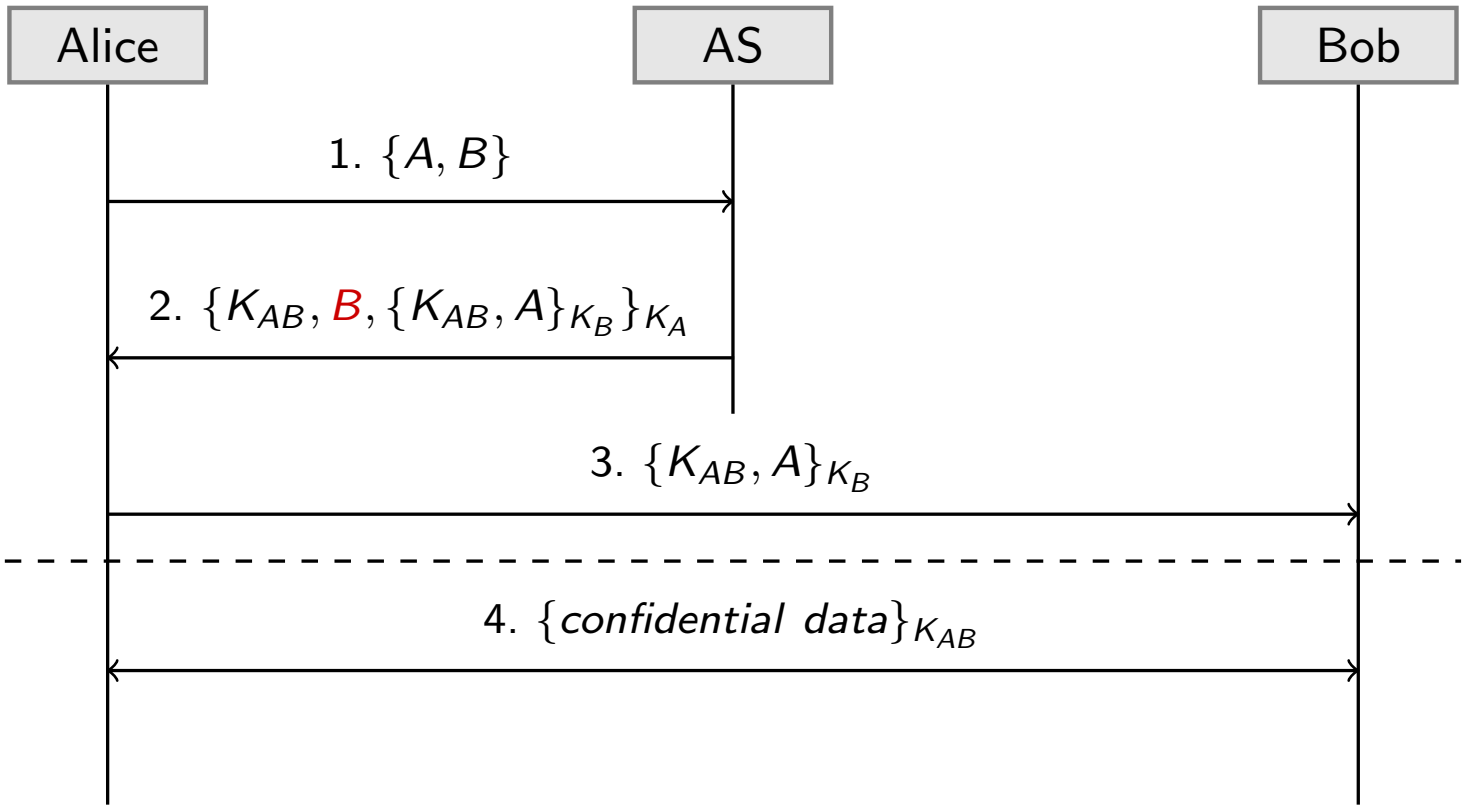
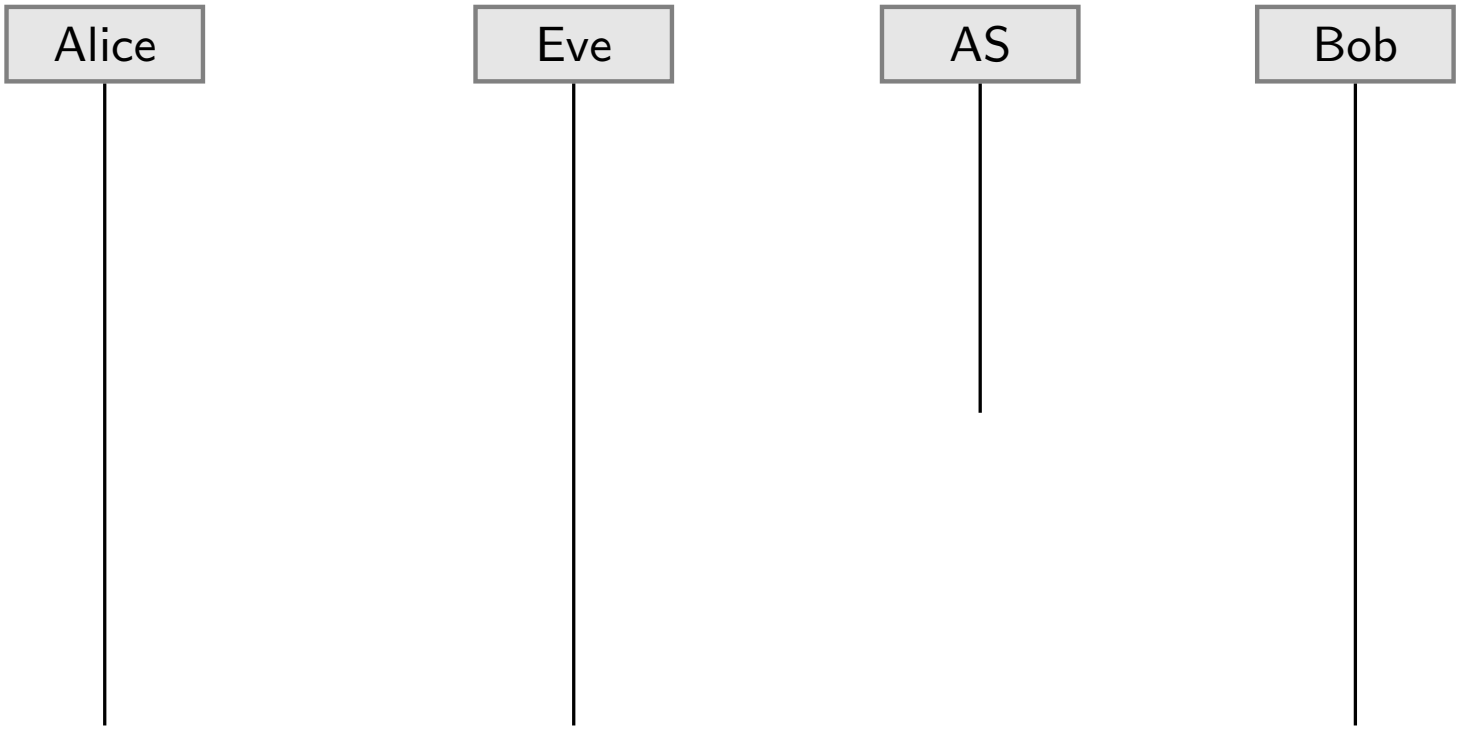


By specifying Bob's identity in step 2, Alice is able to detect the Man-in-the-middle attack!

Detecting a Man-in-the-middle Attack



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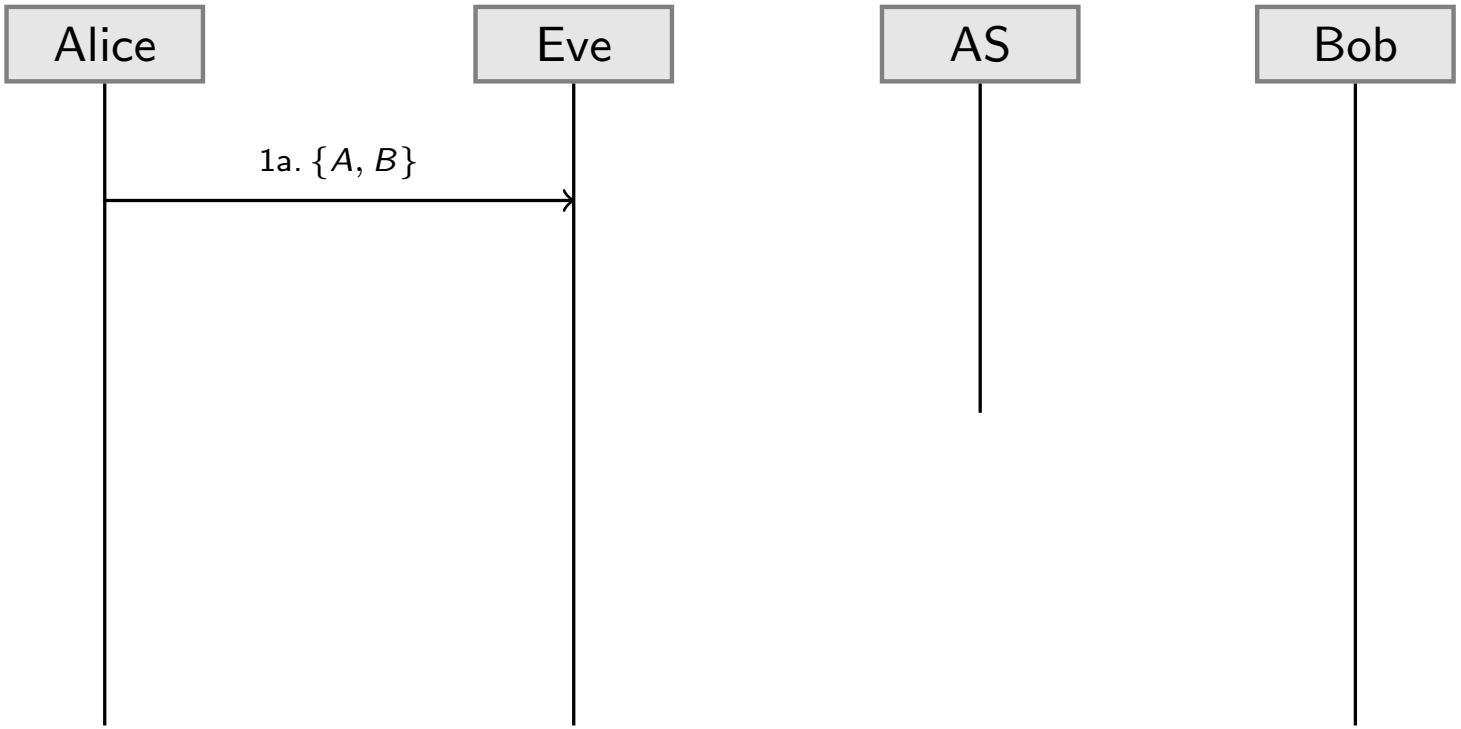

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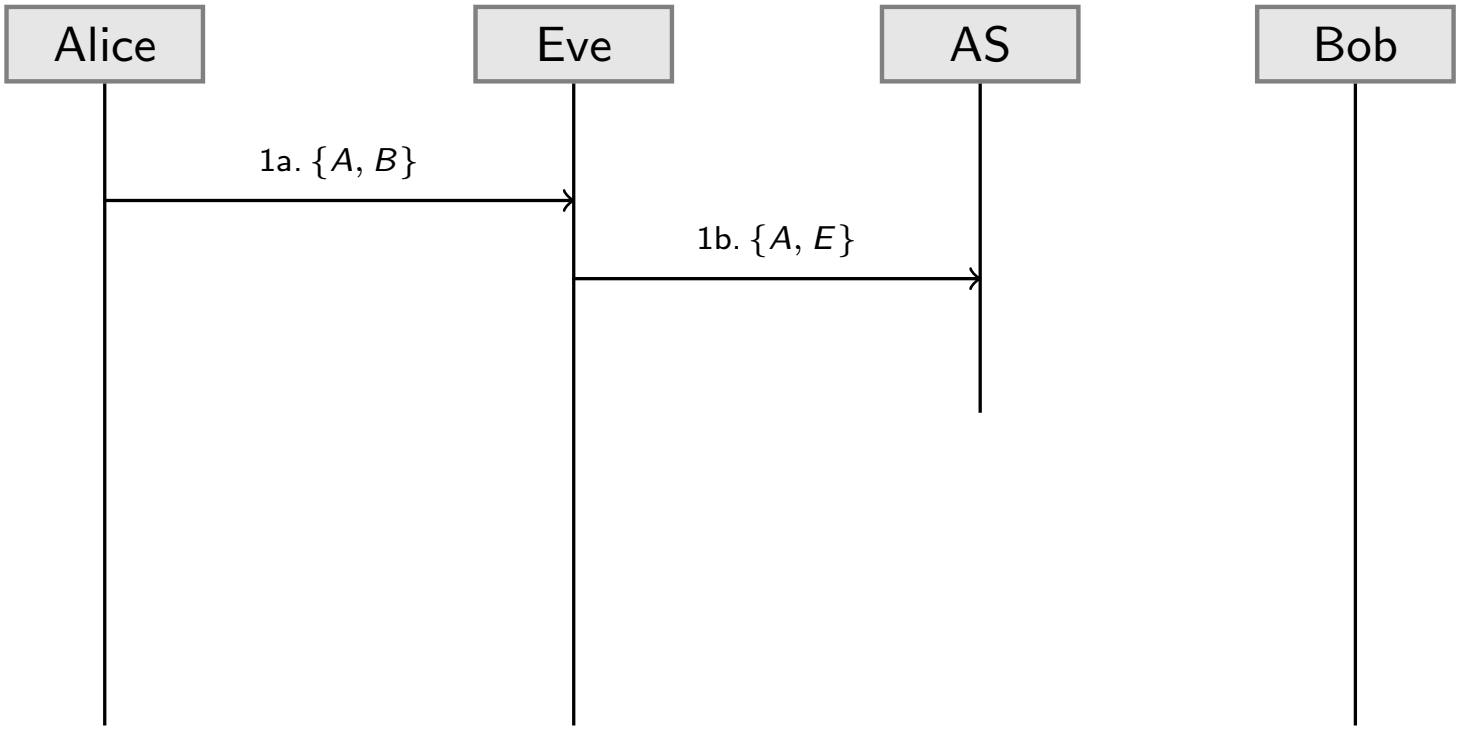

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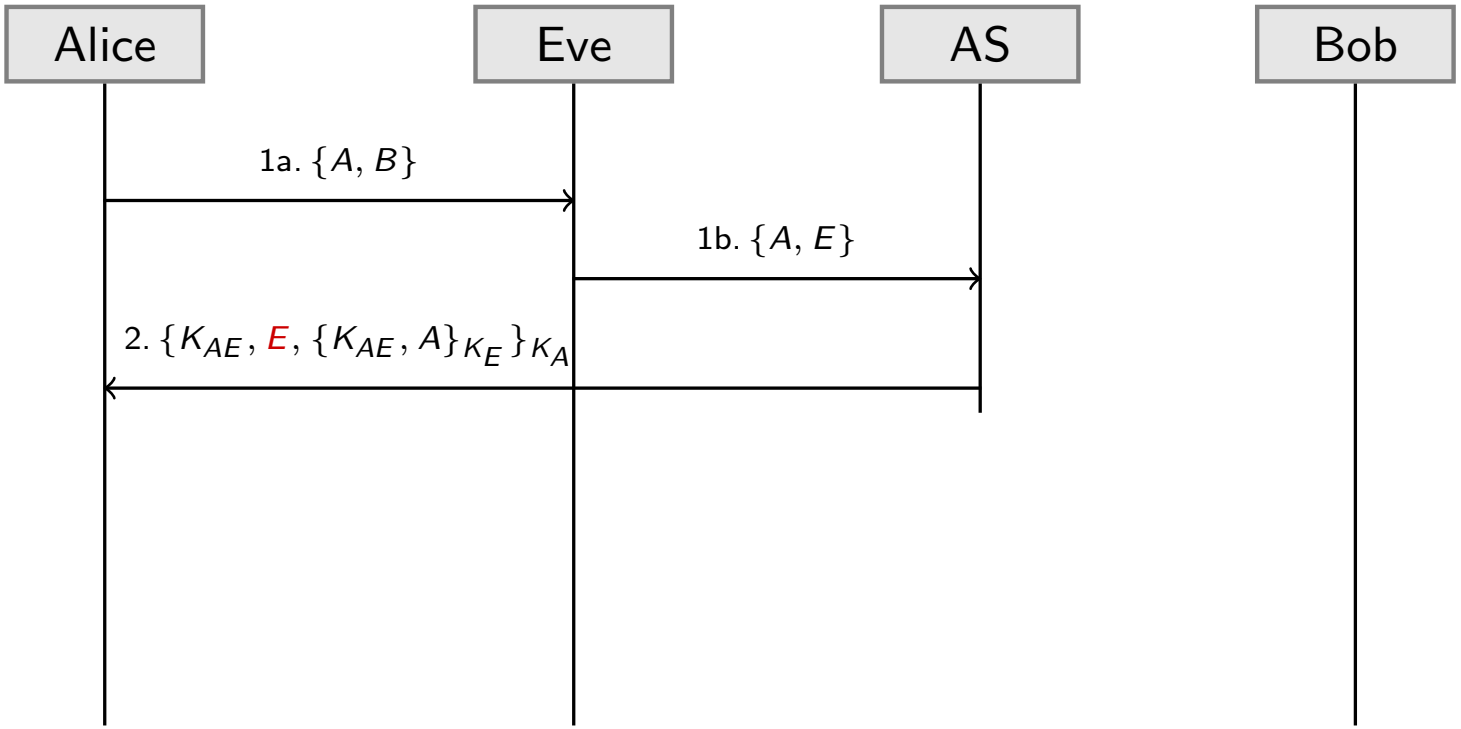

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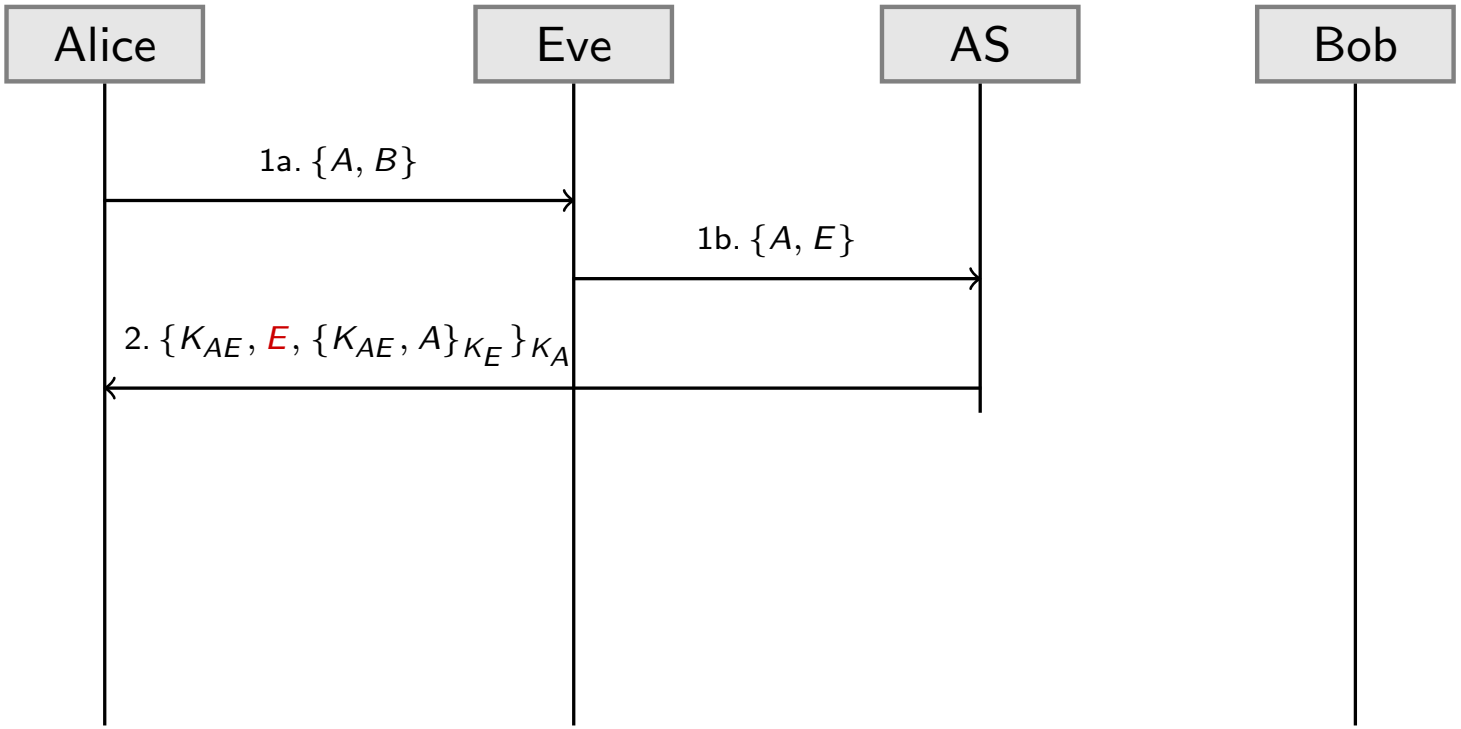
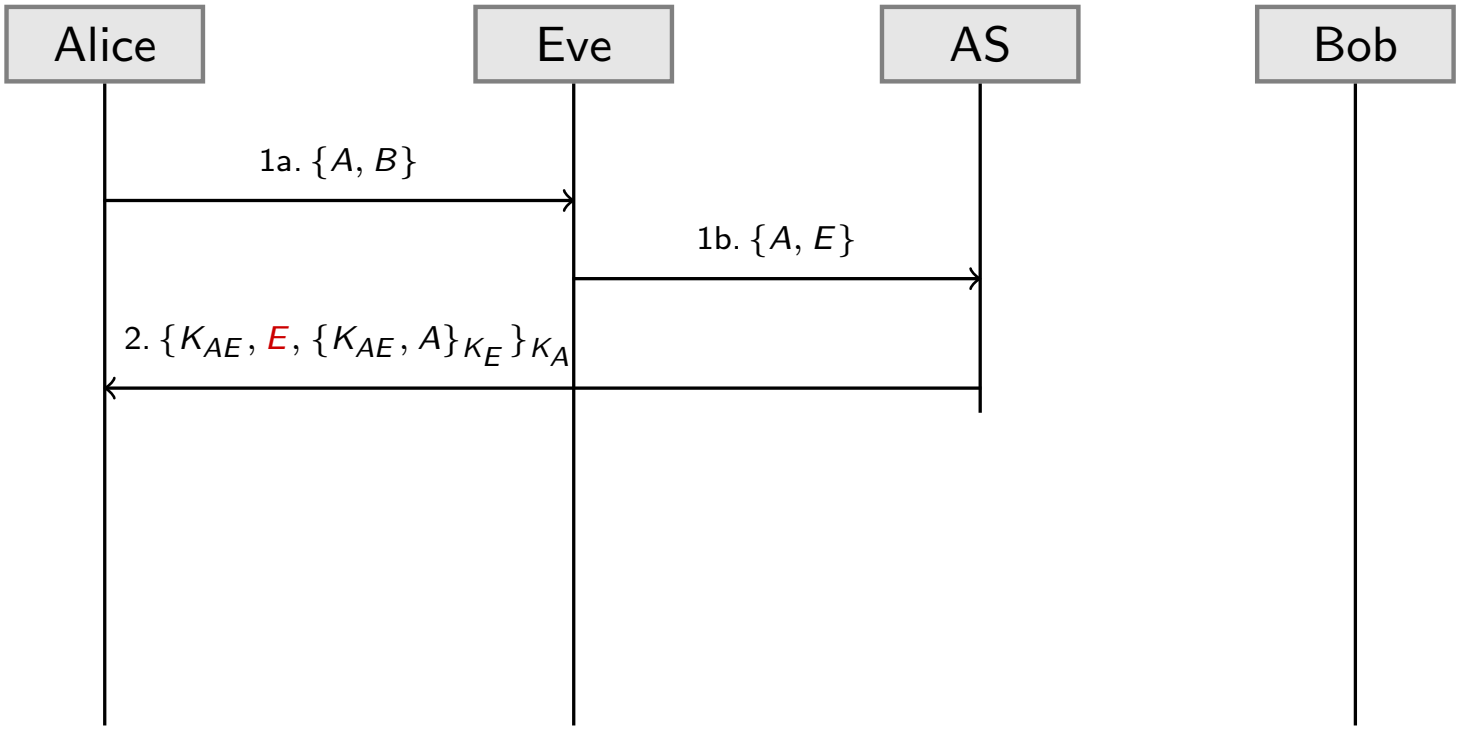


Alice detects in Step 2 that the ticket of the authentication server has been manipulated and cancels the session!

Detecting a Man-in-the-middle Attack



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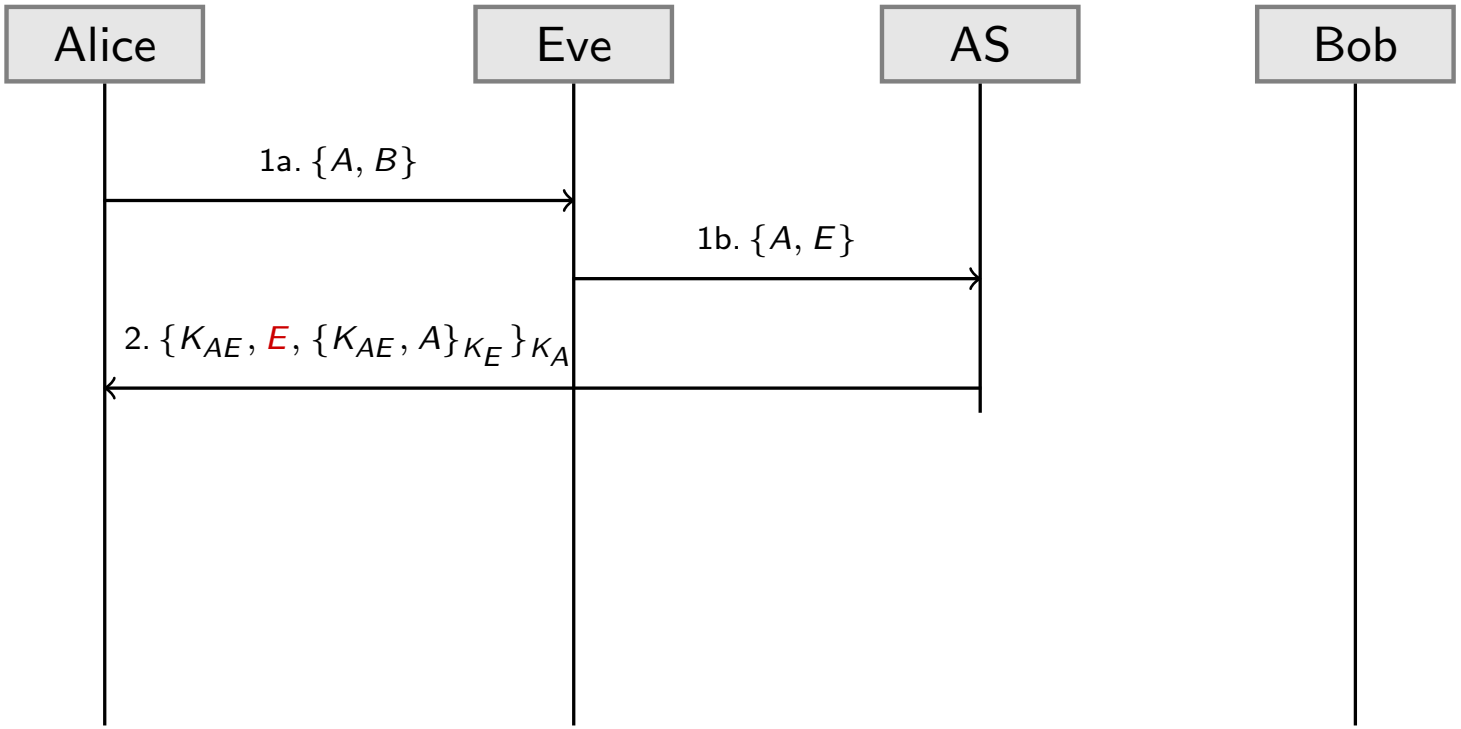
➜ Is the protocol secure now?

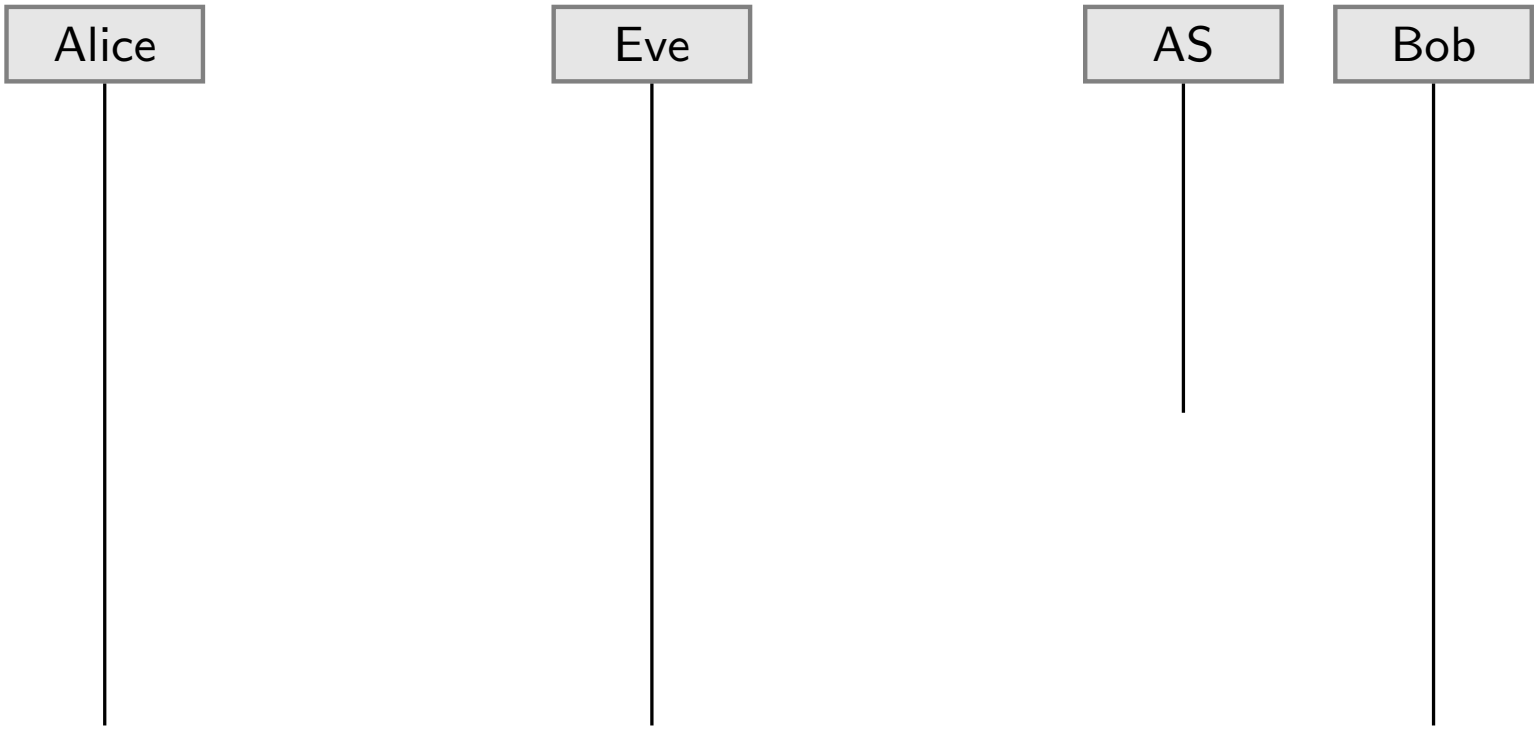
Detecting a Man-in-the-middle Attack



Alice detects in Step 2 that the ticket of the authentication server has been manipulated and cancels the session!

➜ Is the protocol secure now? No, because replay attacks are possible

Attack for Variant 2 of the Symmetric NSP



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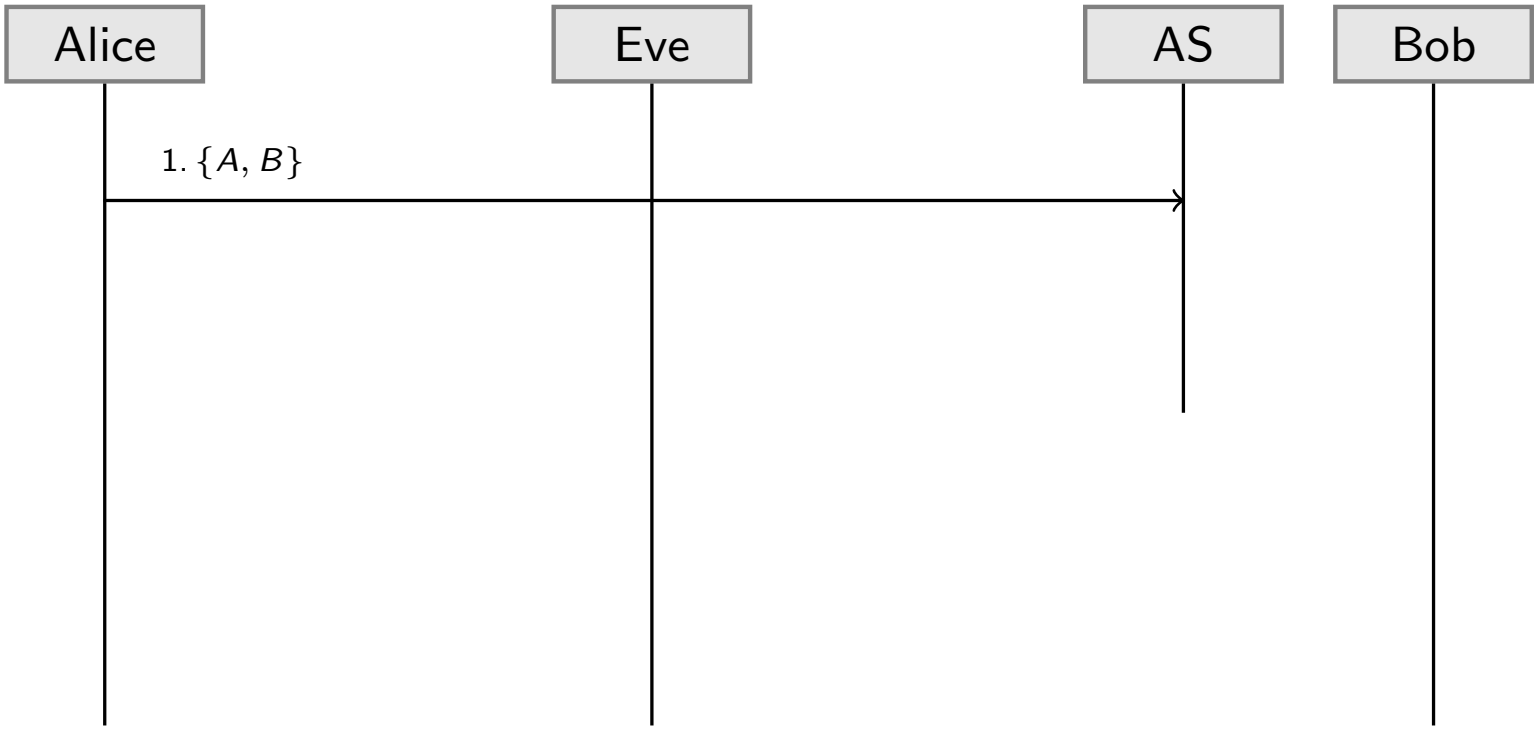

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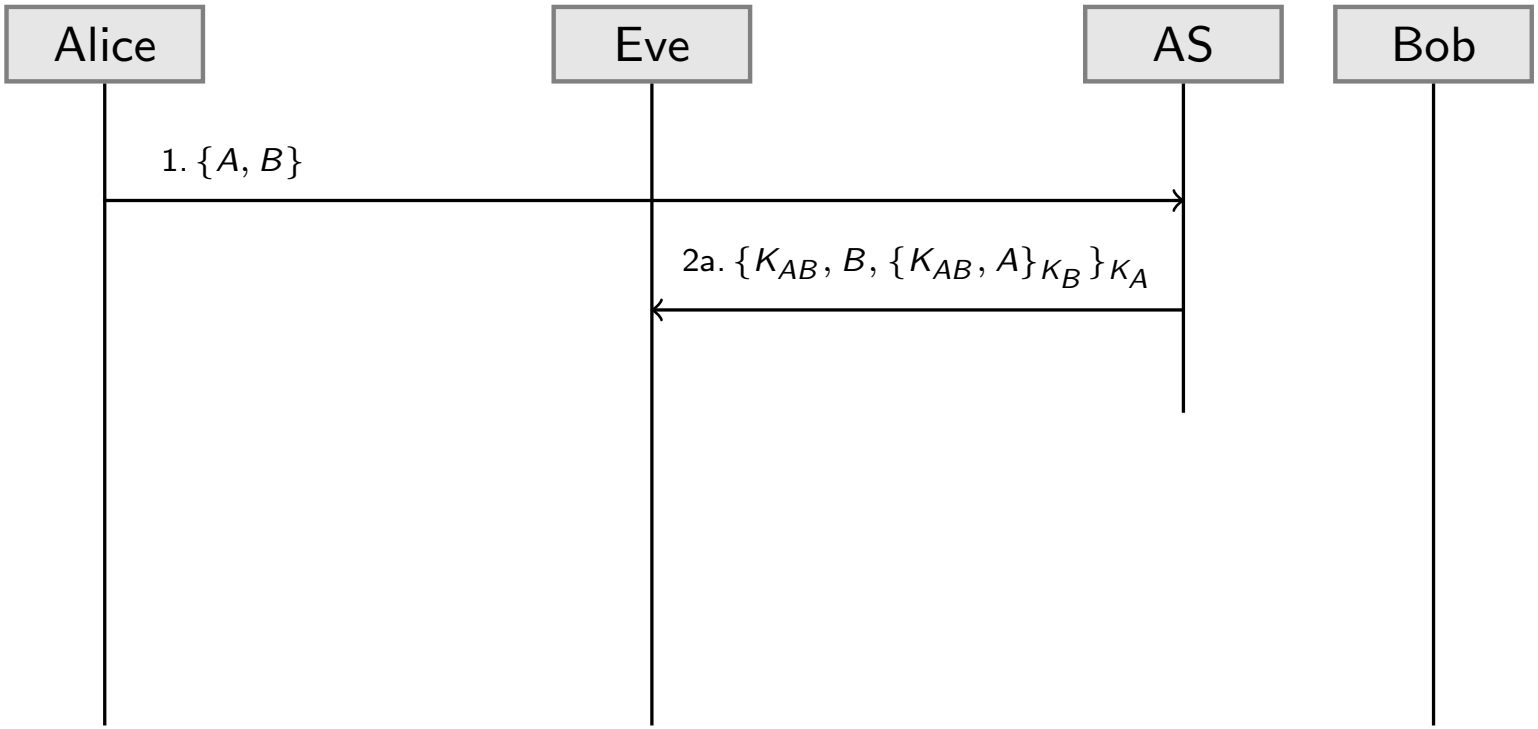

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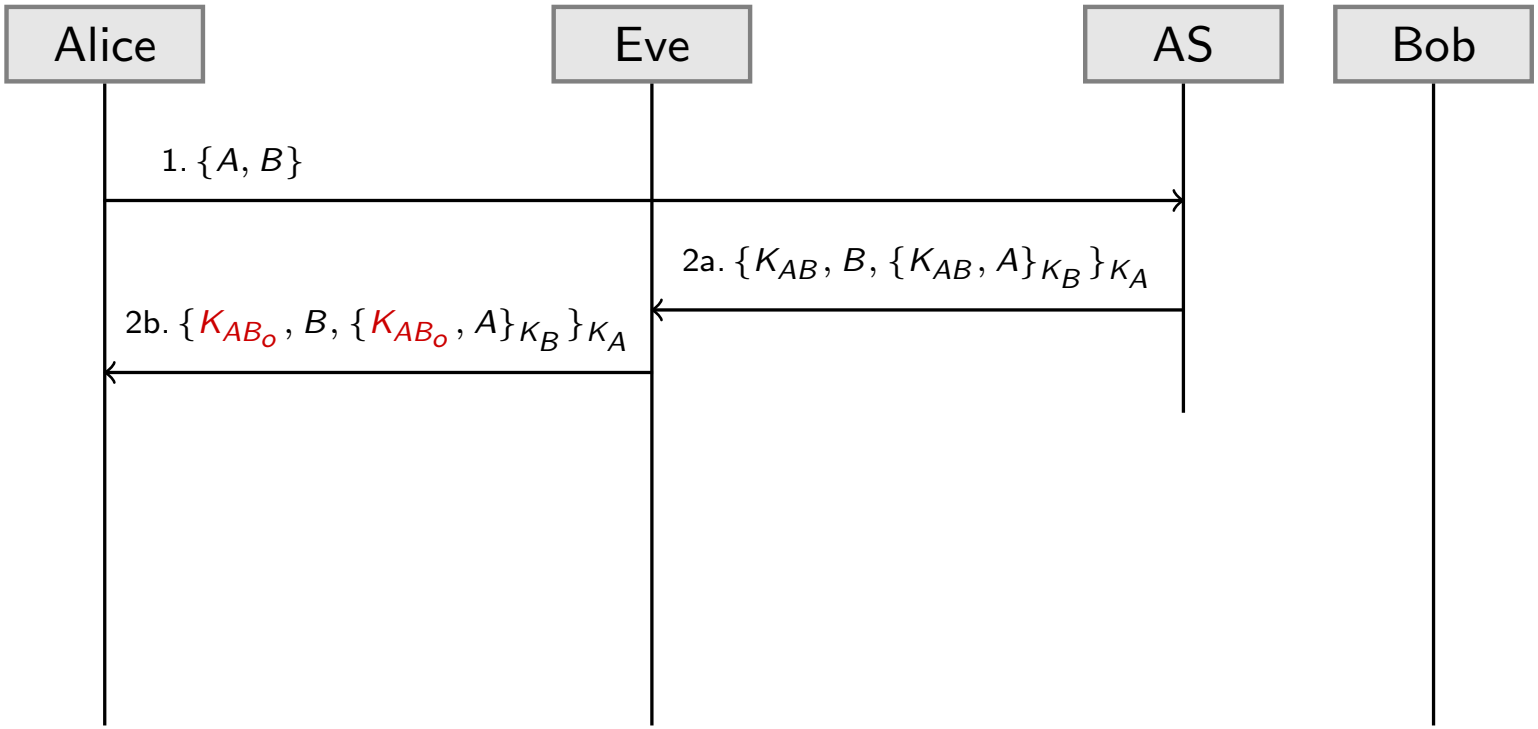

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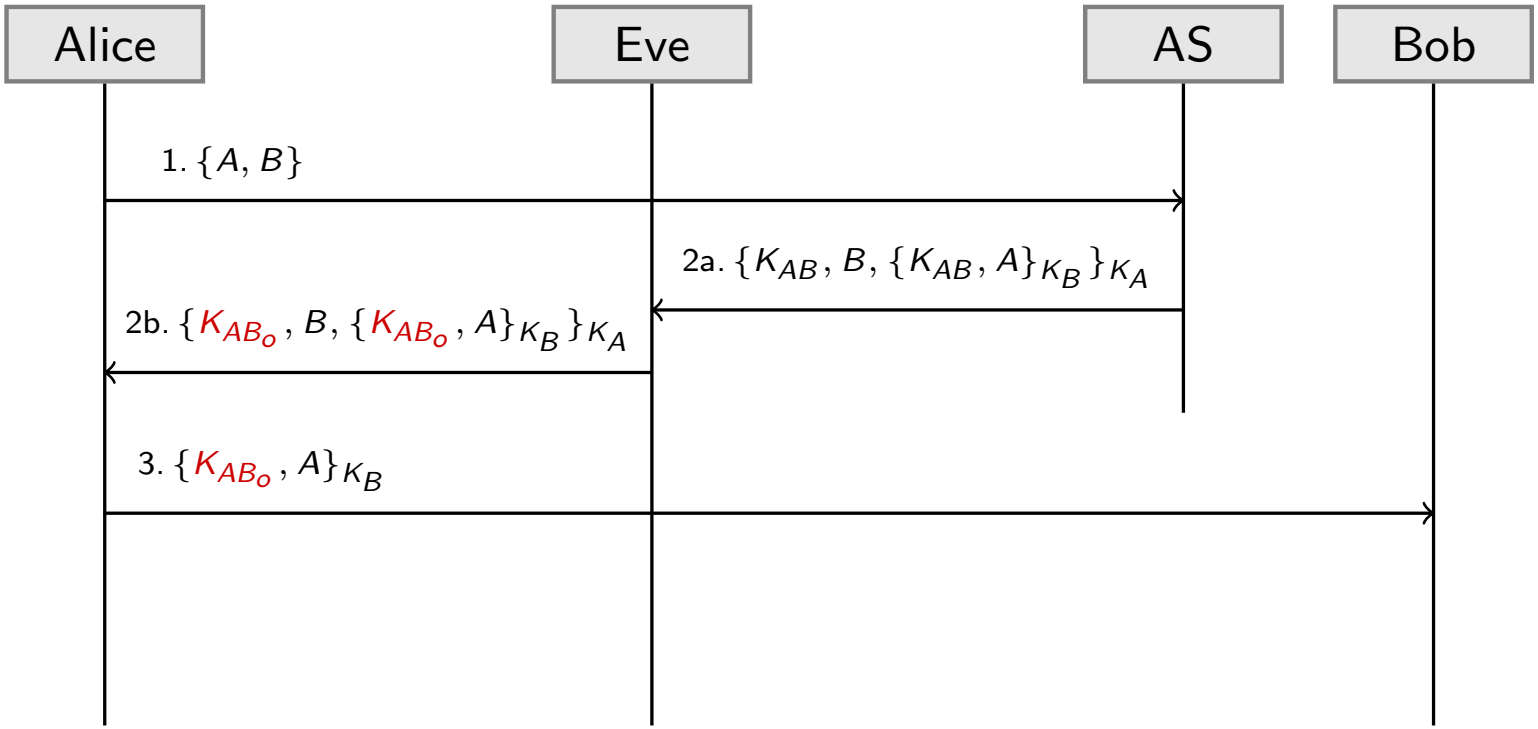

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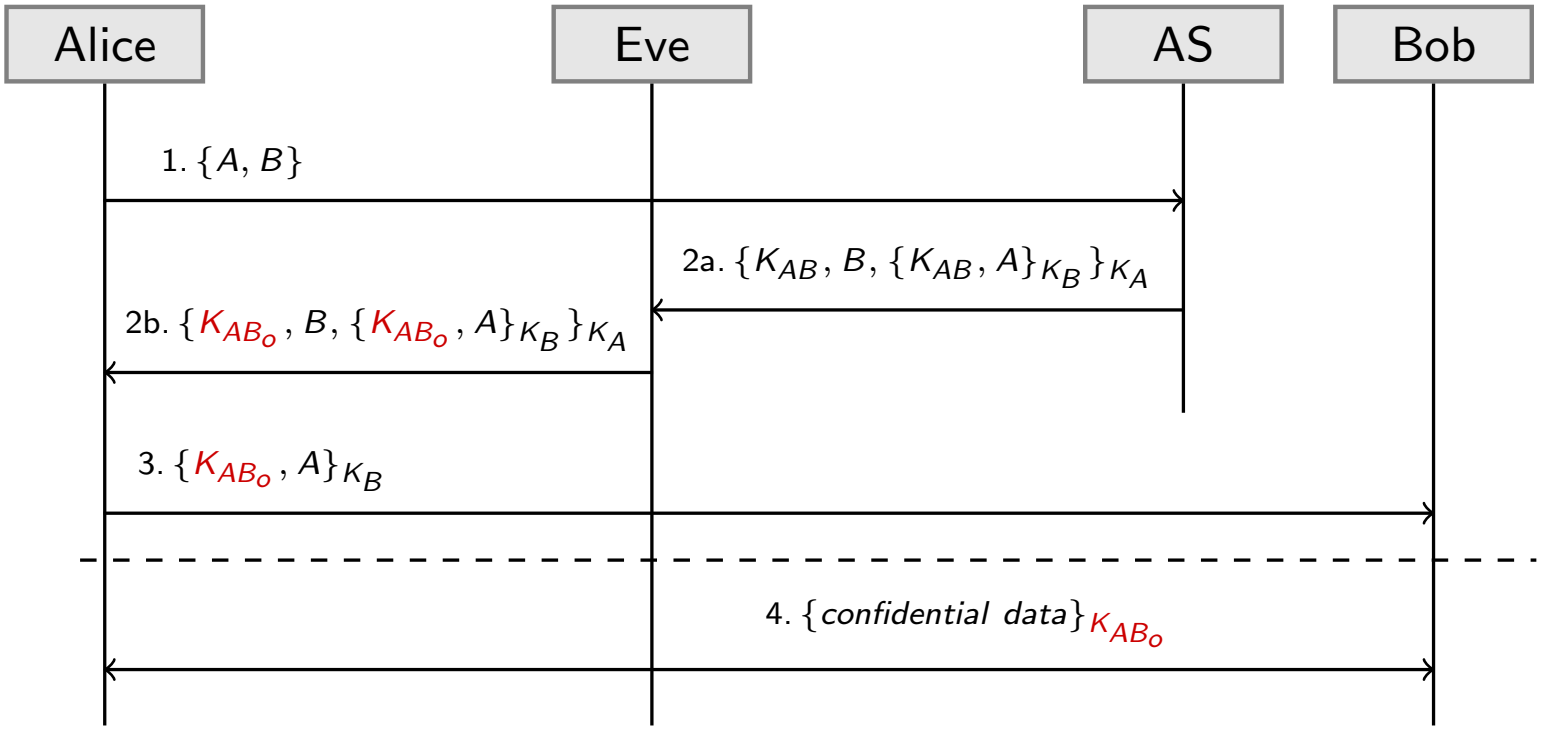

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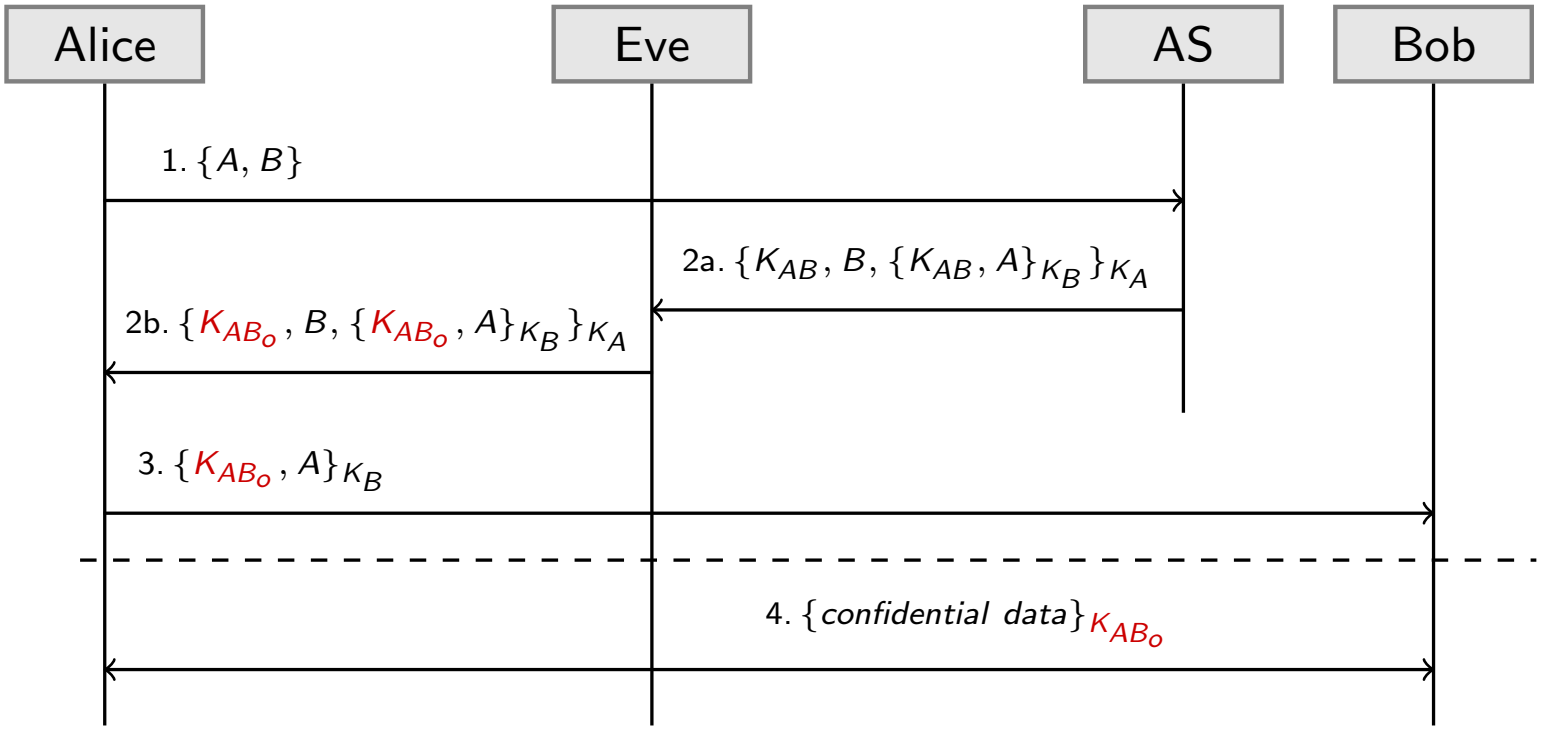

Assumption: Eve knows the old session key K_{AB_o} of Alice & Bob and also the corresponding ticket of the authentication server

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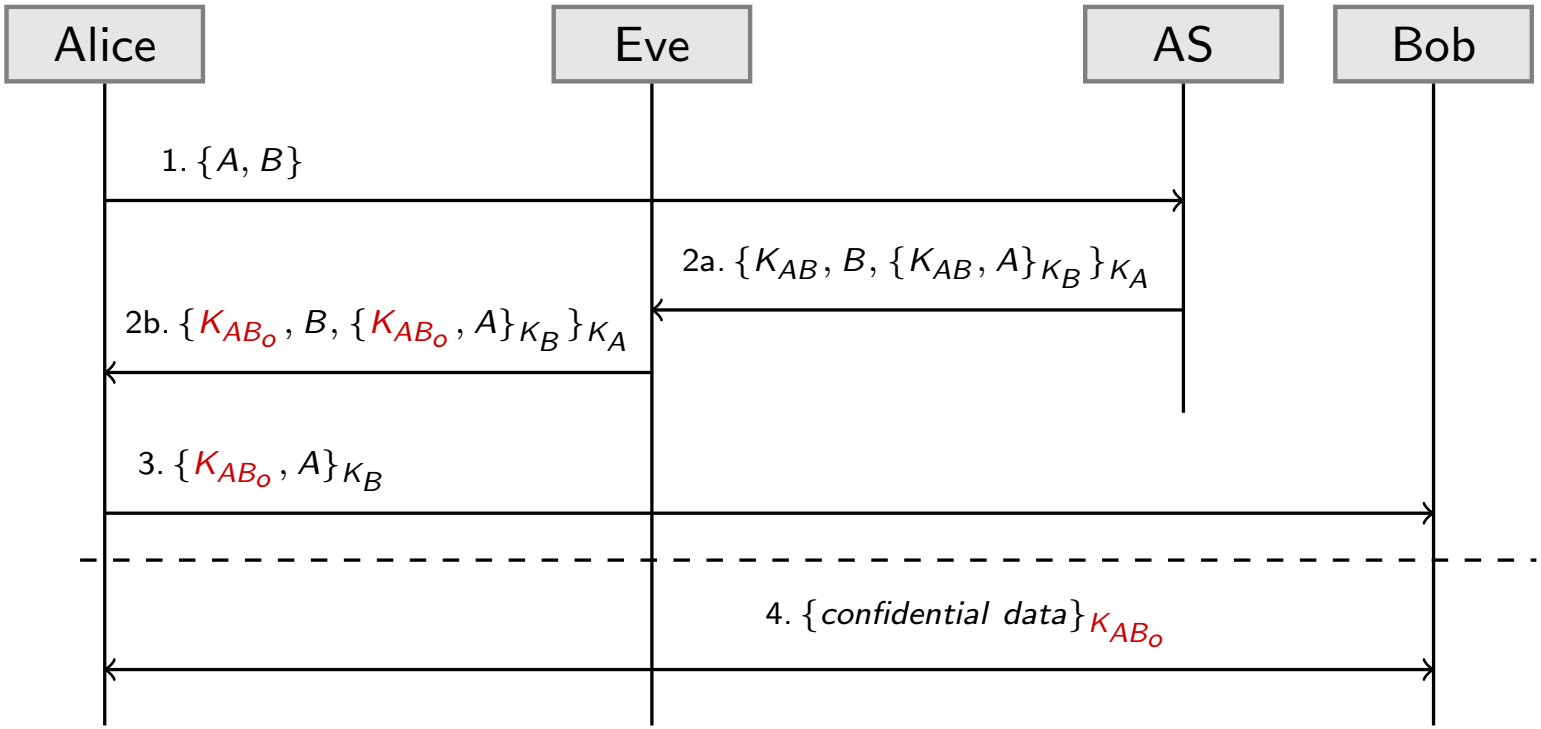

Assumption: Eve knows the old session key K_{AB_o} of Alice & Bob and also the corresponding ticket of the authentication server

➜ How to prevent such a replay attack?

Specify a man-in-the-middle and a replay attack for the NSP example.

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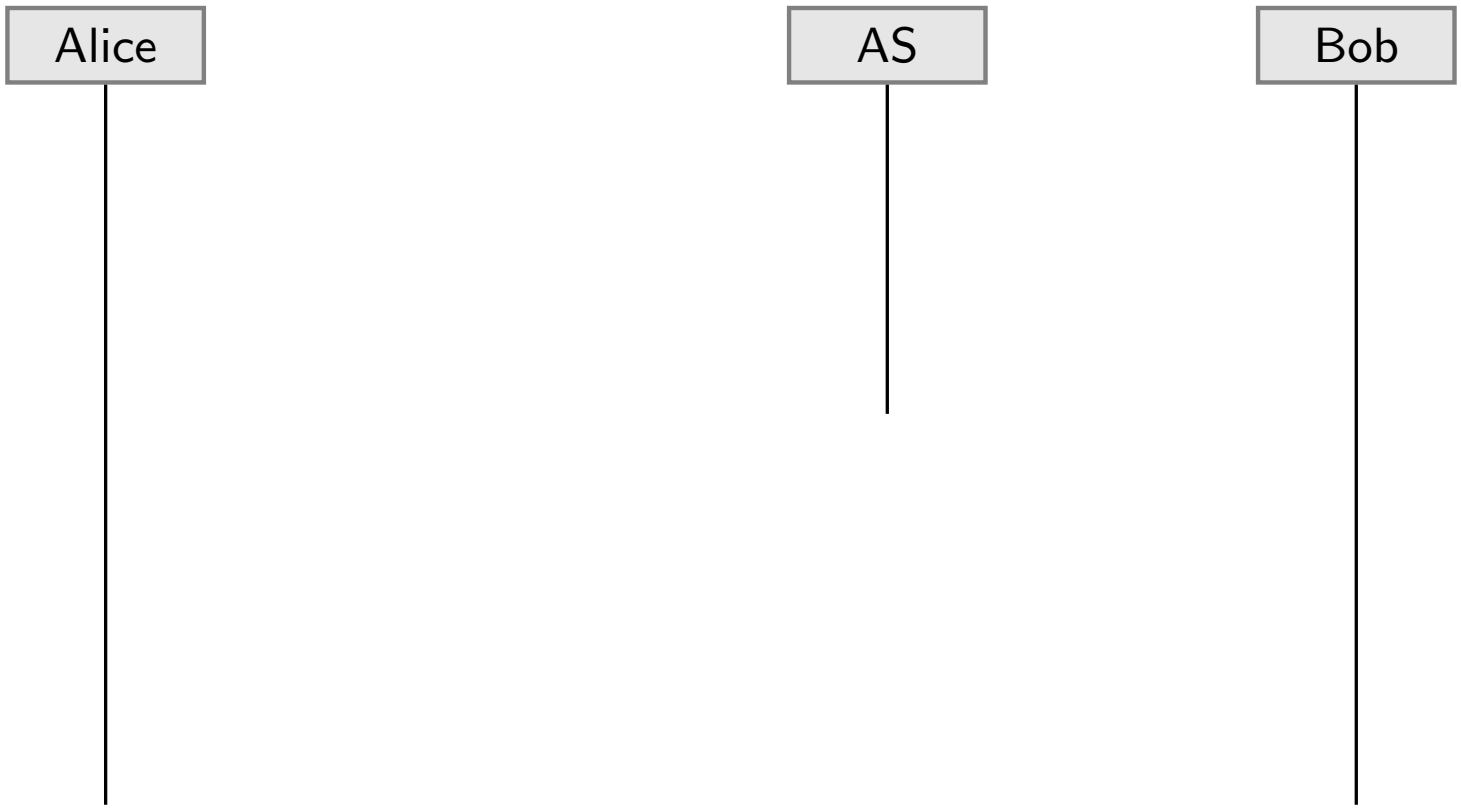

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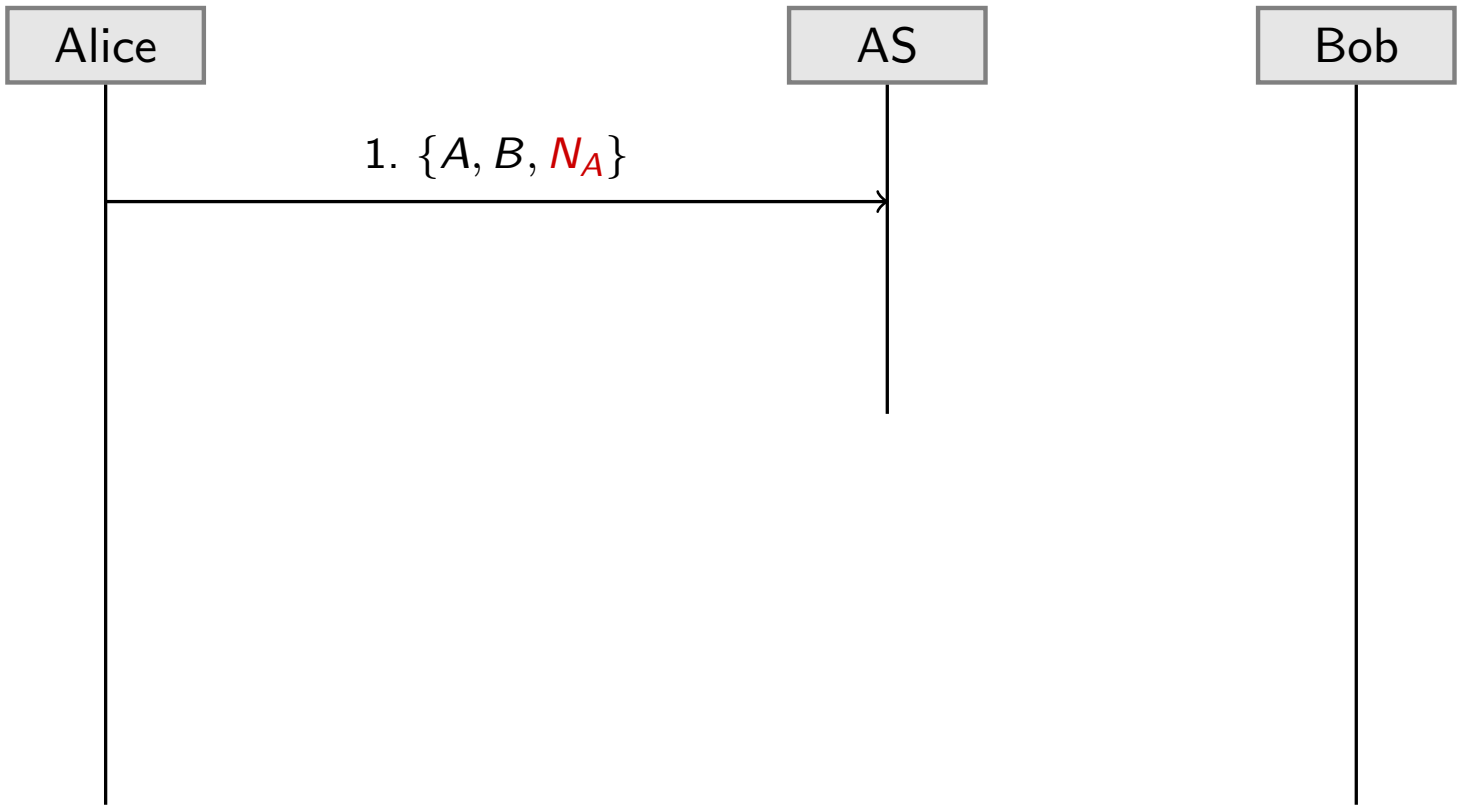

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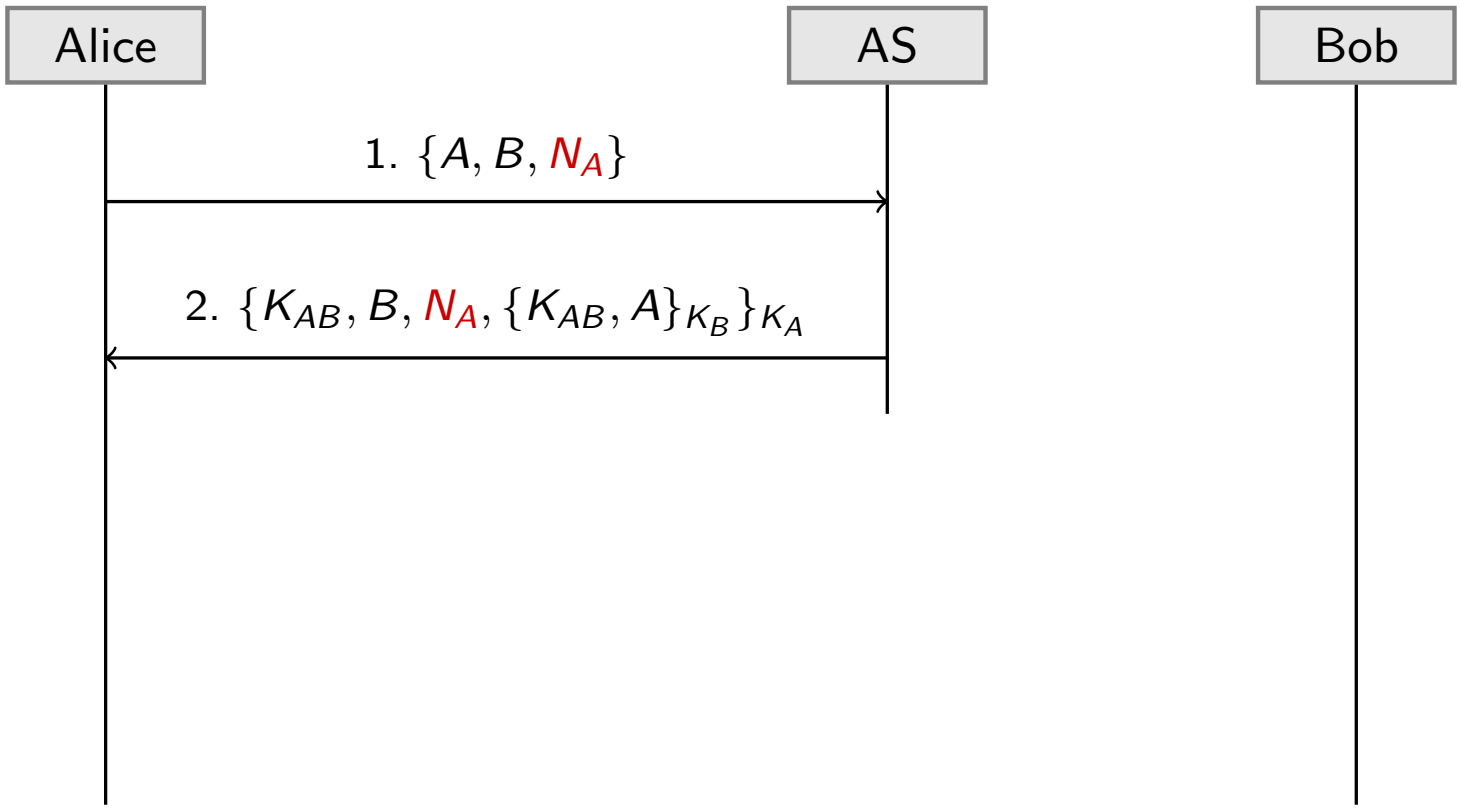

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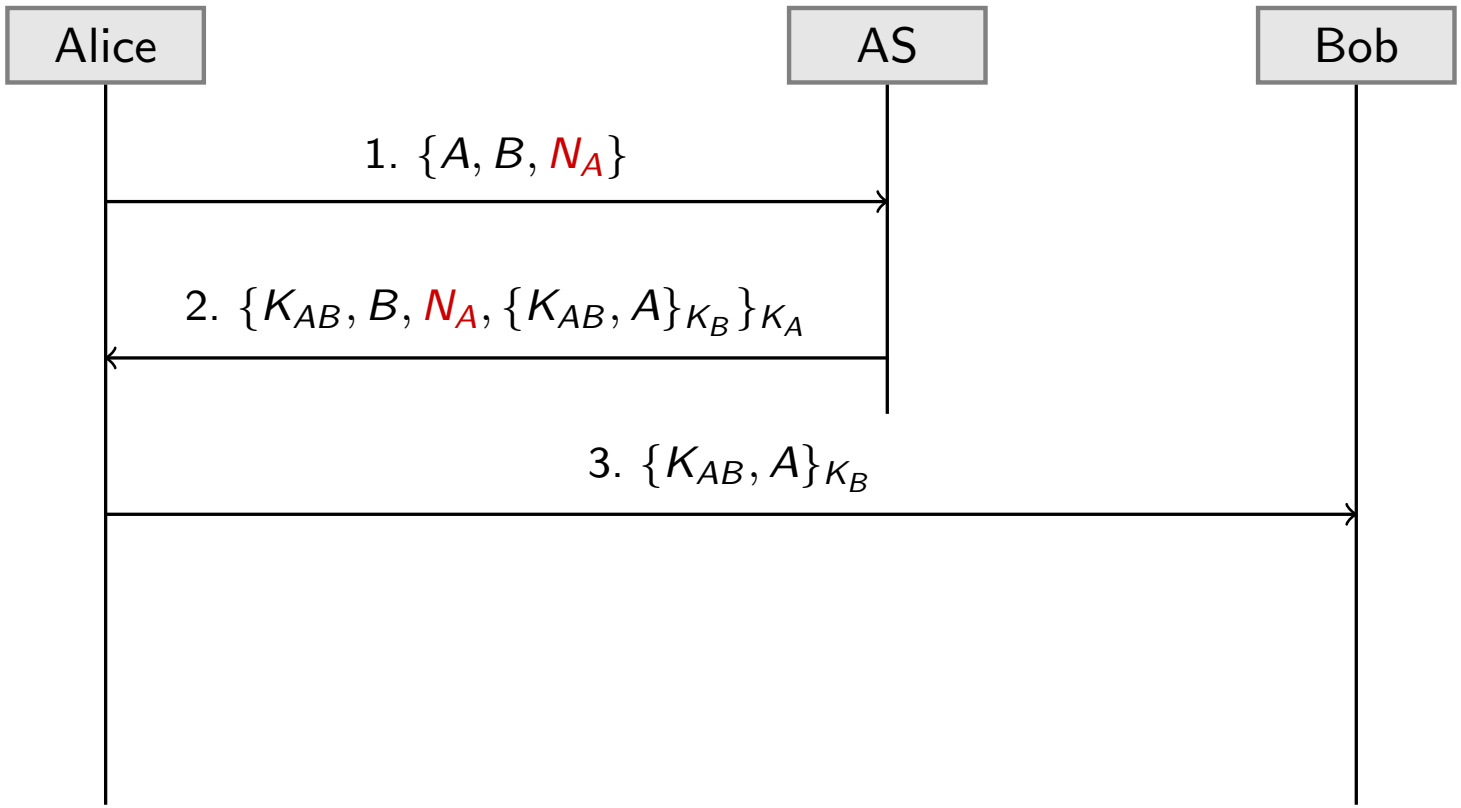

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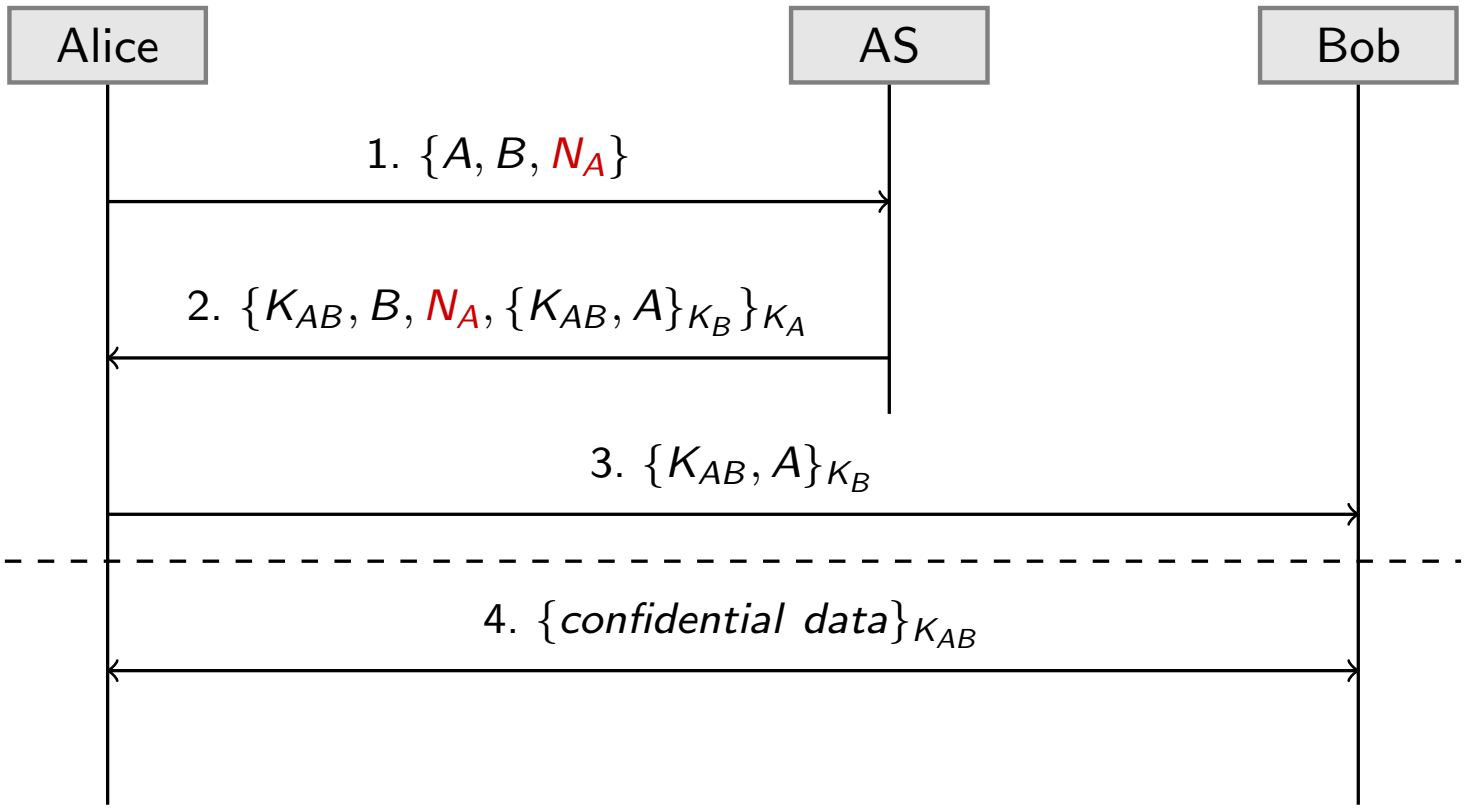

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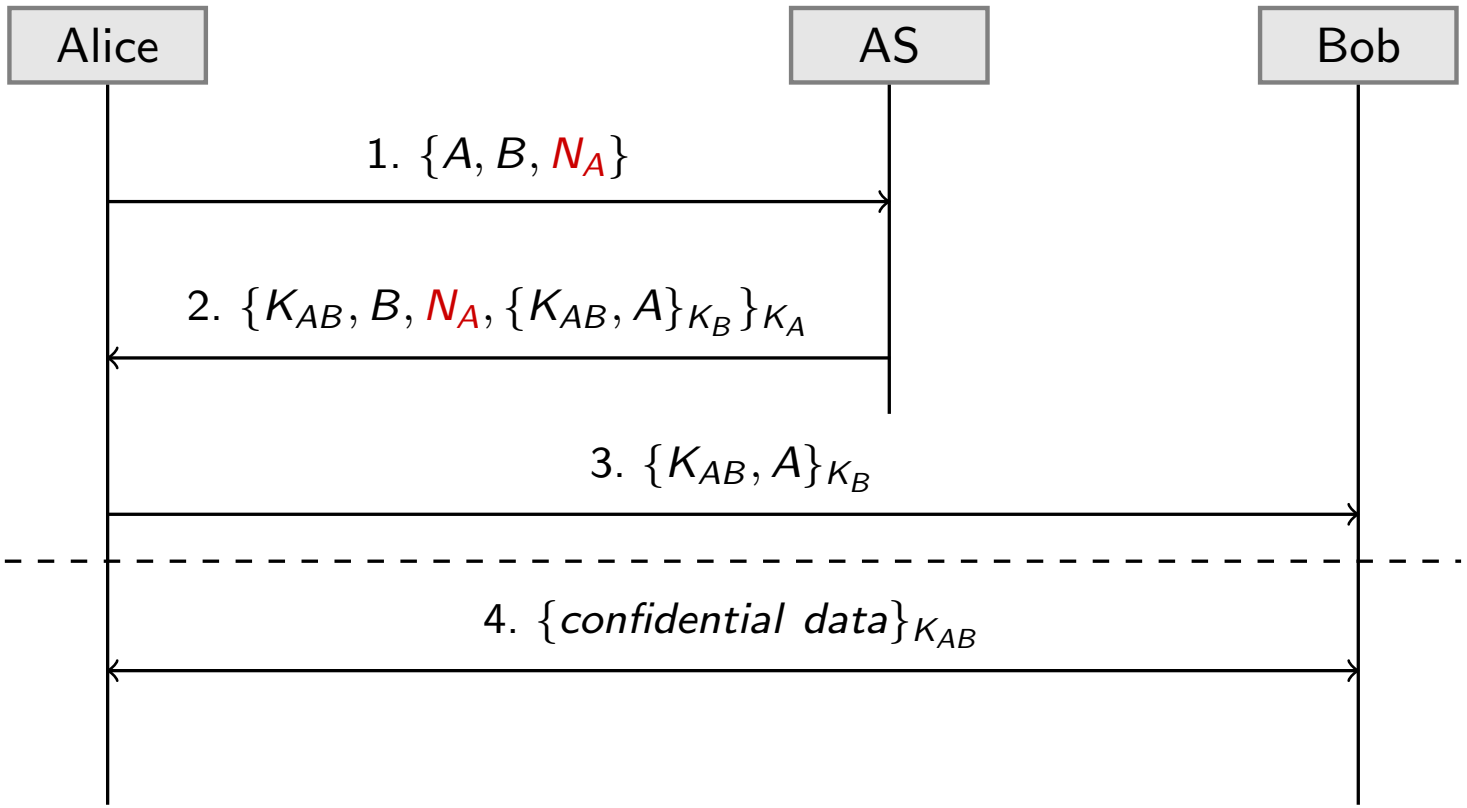
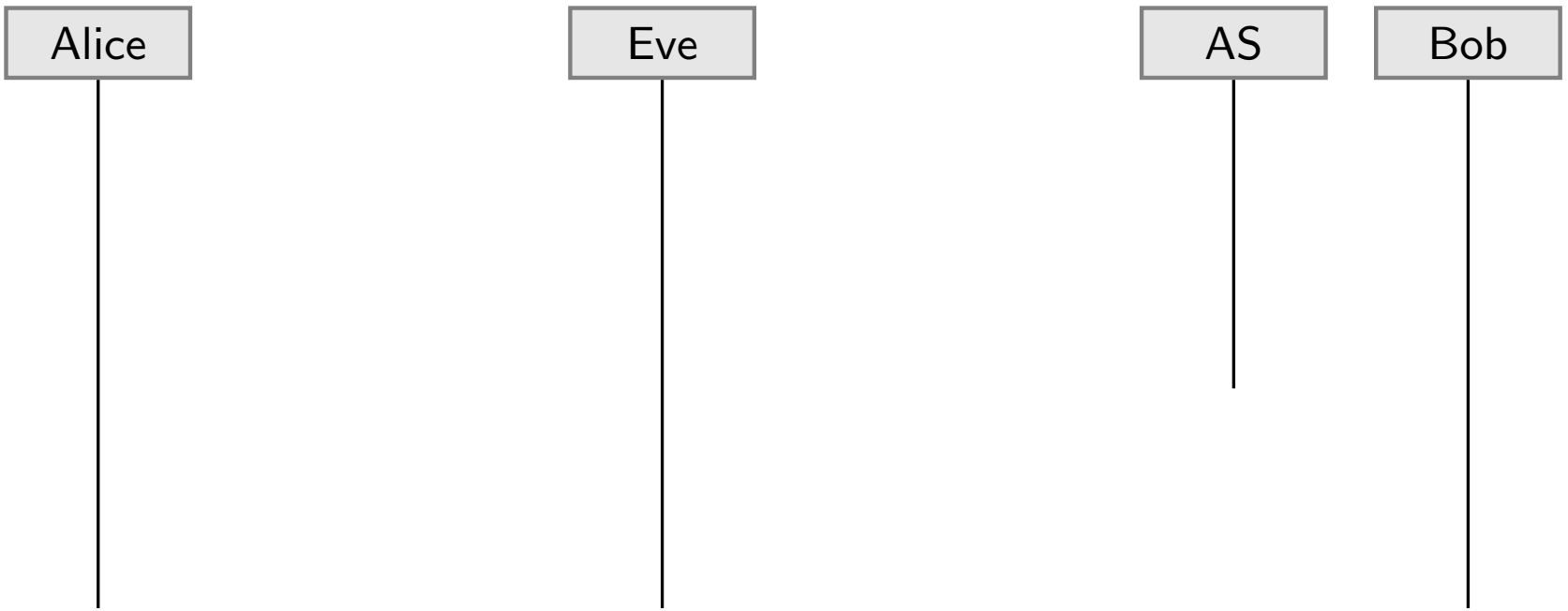


By using Nonce N_A (number used once), a correlation between Step 1 and Step 2 is implemented, such that Alice is able to check the freshness of the received ticket

Detecting a Replay Attack



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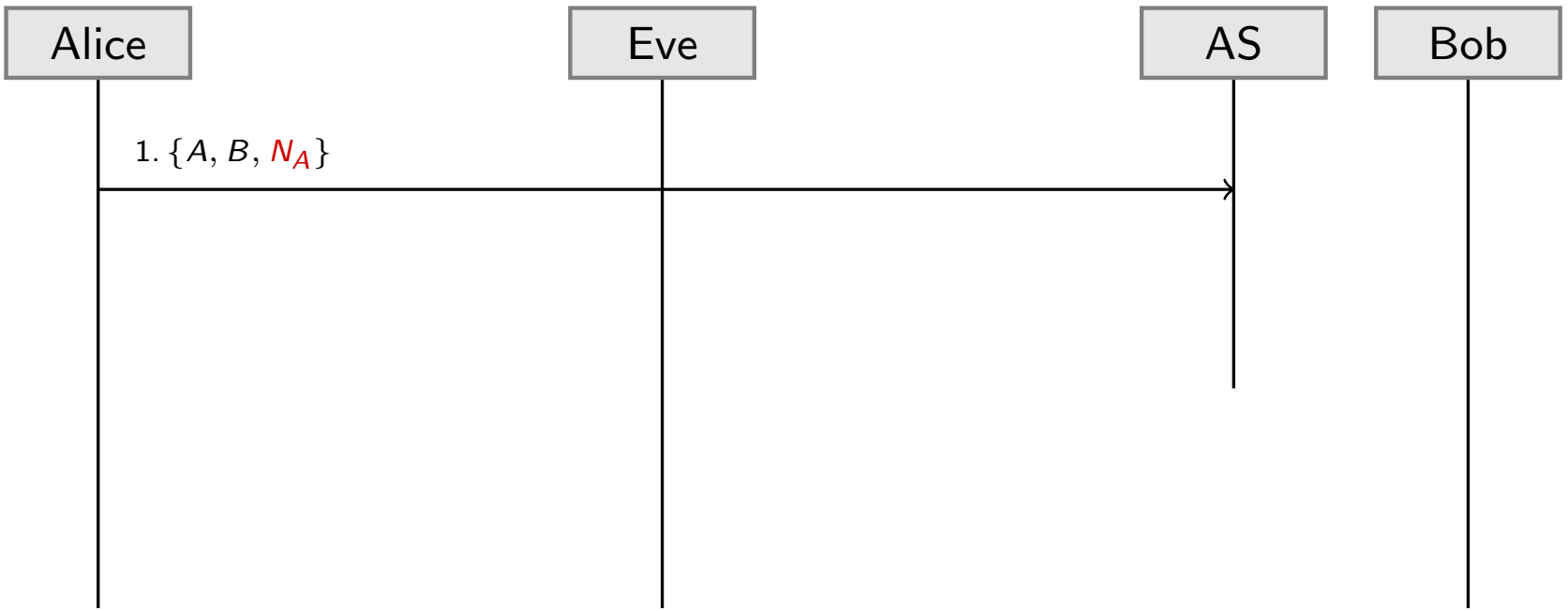

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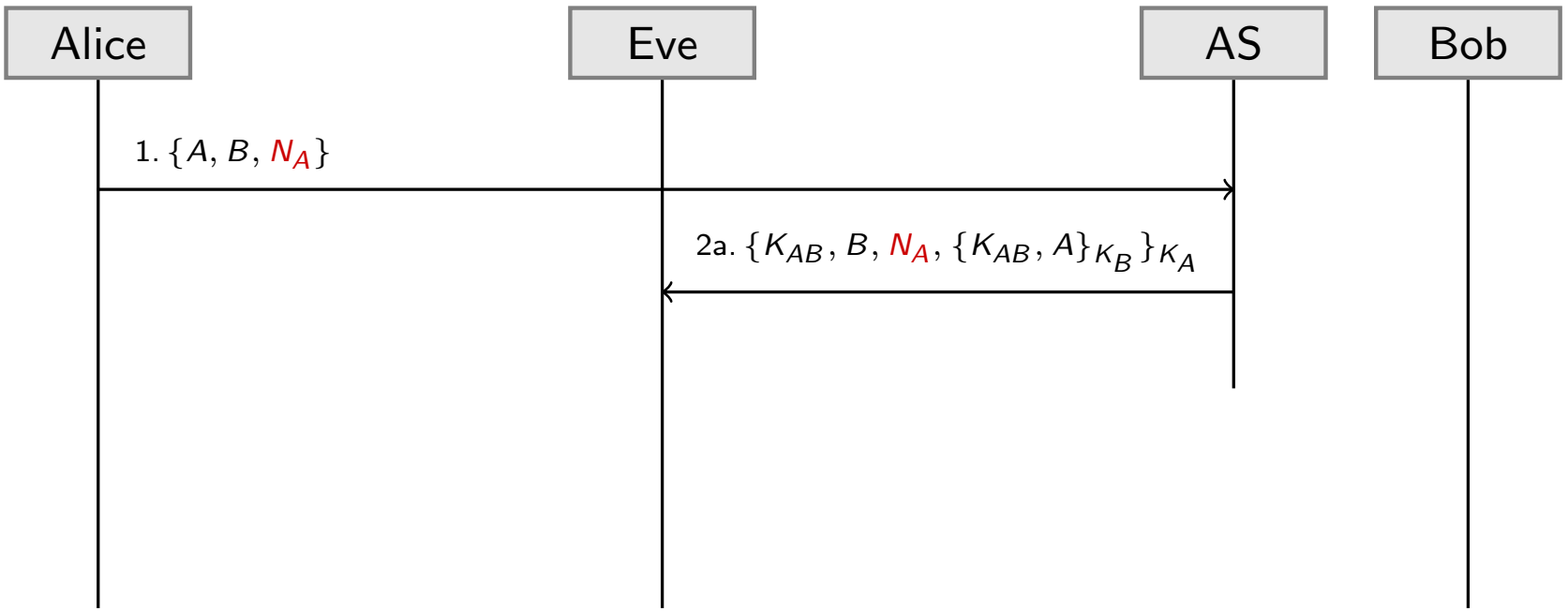

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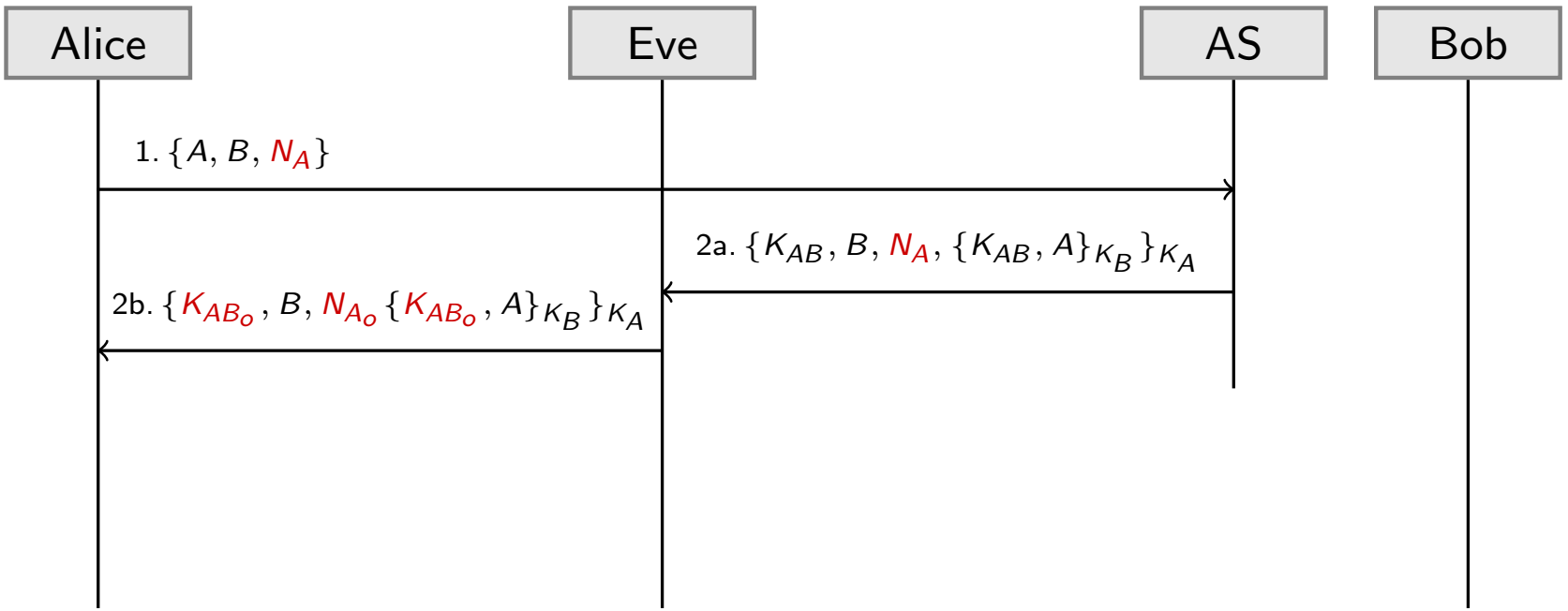
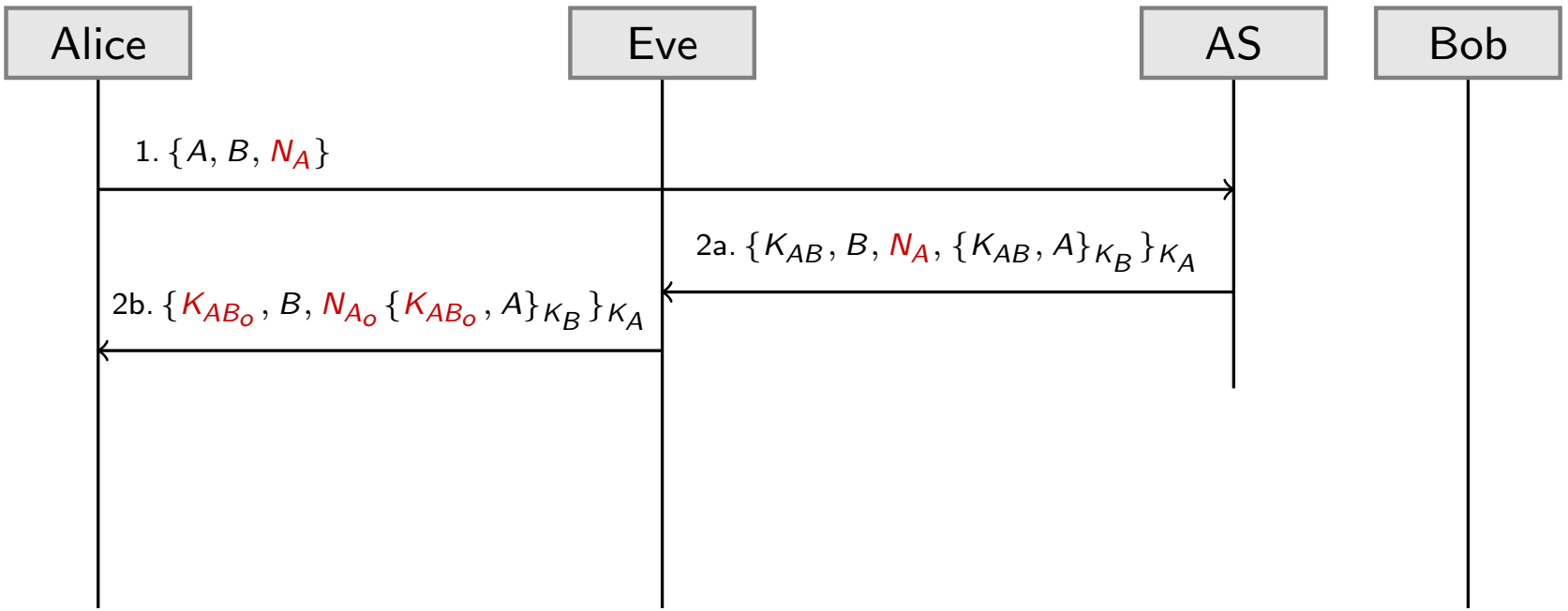
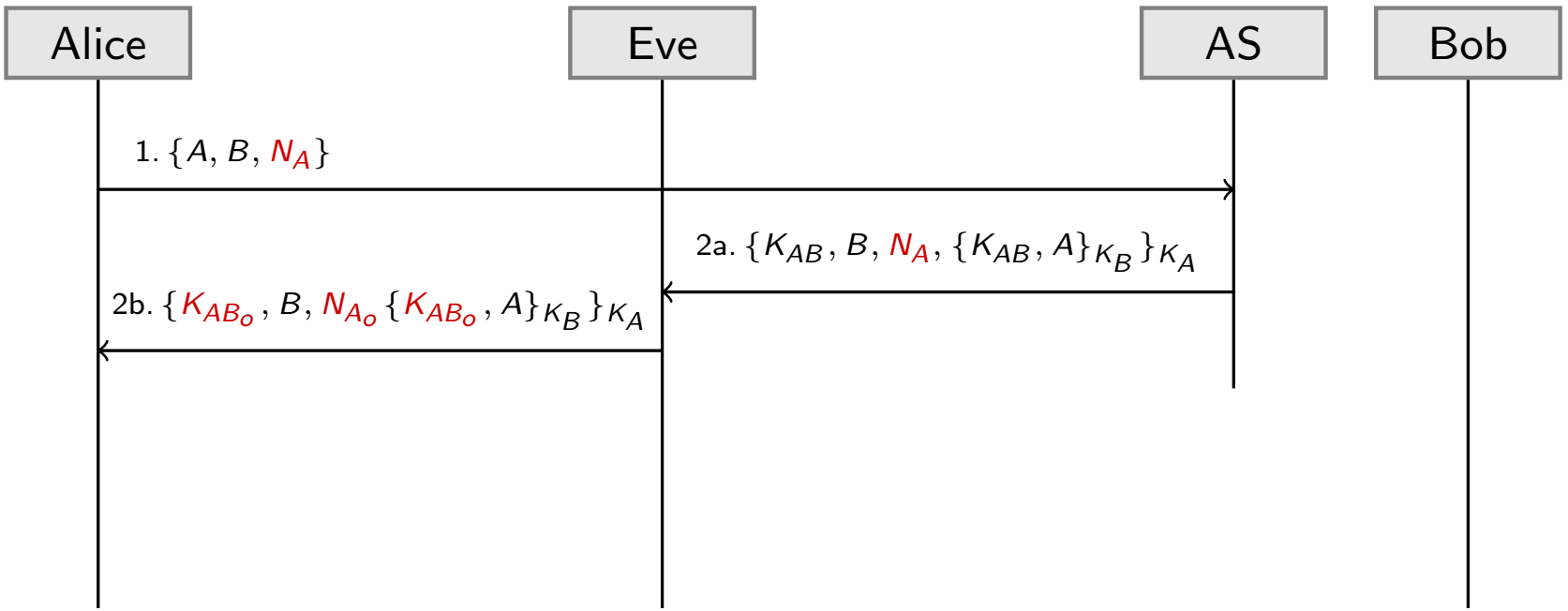


Detecting a Replay Attack



Alice detects Eve's manipulation by finding out that the Nonce N_A has been changed

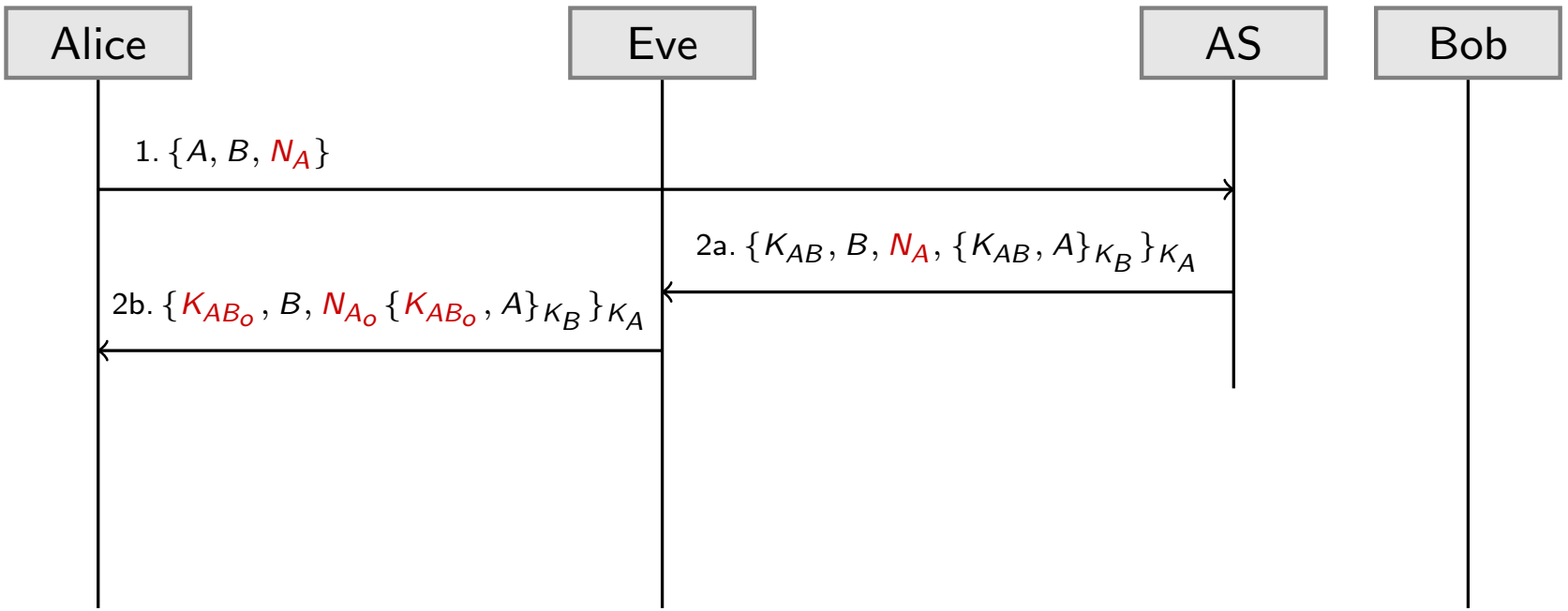
Detecting a Replay Attack



Alice detects Eve's manipulation by finding out that the Nonce N_A has been changed

➜ Is the protocol now finally secure?

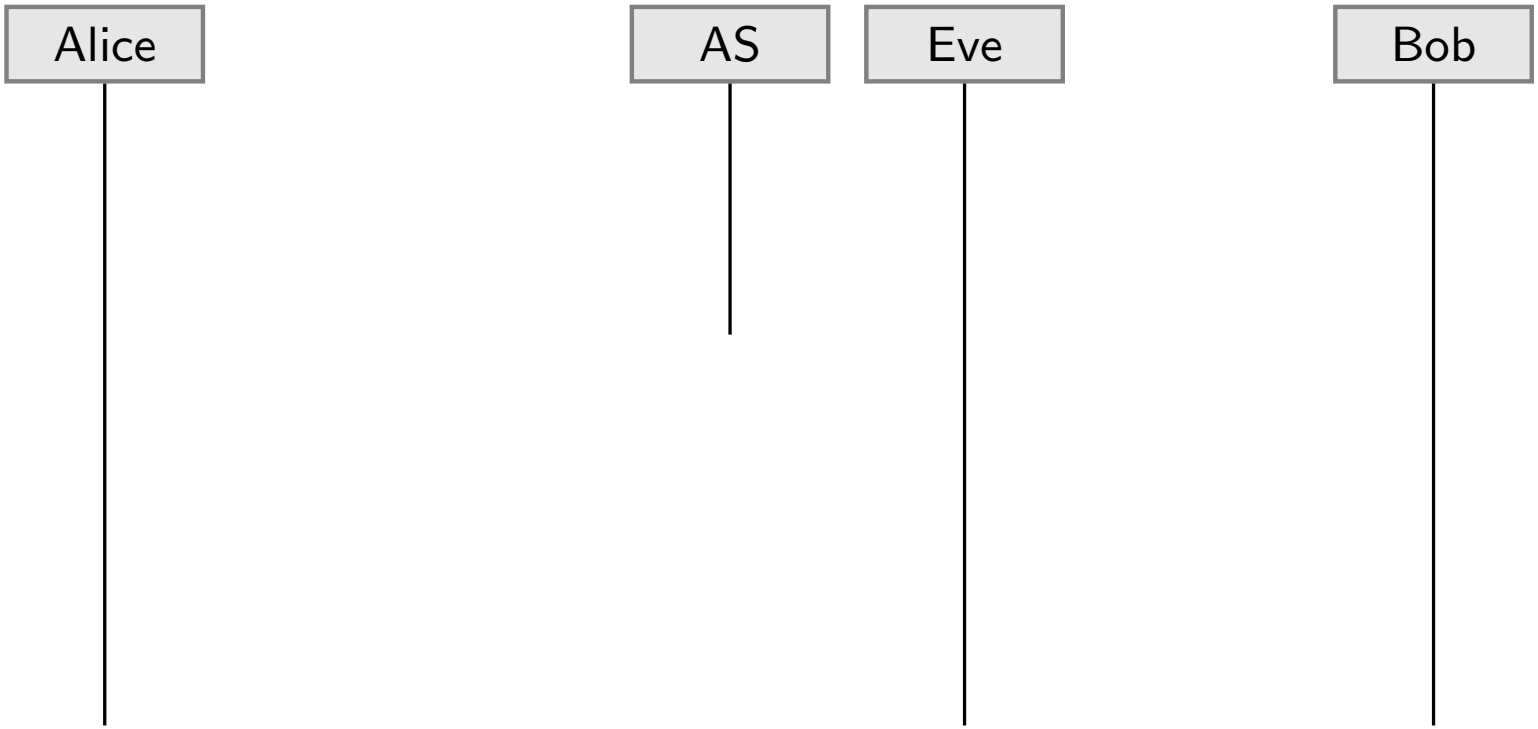
Detecting a Replay Attack



Alice detects Eve's manipulation by finding out that the Nonce N_A has been changed

➜ Is the protocol now finally secure? No, because Bob is attackable!

Attack for Variant 3 of the symmetric NSP



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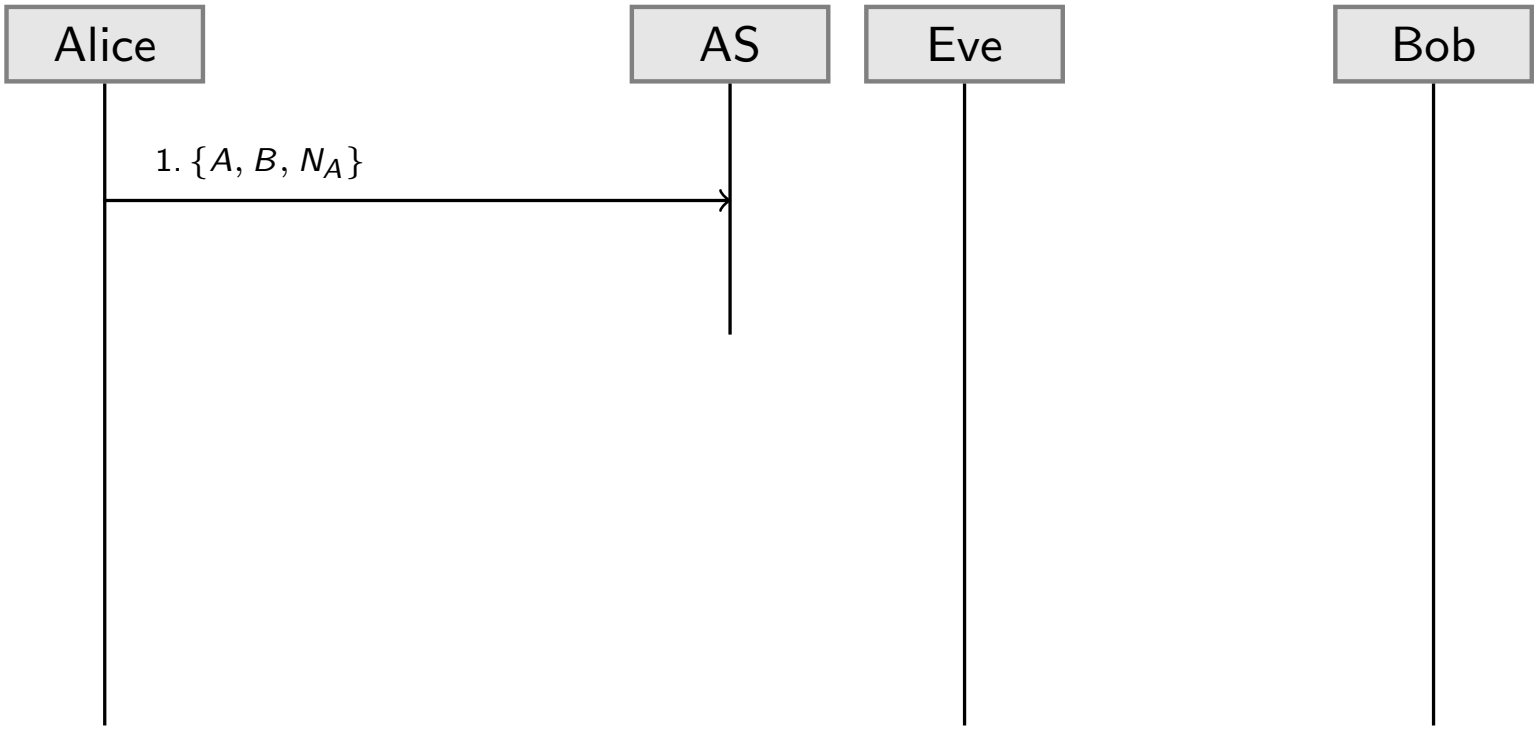

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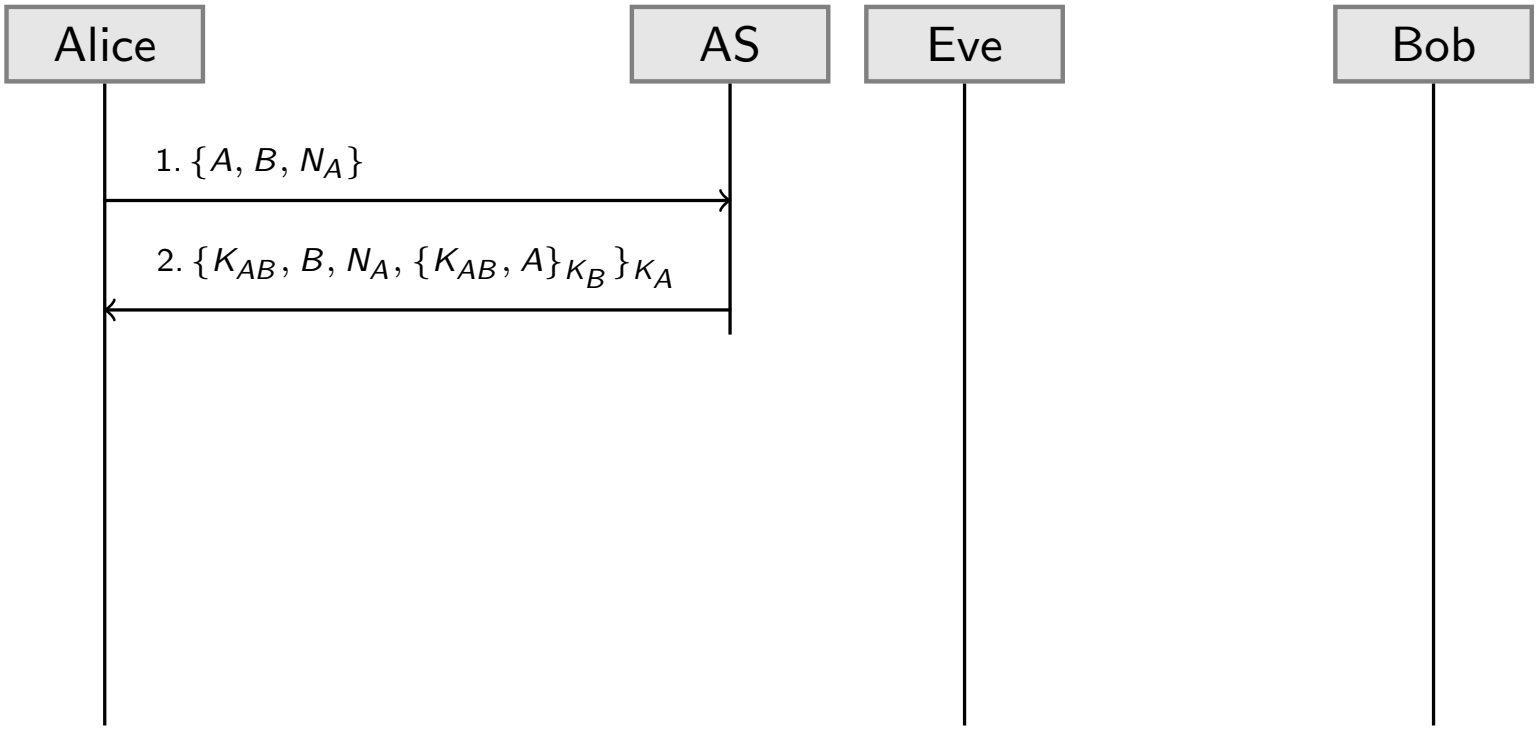

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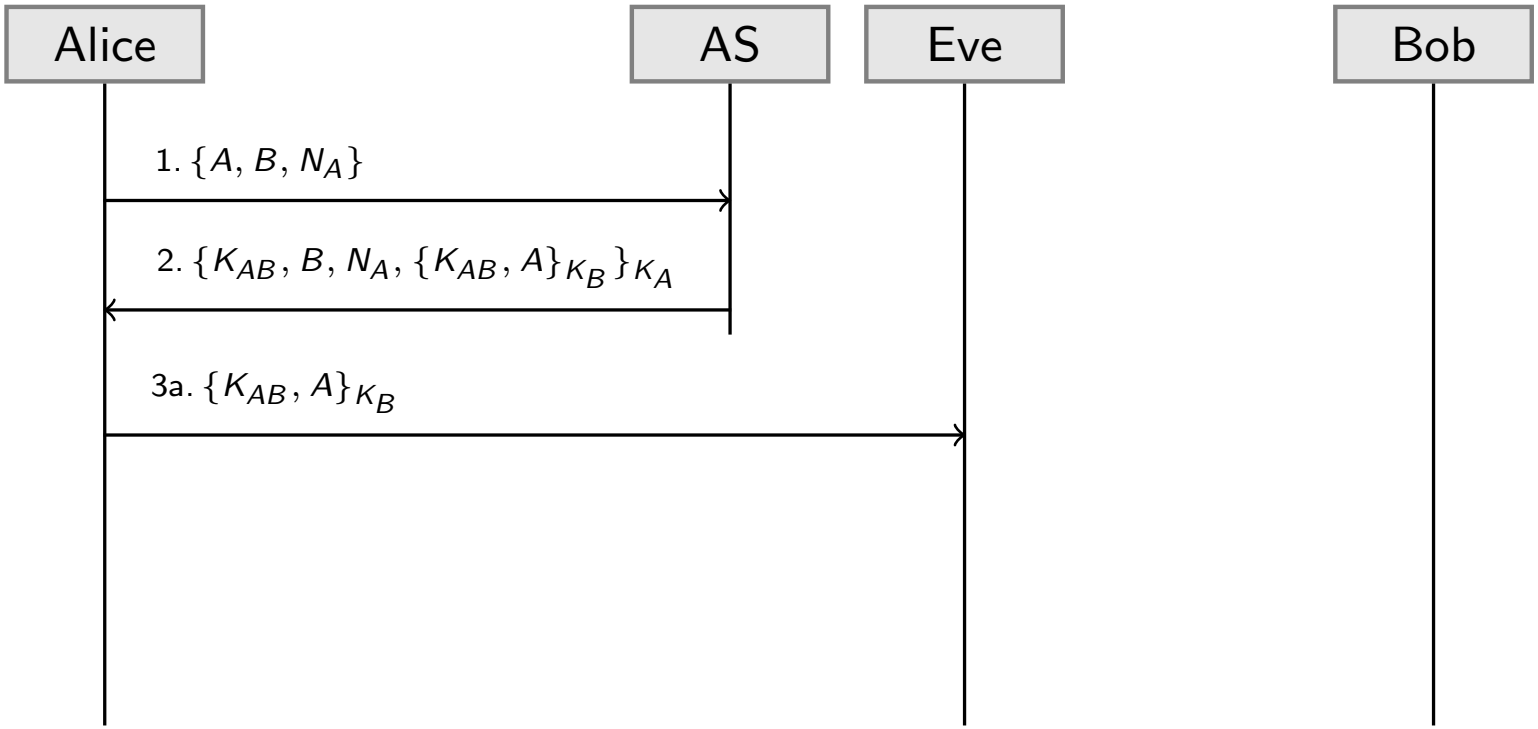

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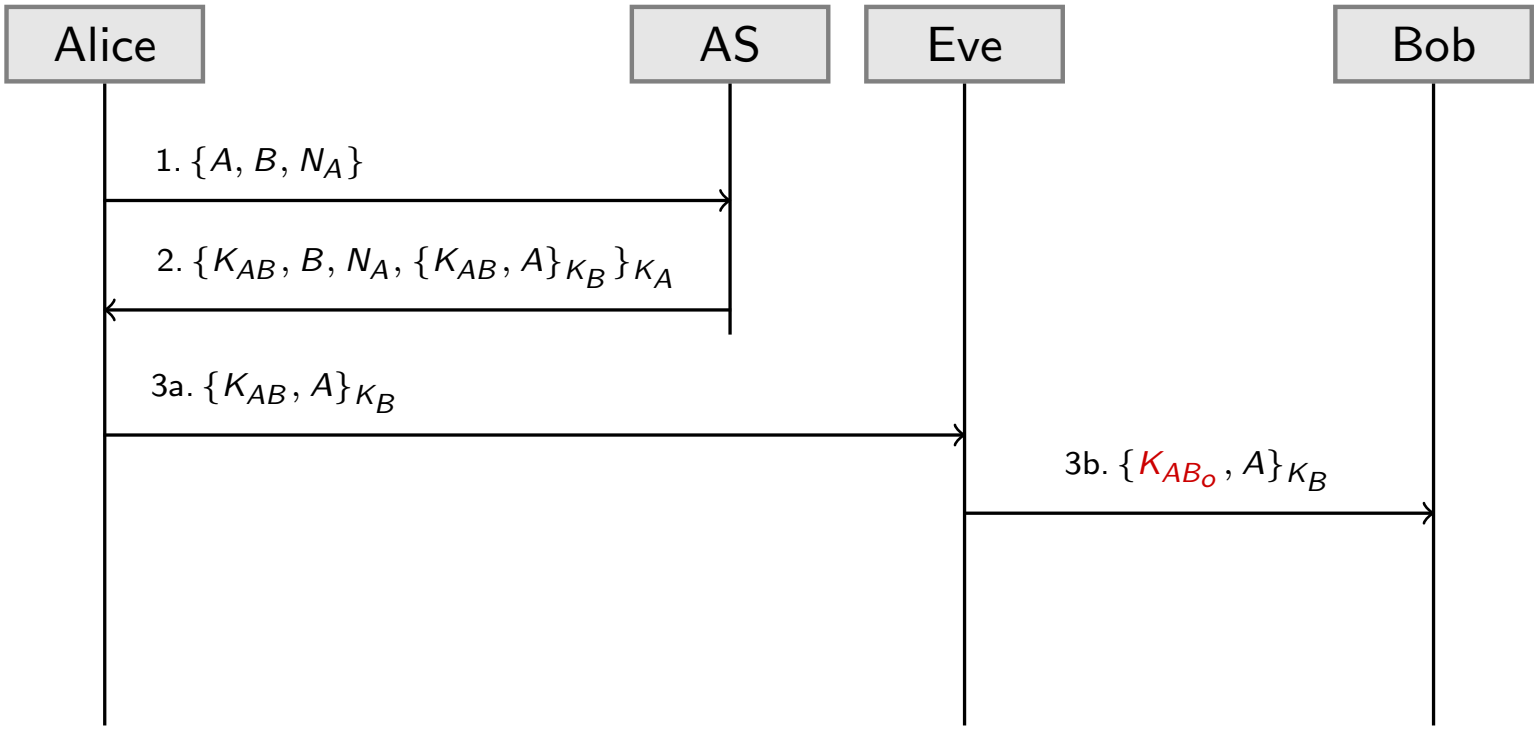

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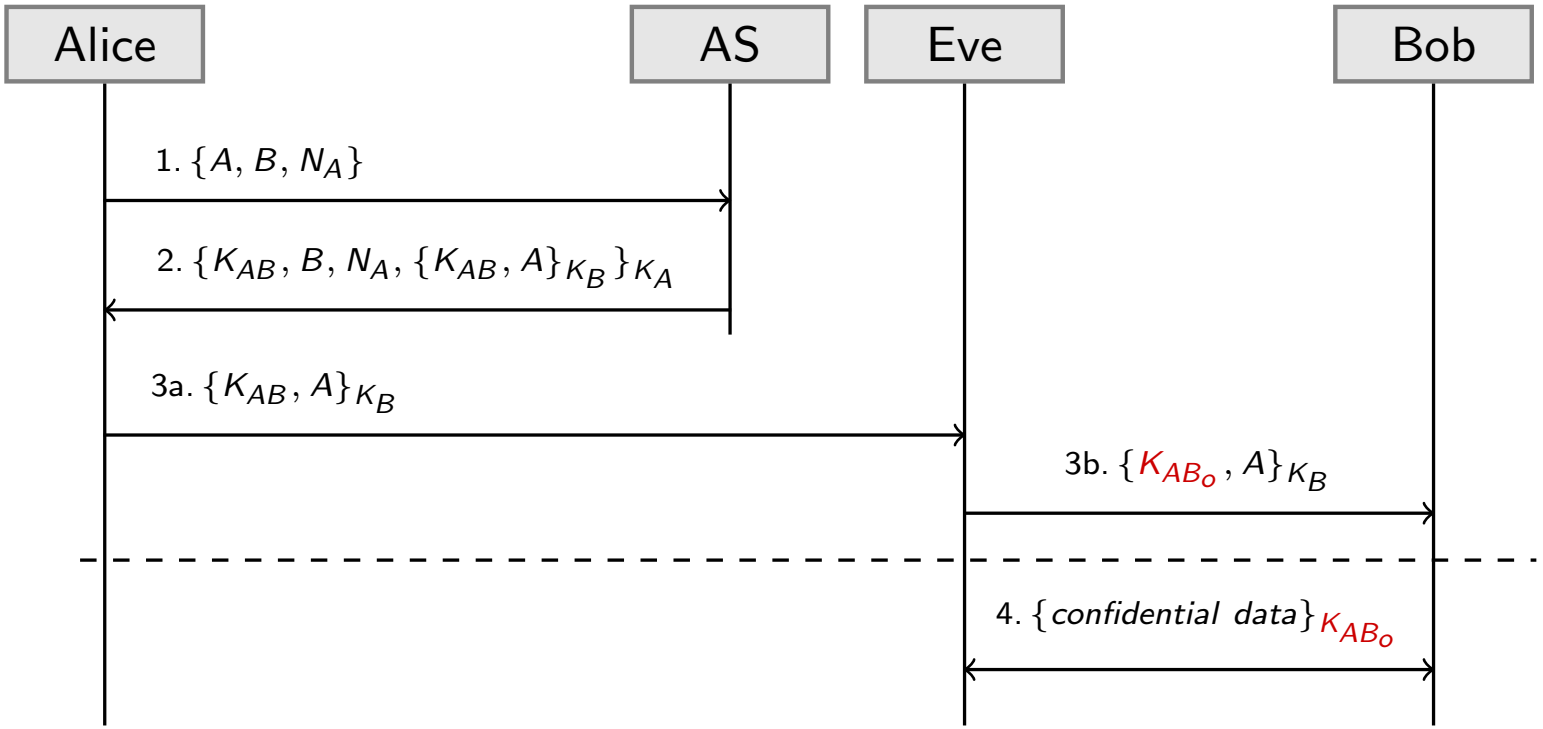

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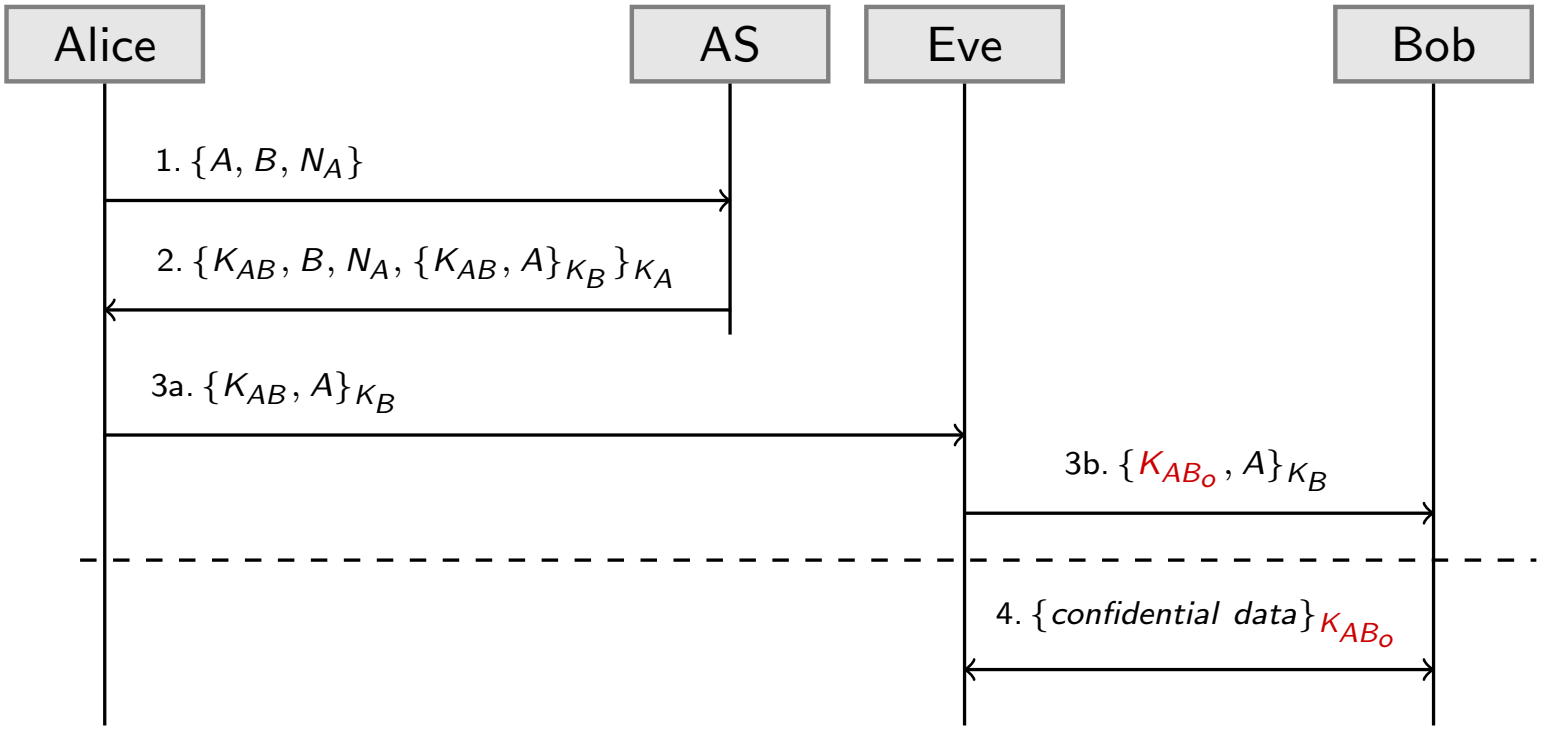
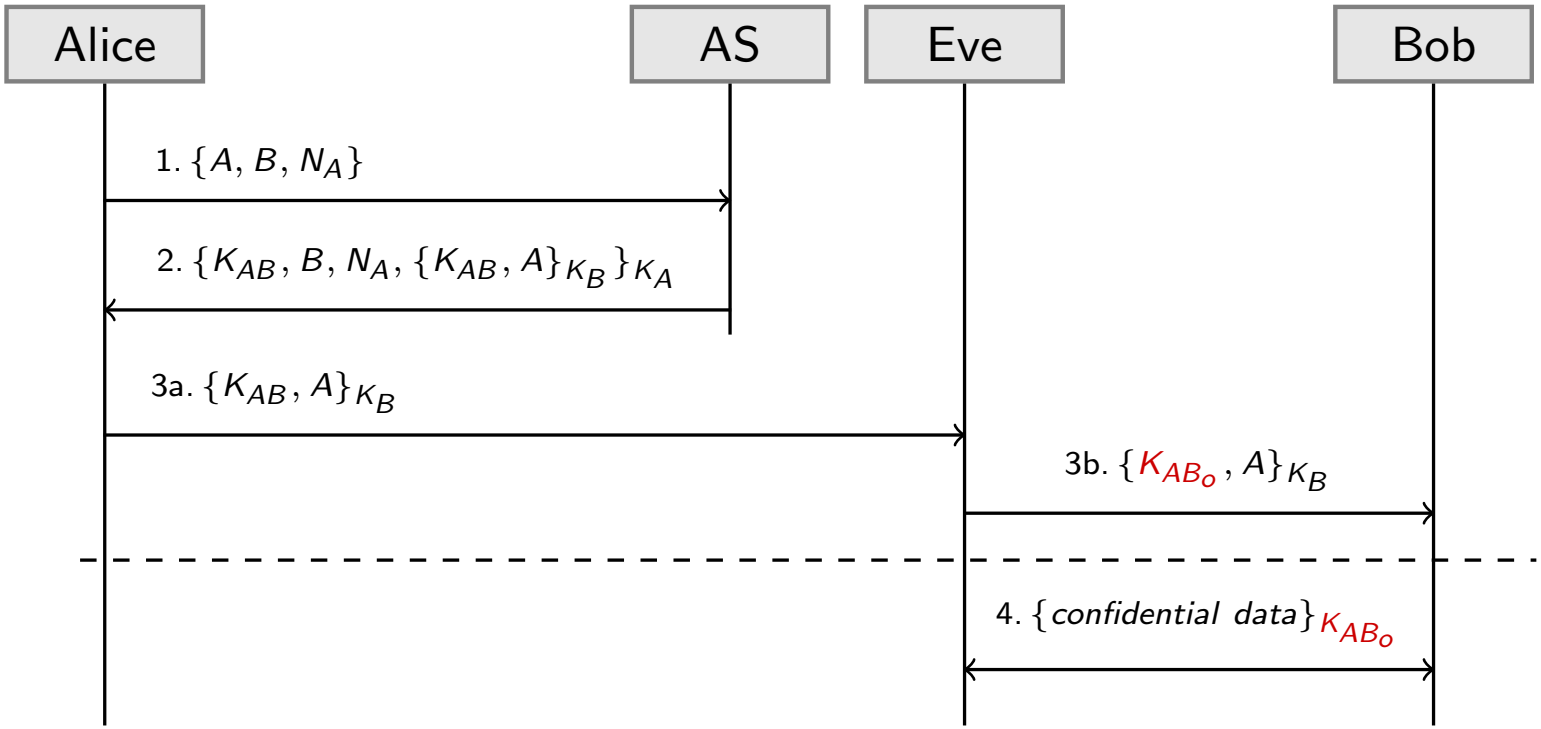


Assumption: Eve knows the old session key K_{AB_o} of Alice & Bob and also the corresponding ticket of Step 3b

Attack for Variant 3 of the symmetric NSP

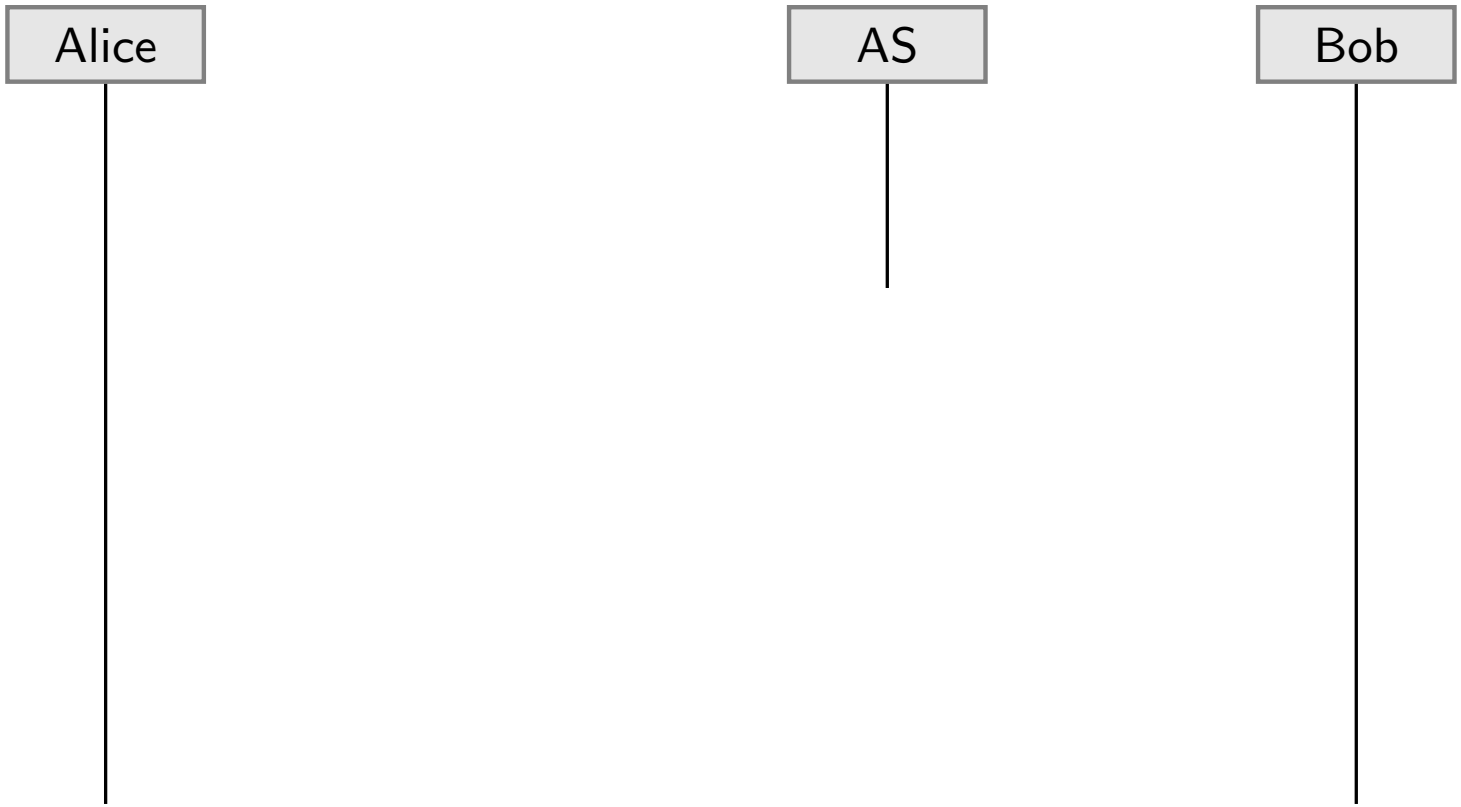


Assumption: Eve knows the old session key K_{AB_o} of Alice & Bob and also the corresponding ticket of Step 3b

➜ How can this replay attack against Bob be prevented?

Specify a man-in-the-middle and a replay attack for the NSP example.

Variant 4: Symmetric NSP with Handshake



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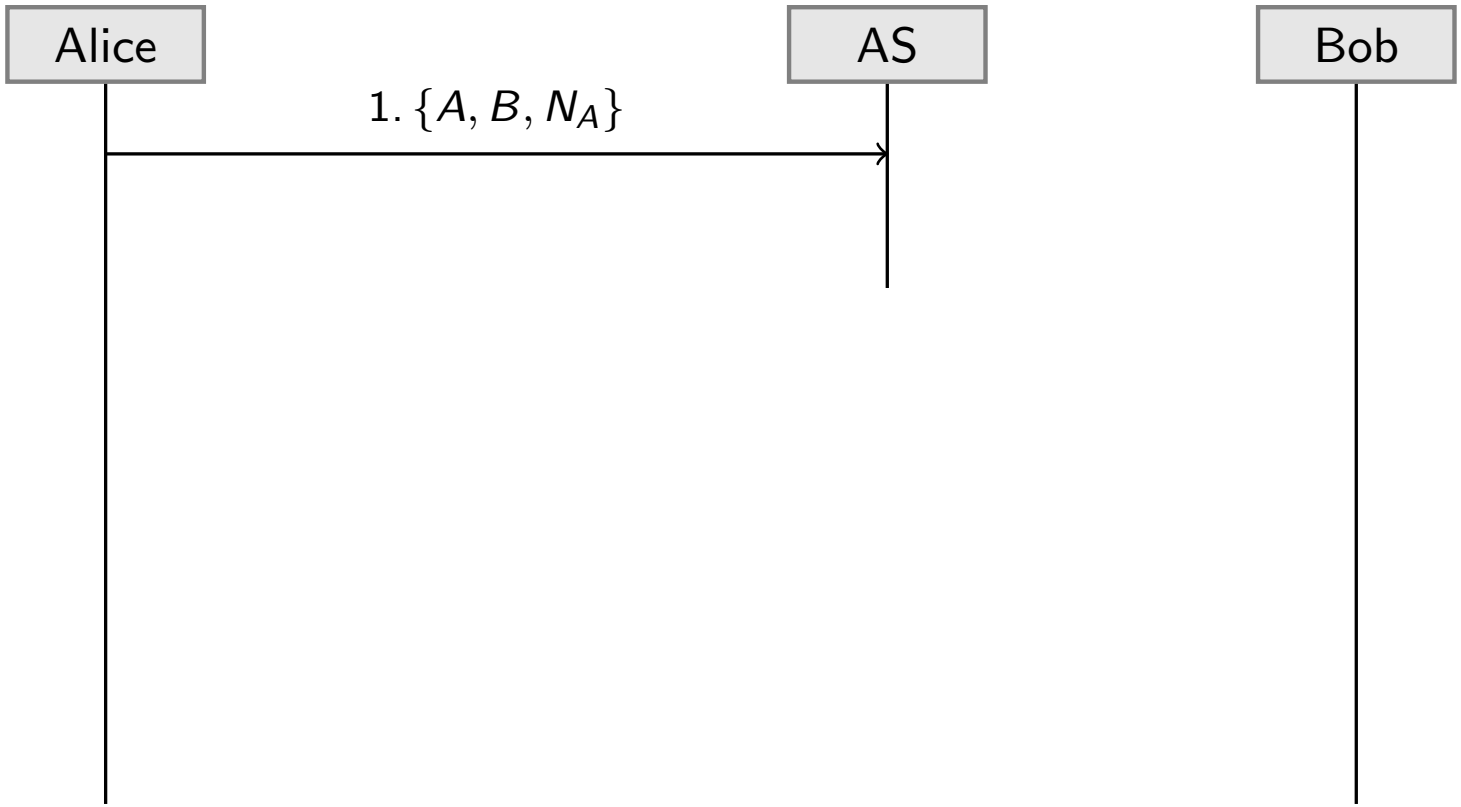

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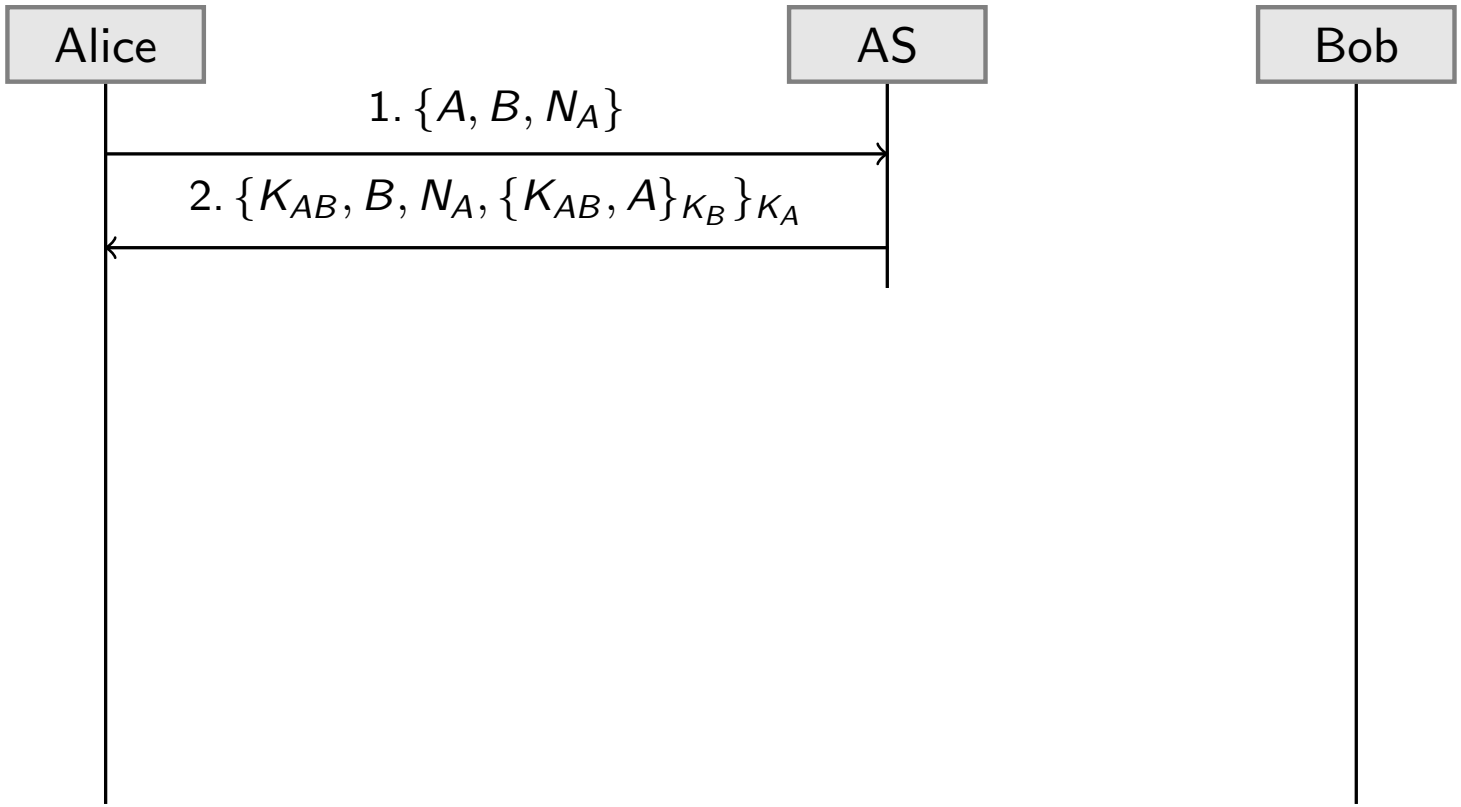

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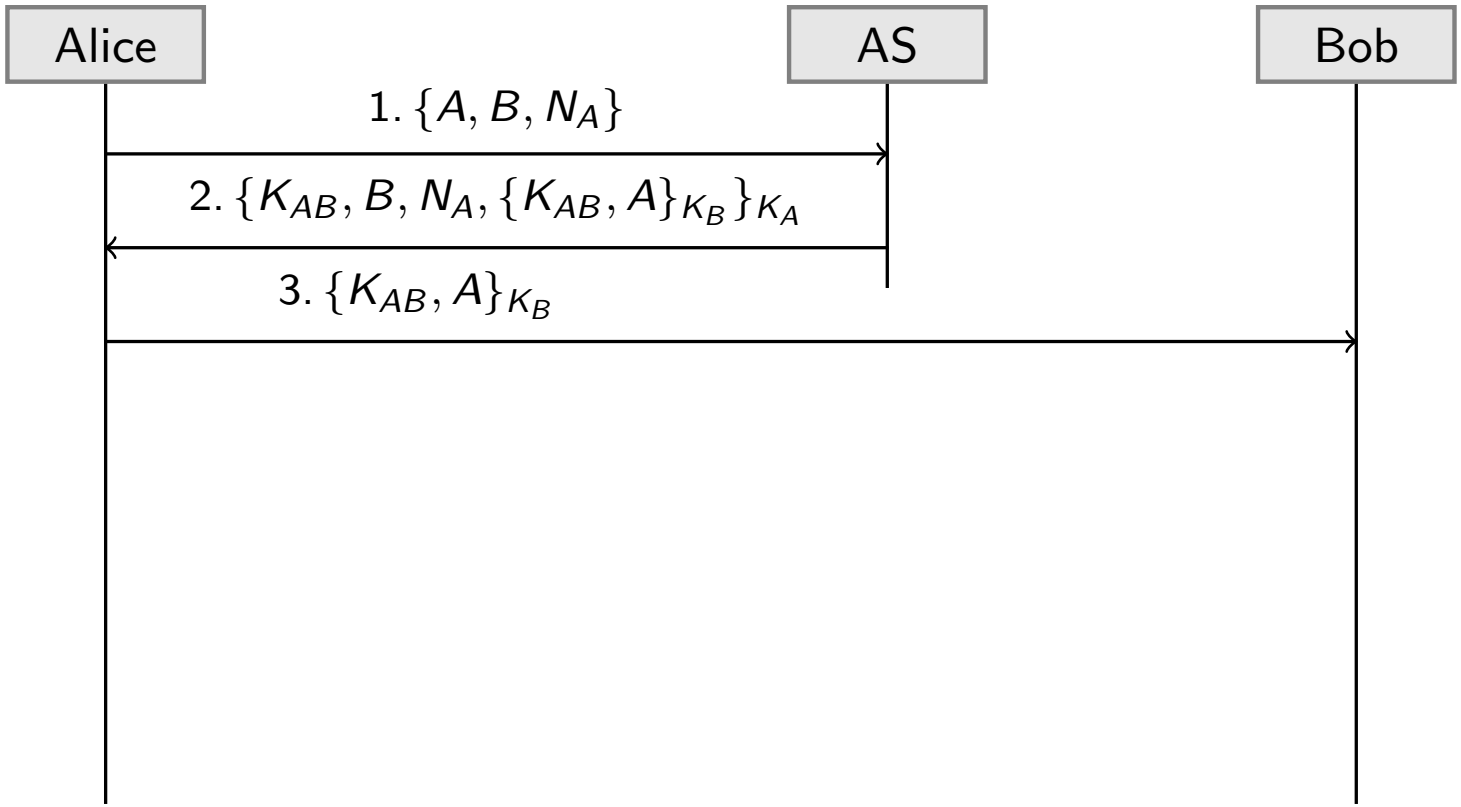

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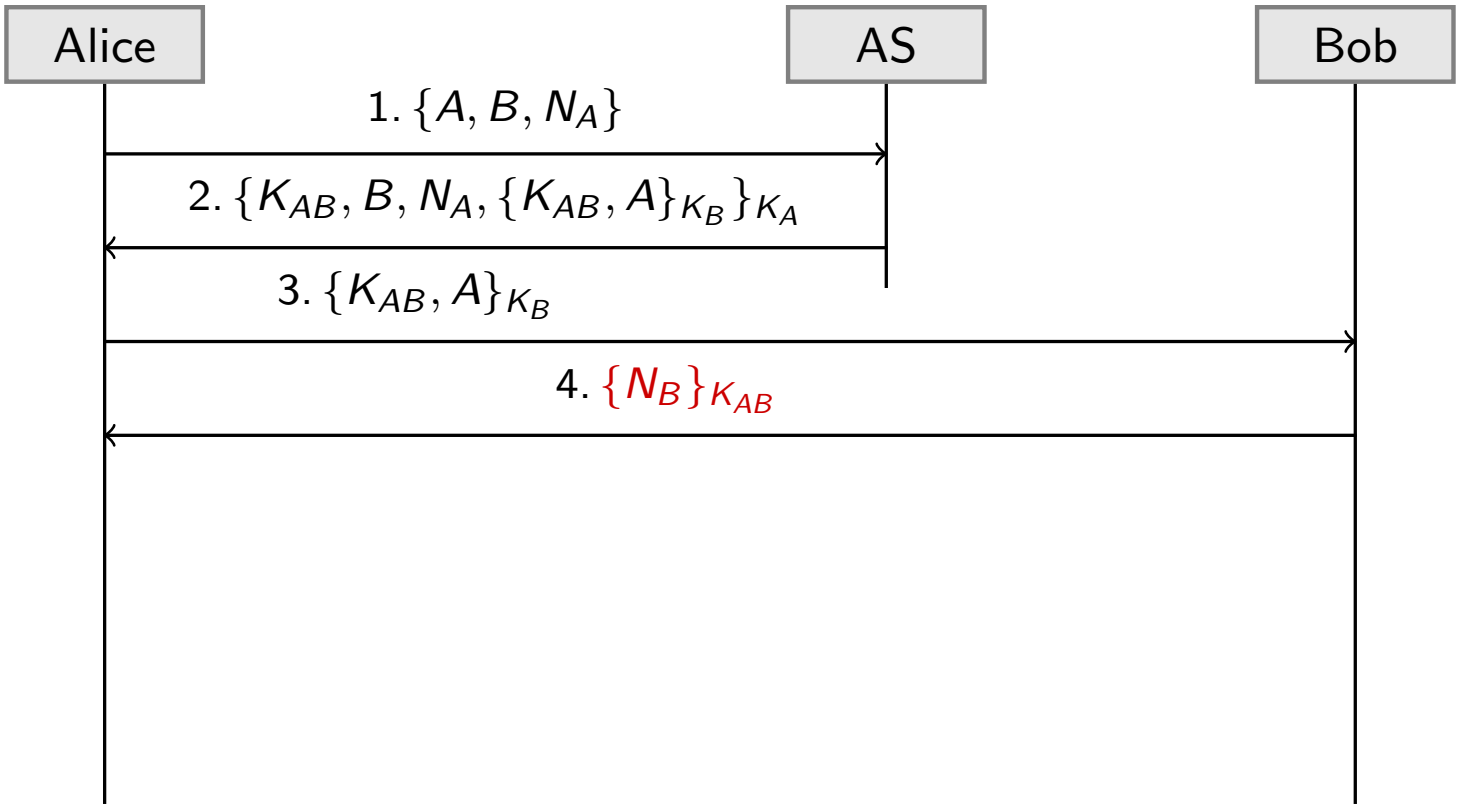

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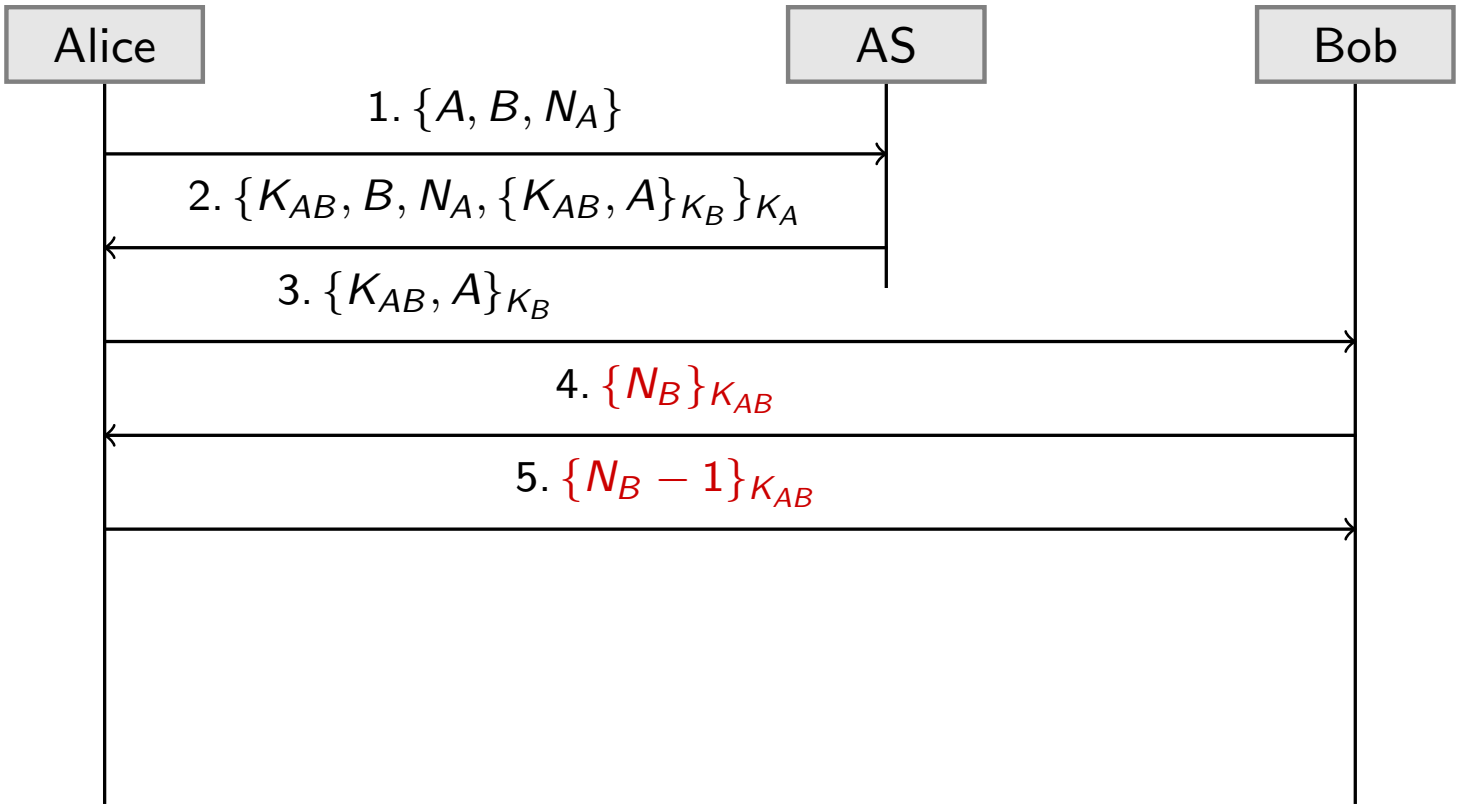

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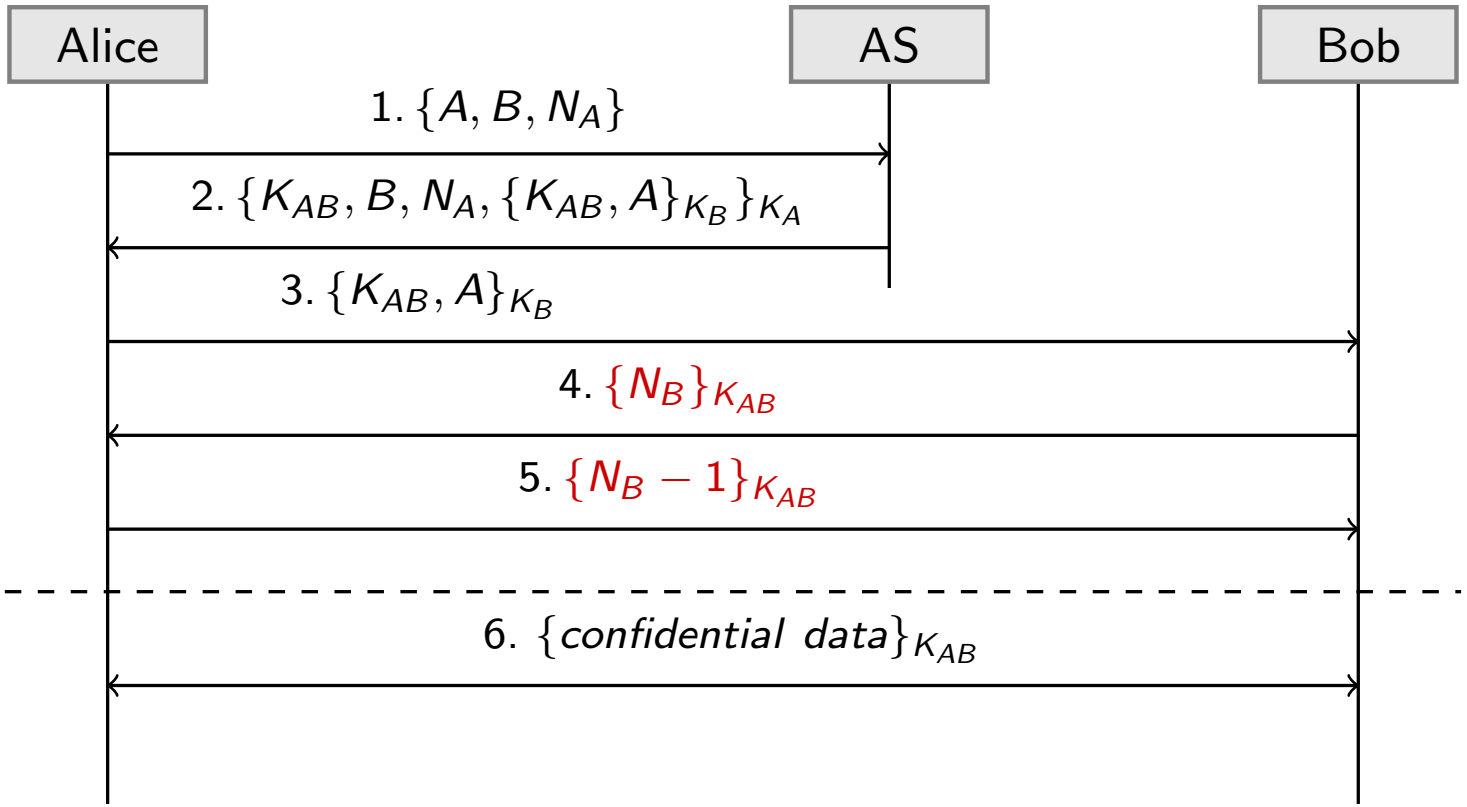

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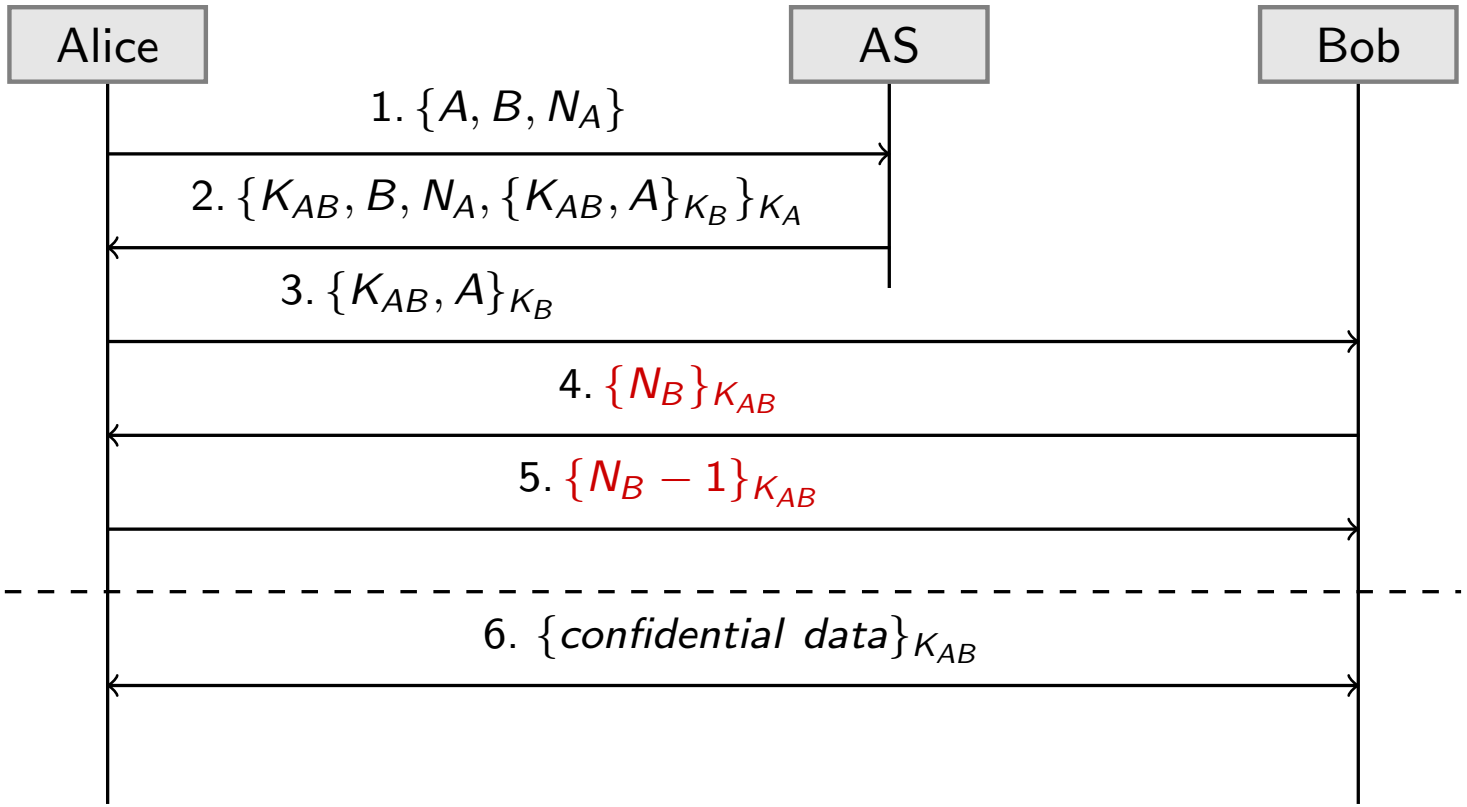
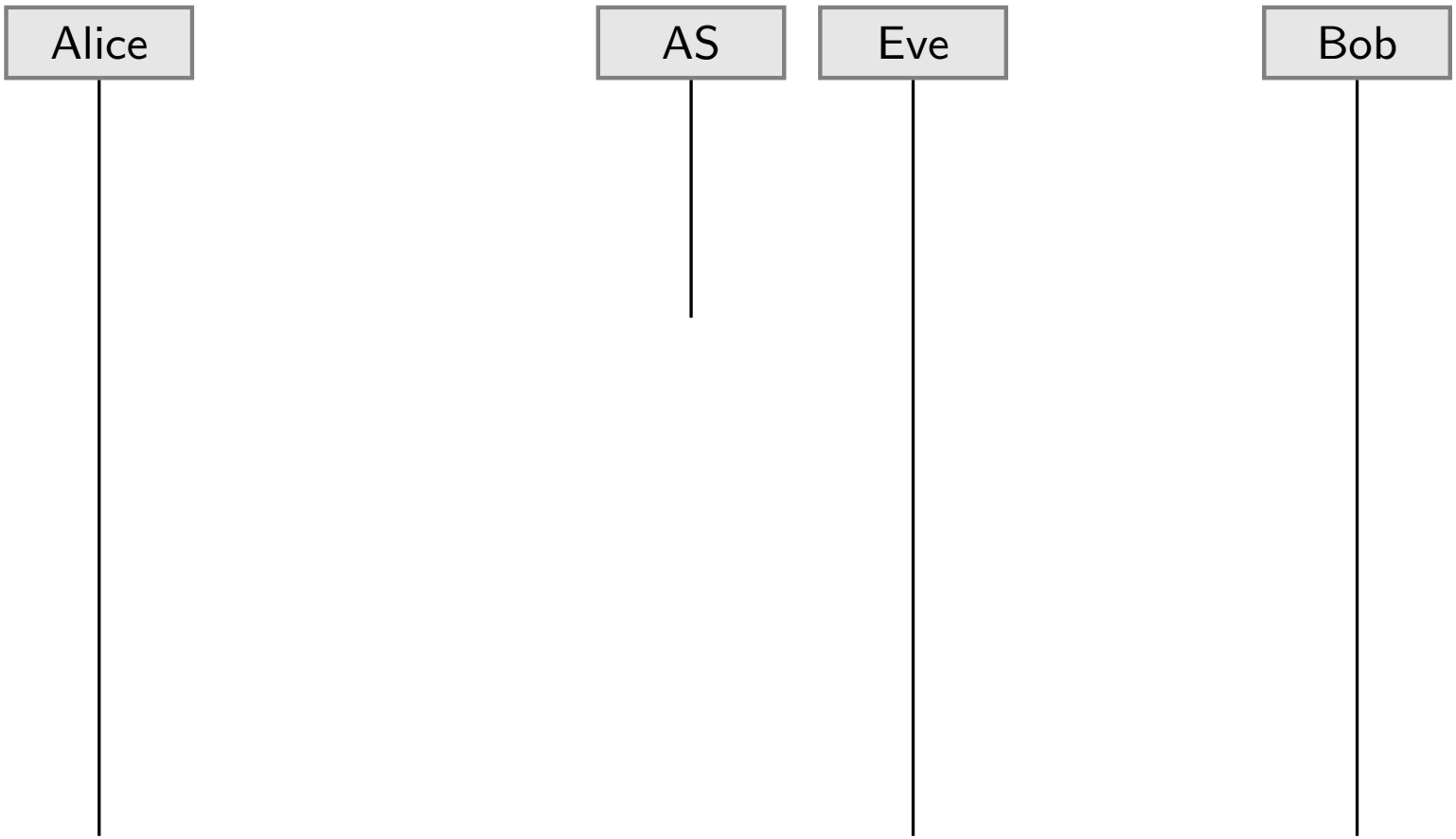


The handshake implemented in the original NSP does *not offer* Bob additional protection against replay attacks! Why?

Attack of Variant 4 of the Symmetric NSP



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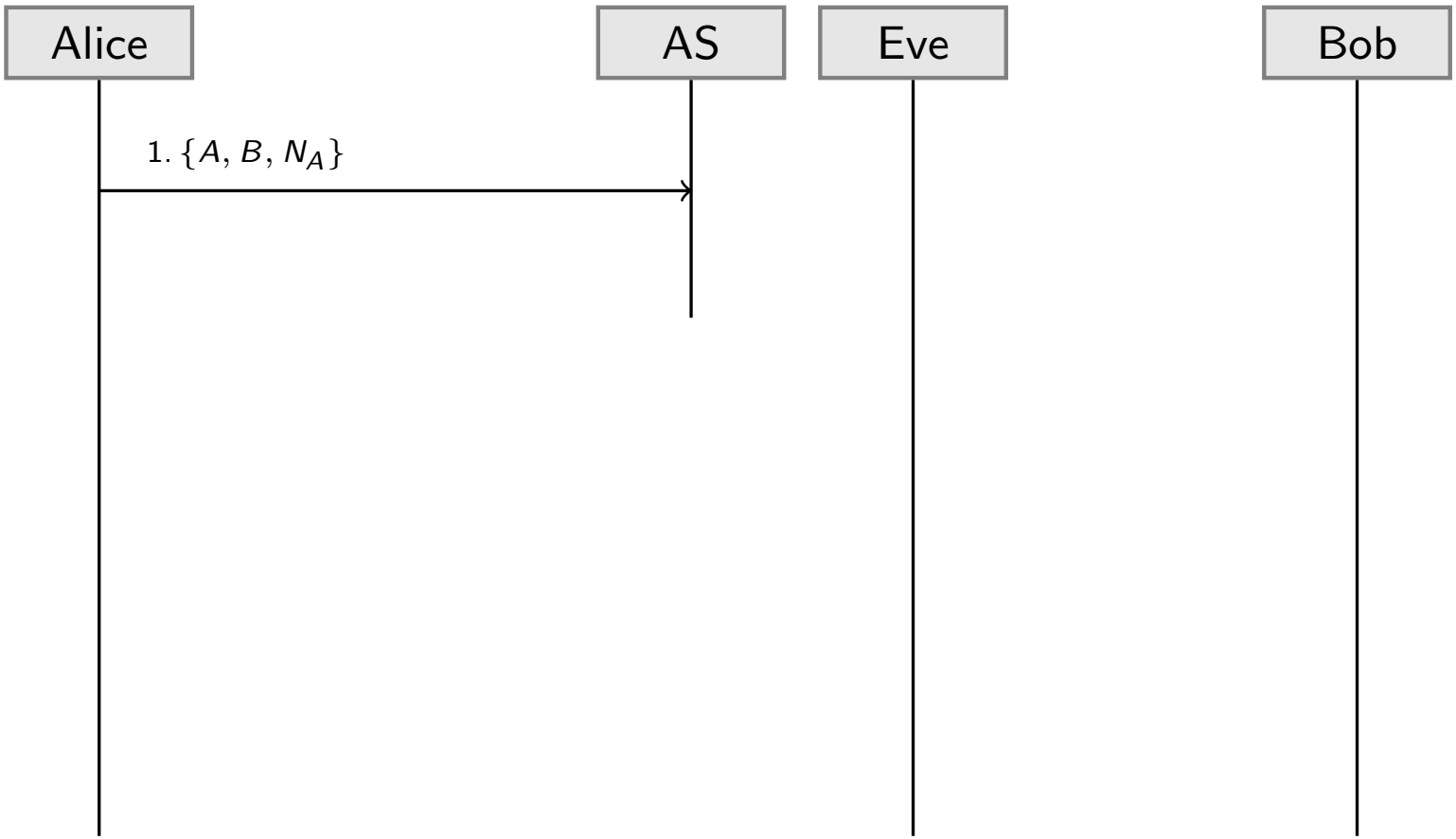

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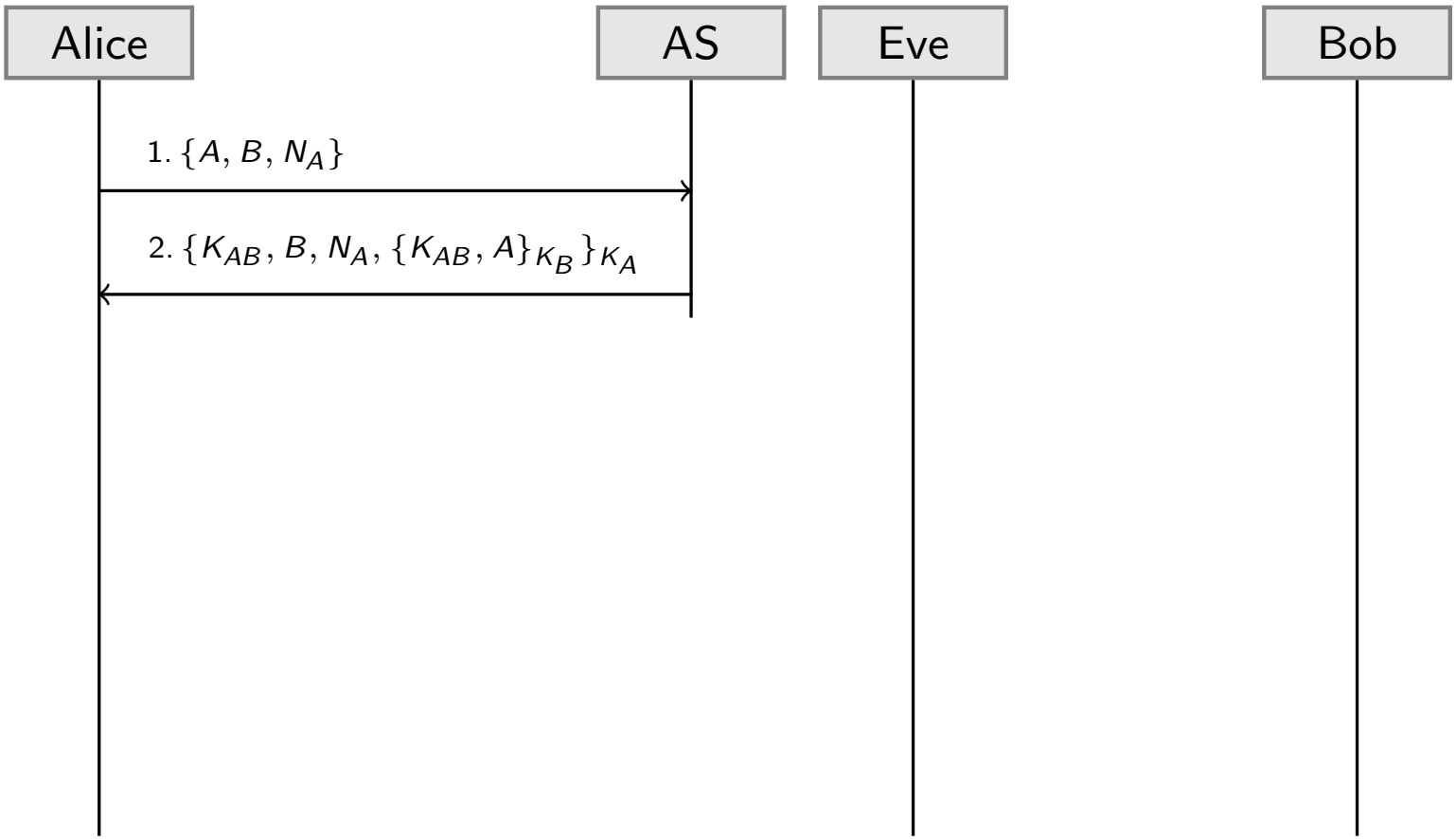

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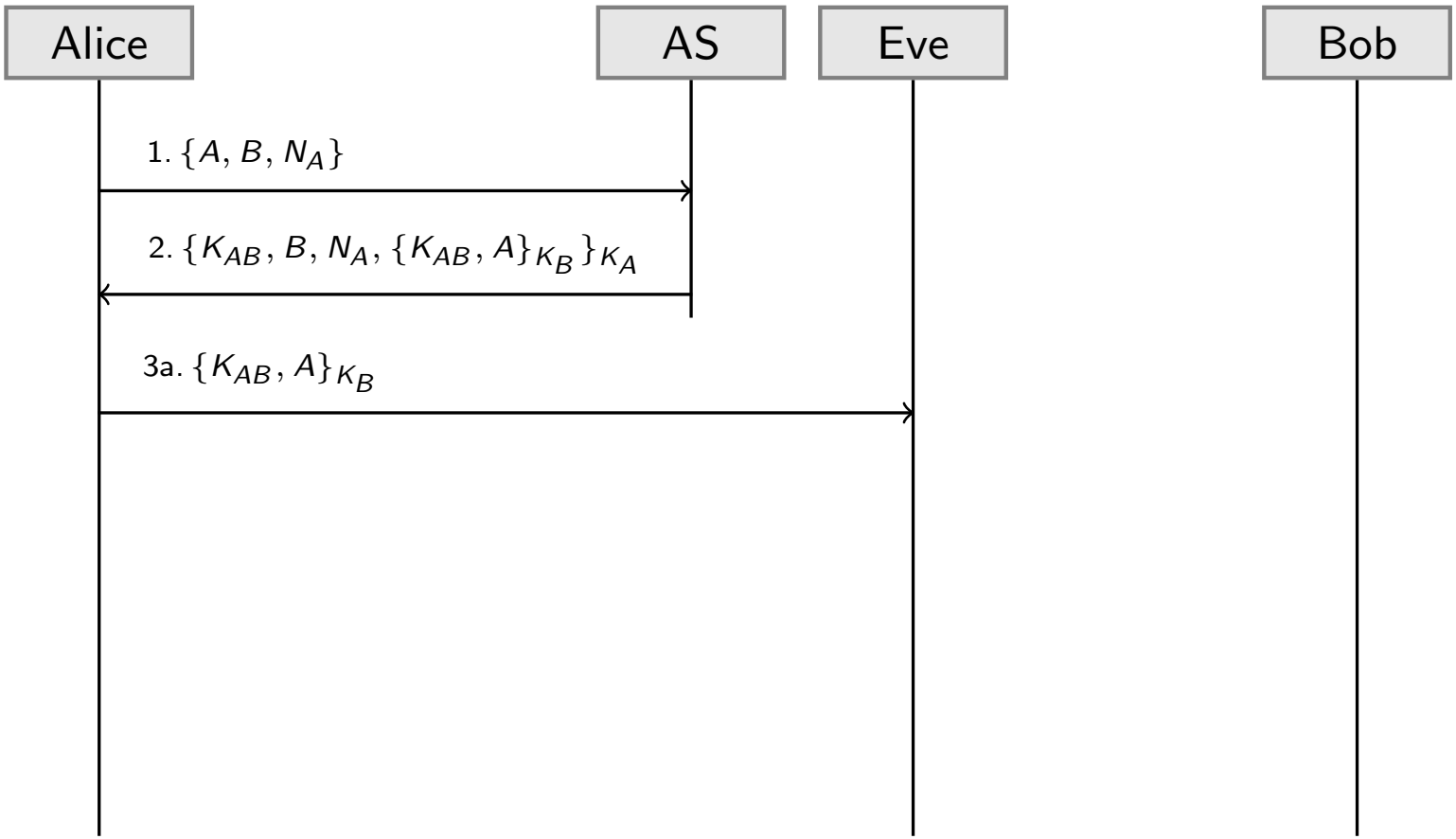

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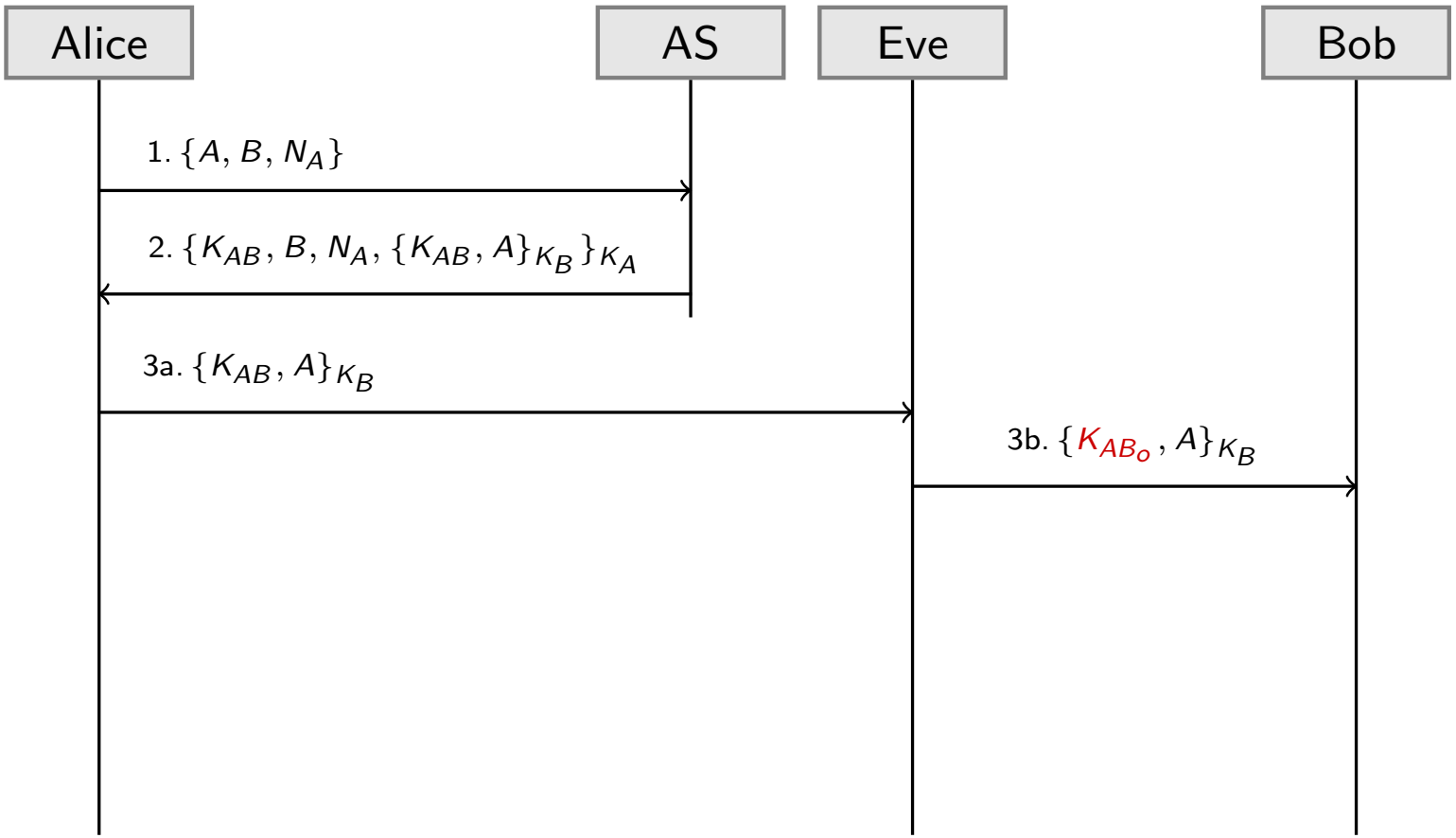

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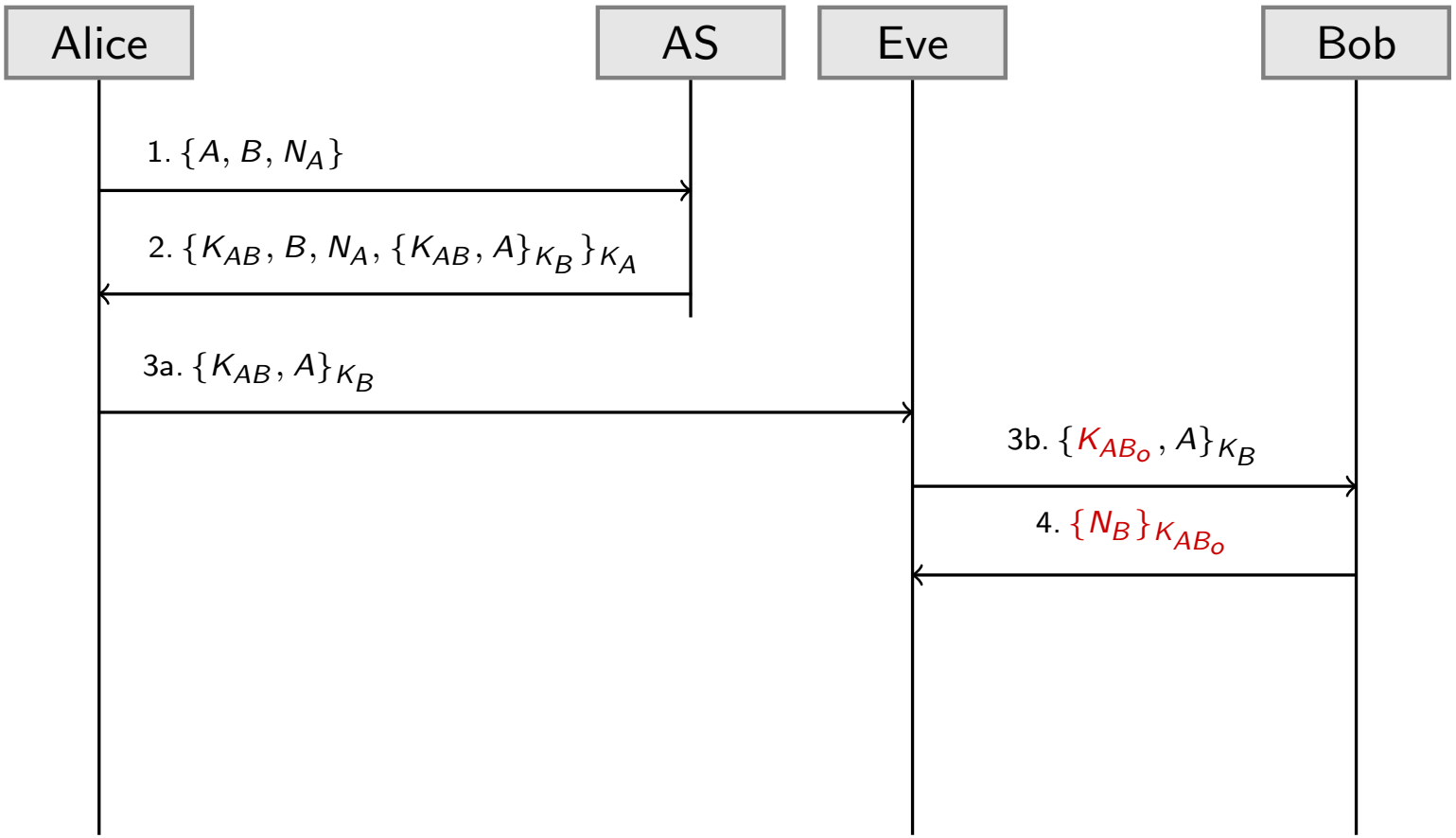

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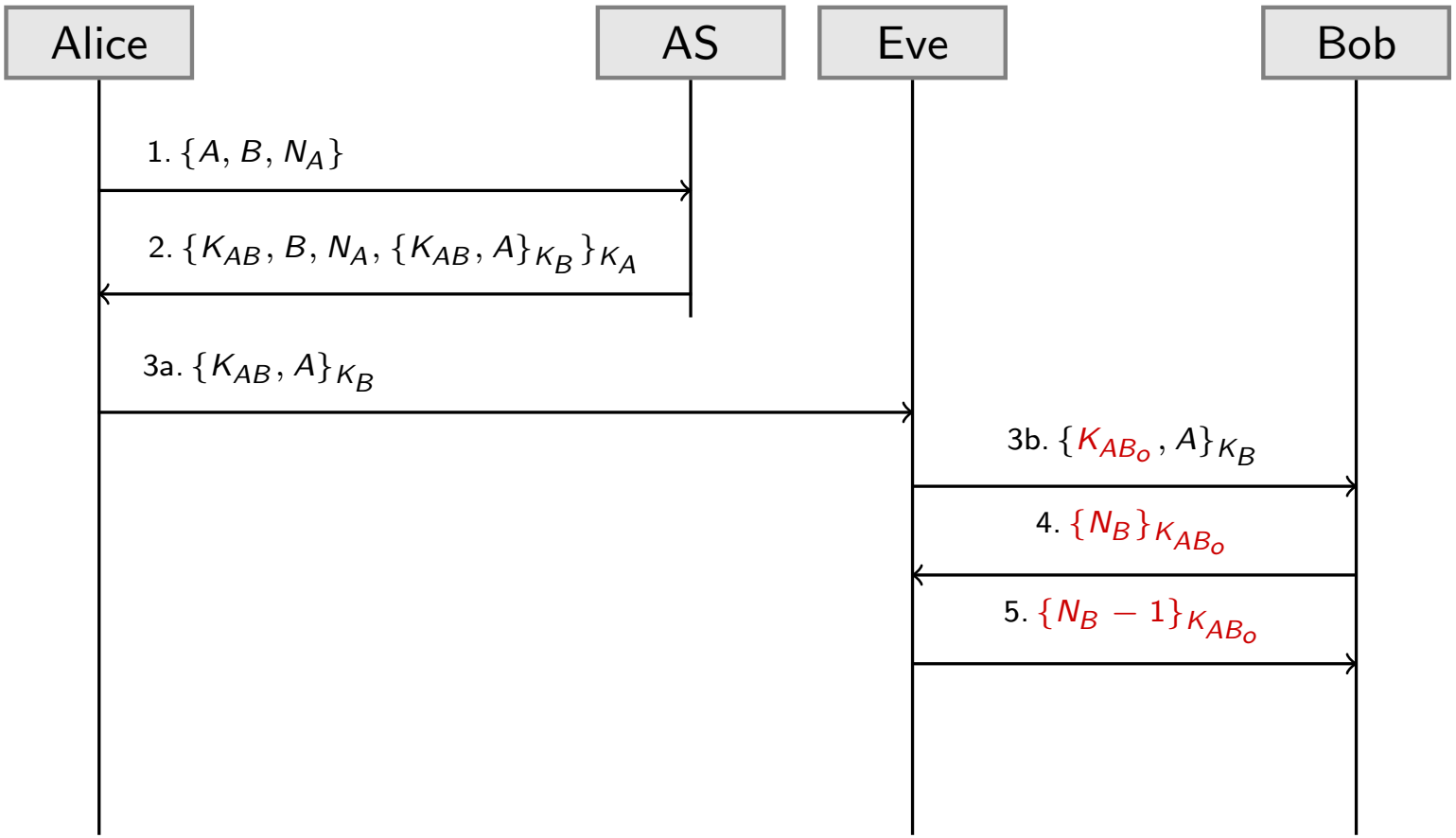

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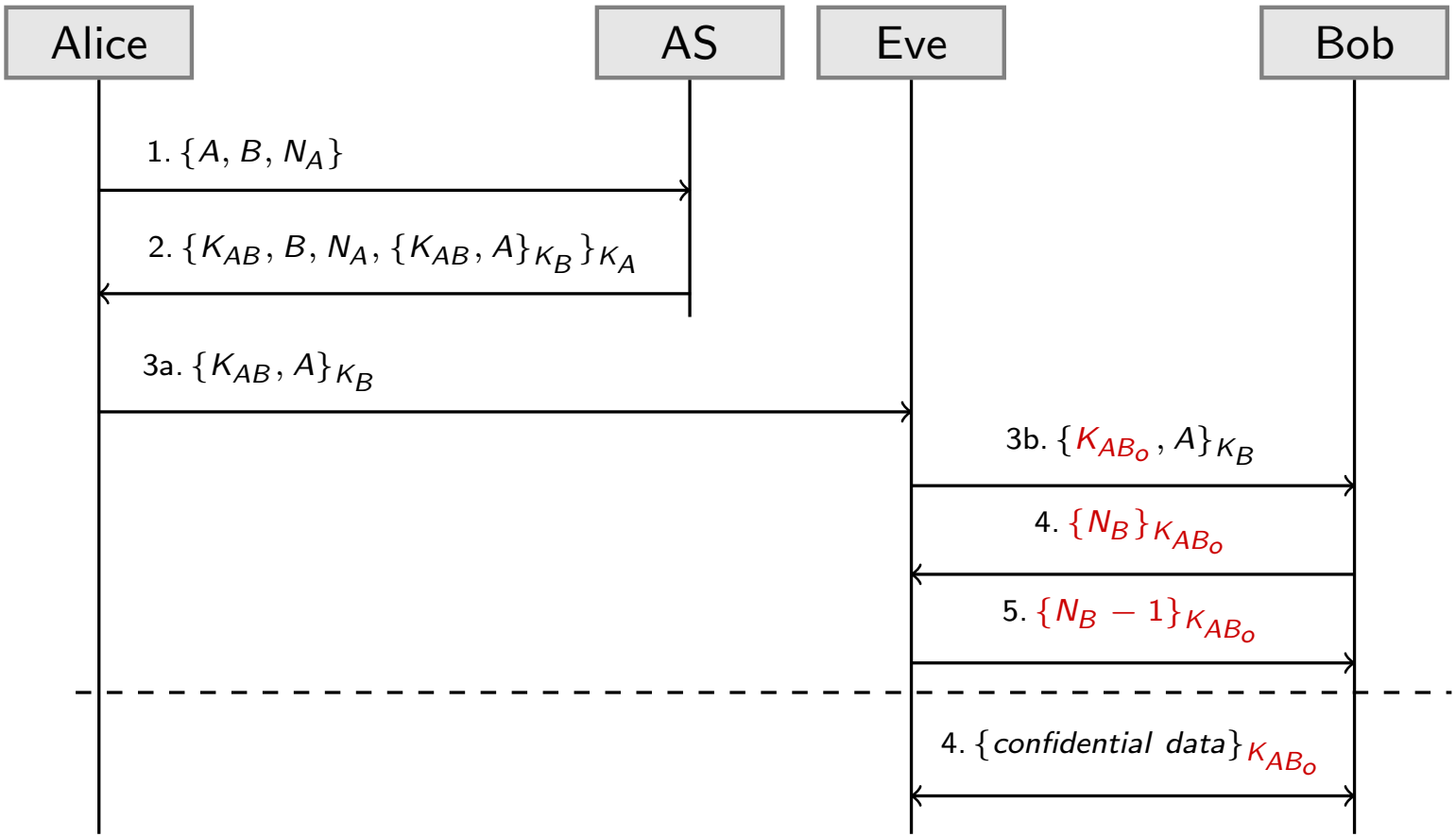

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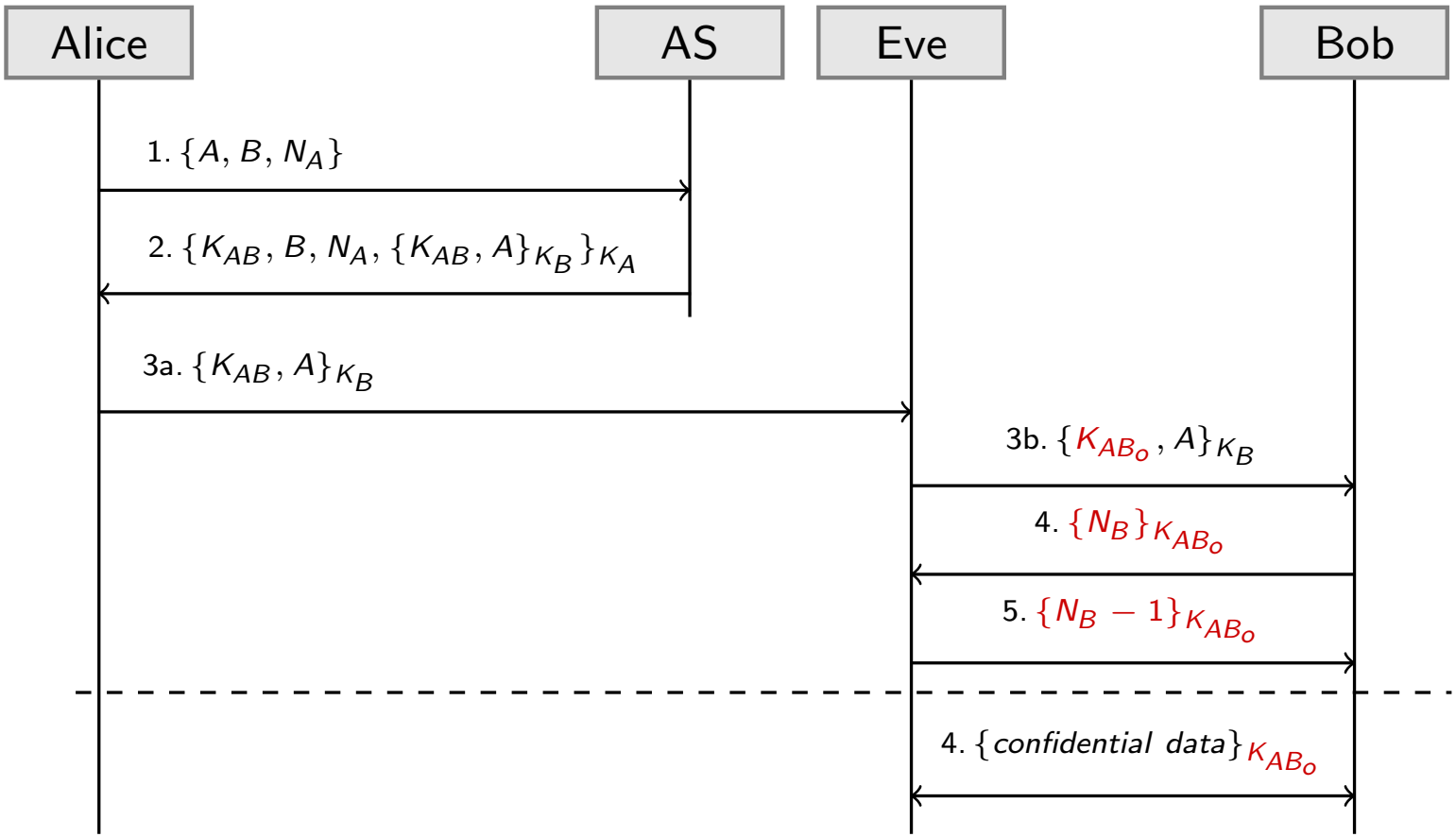
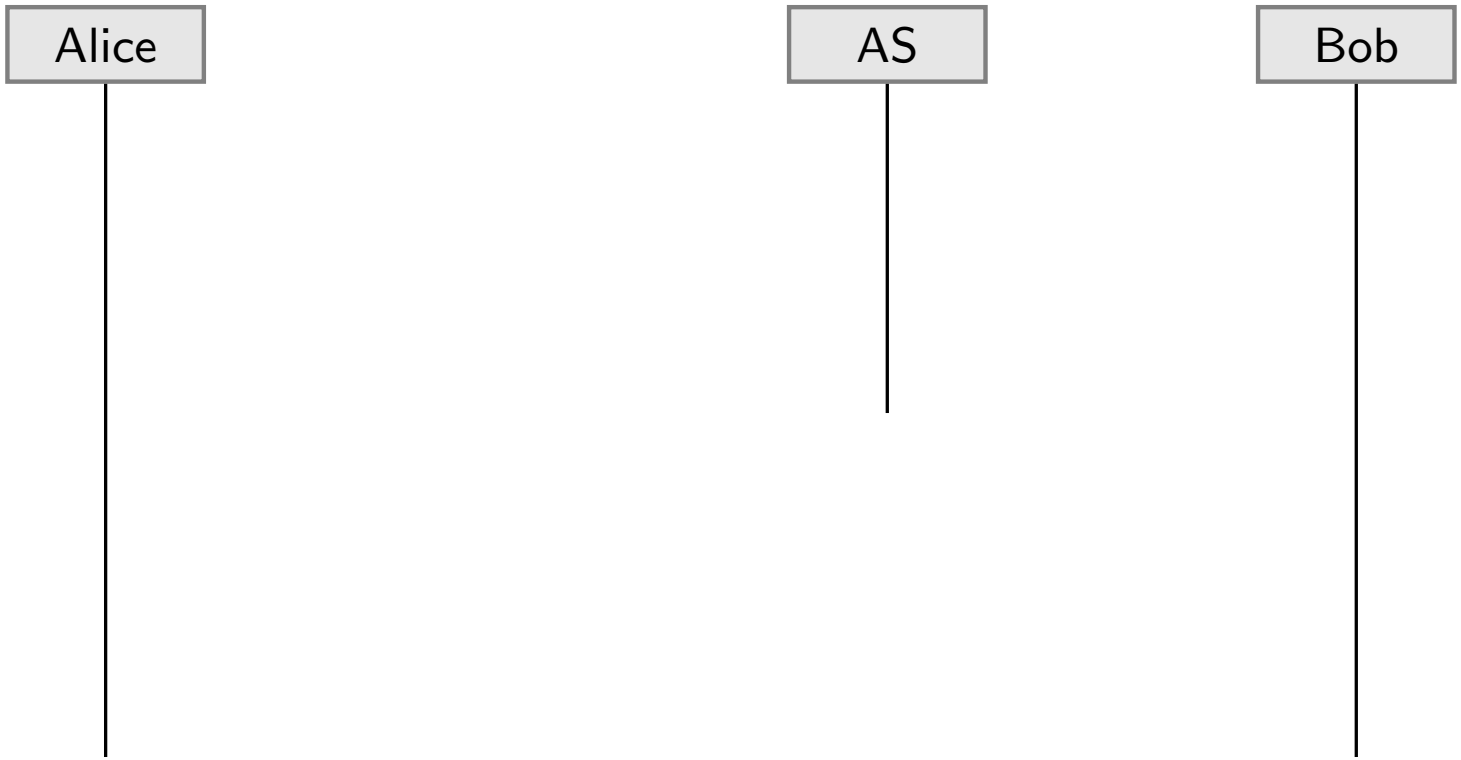


How to uncover the replay attack against Bob?

Variant 5: Symmetric NSP & Time Stamps



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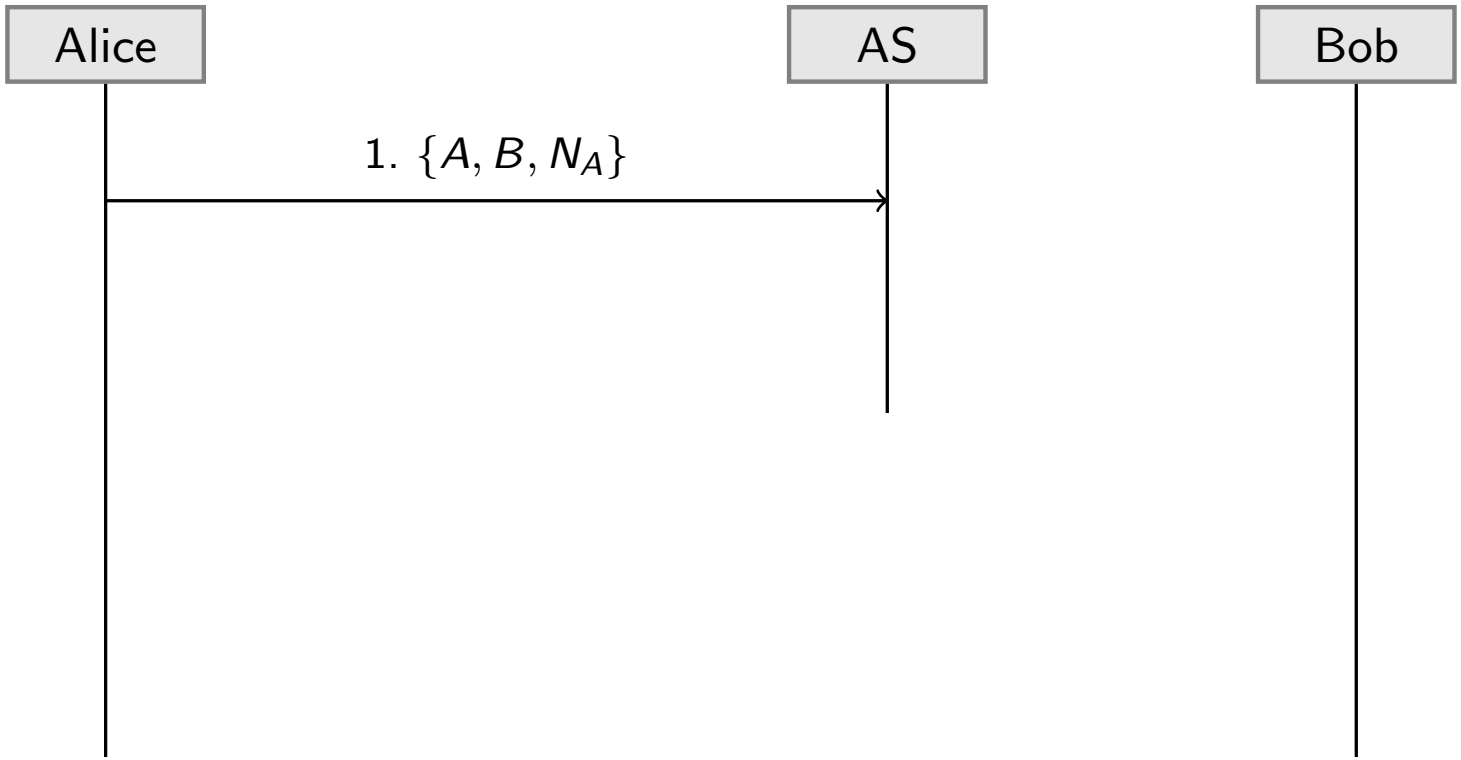

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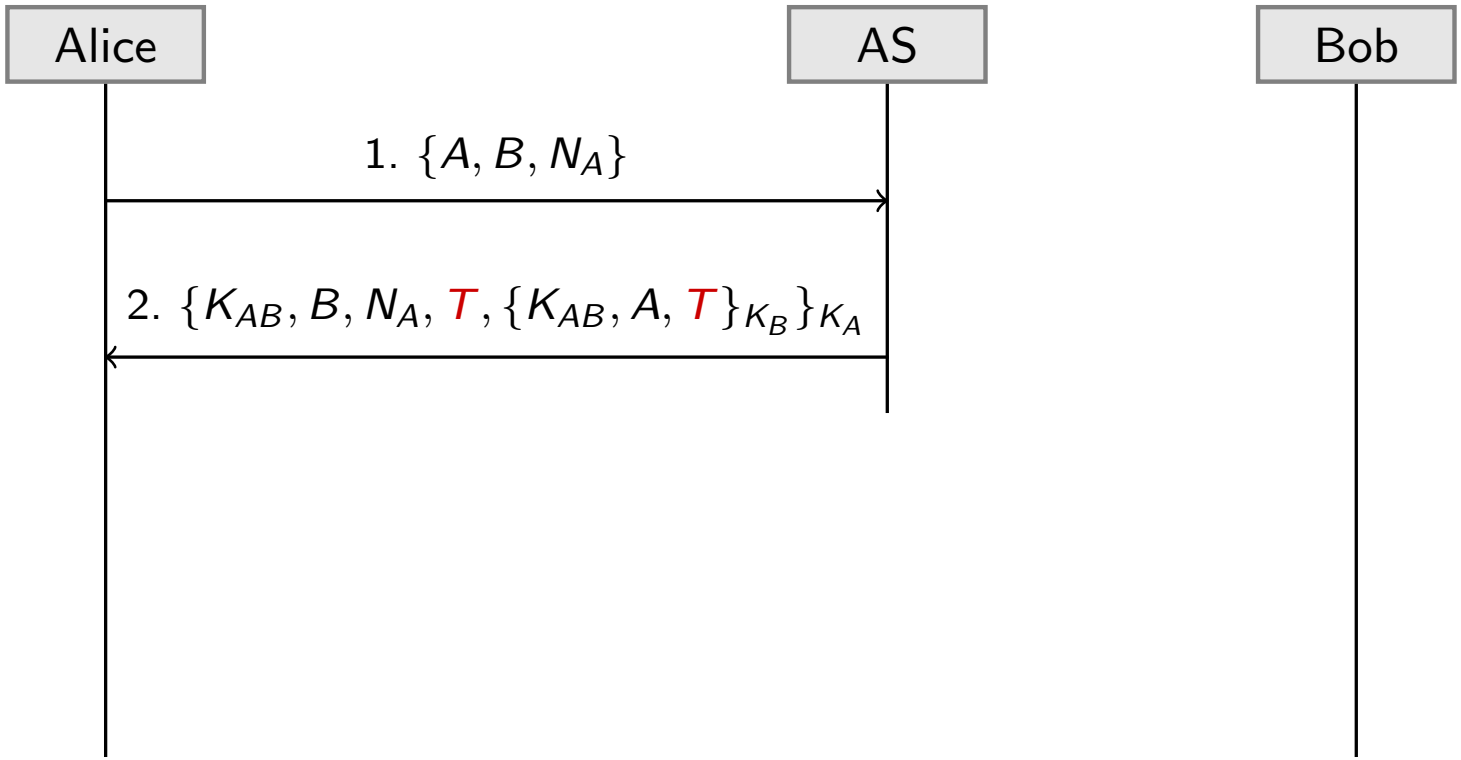

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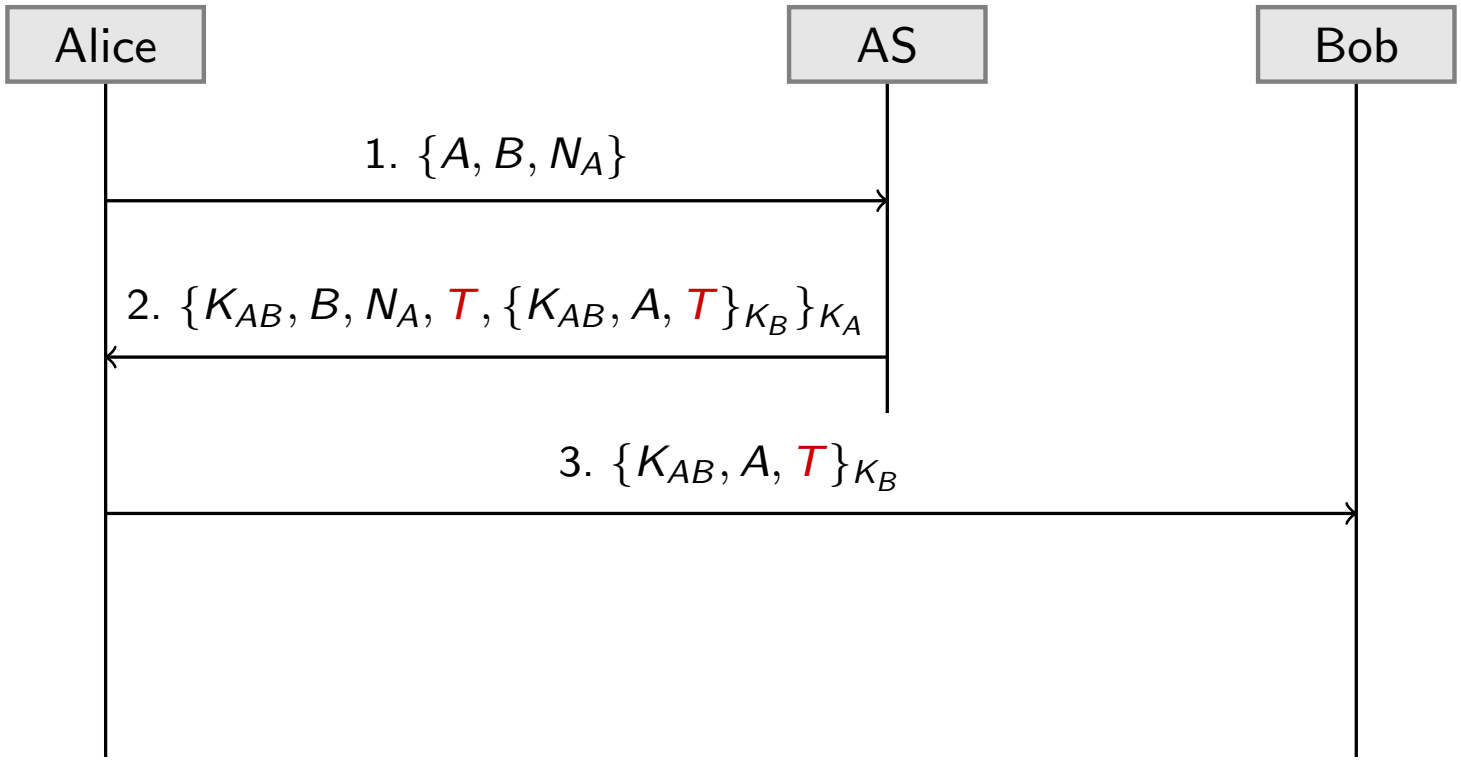

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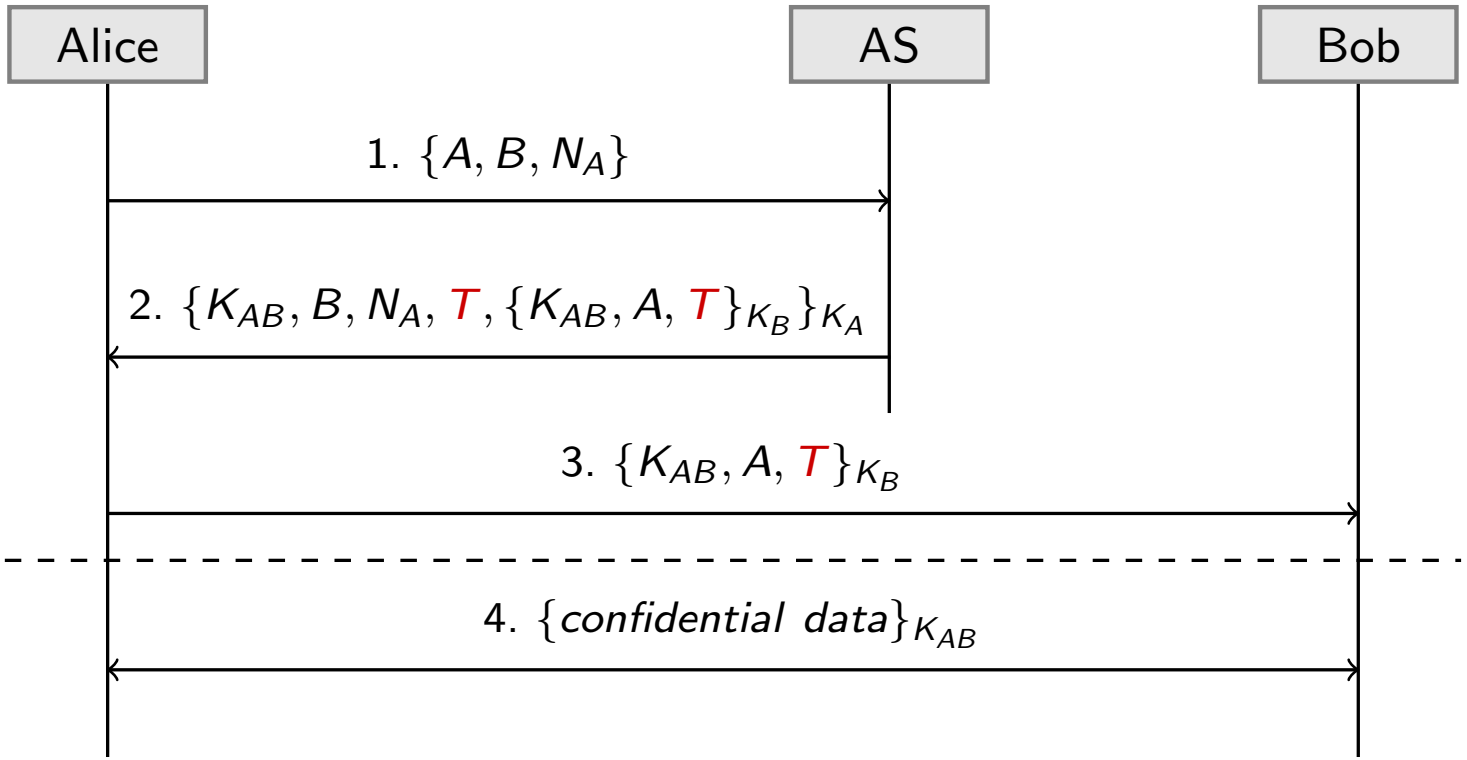

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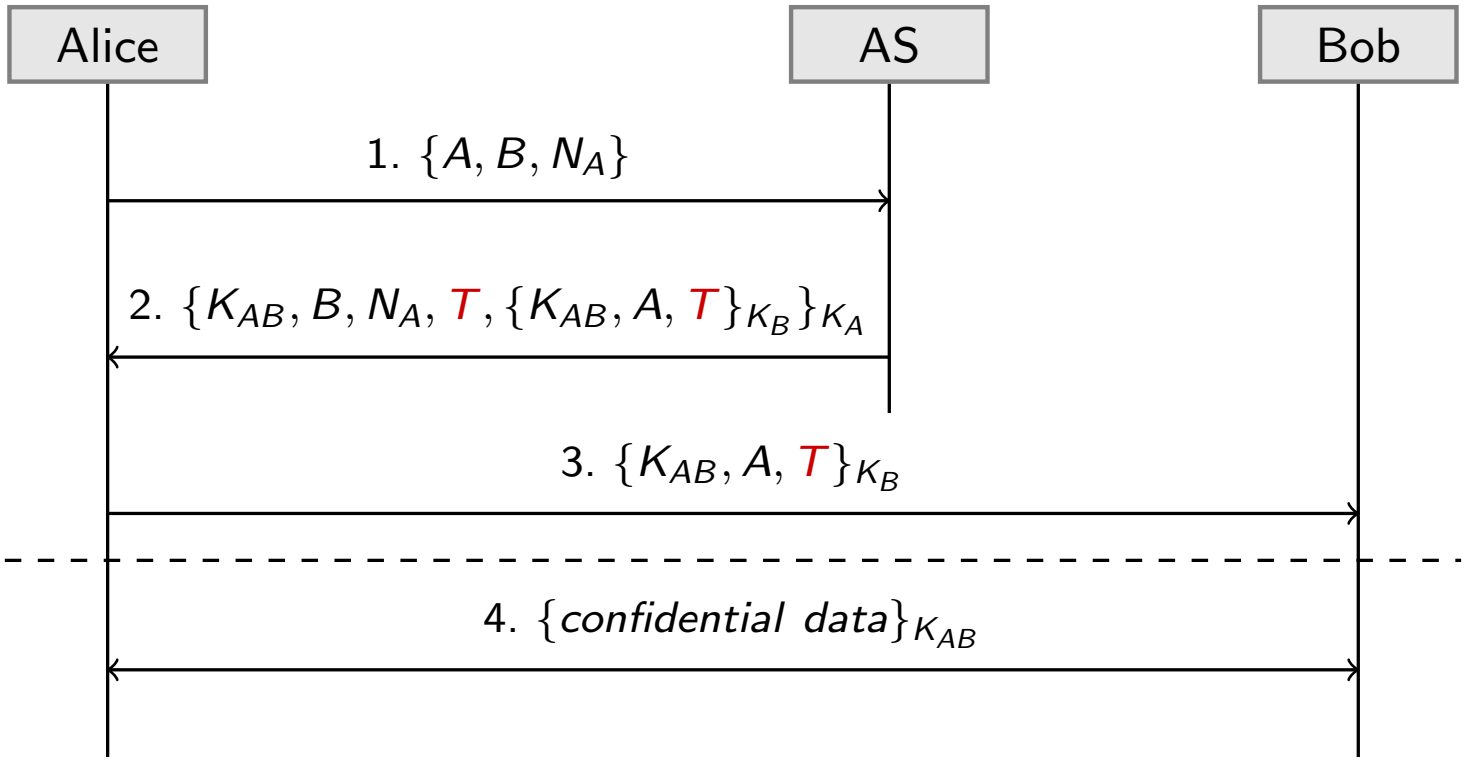

A time stamp T gives information about the freshness of tickets and enables Bob to detect replay attacks

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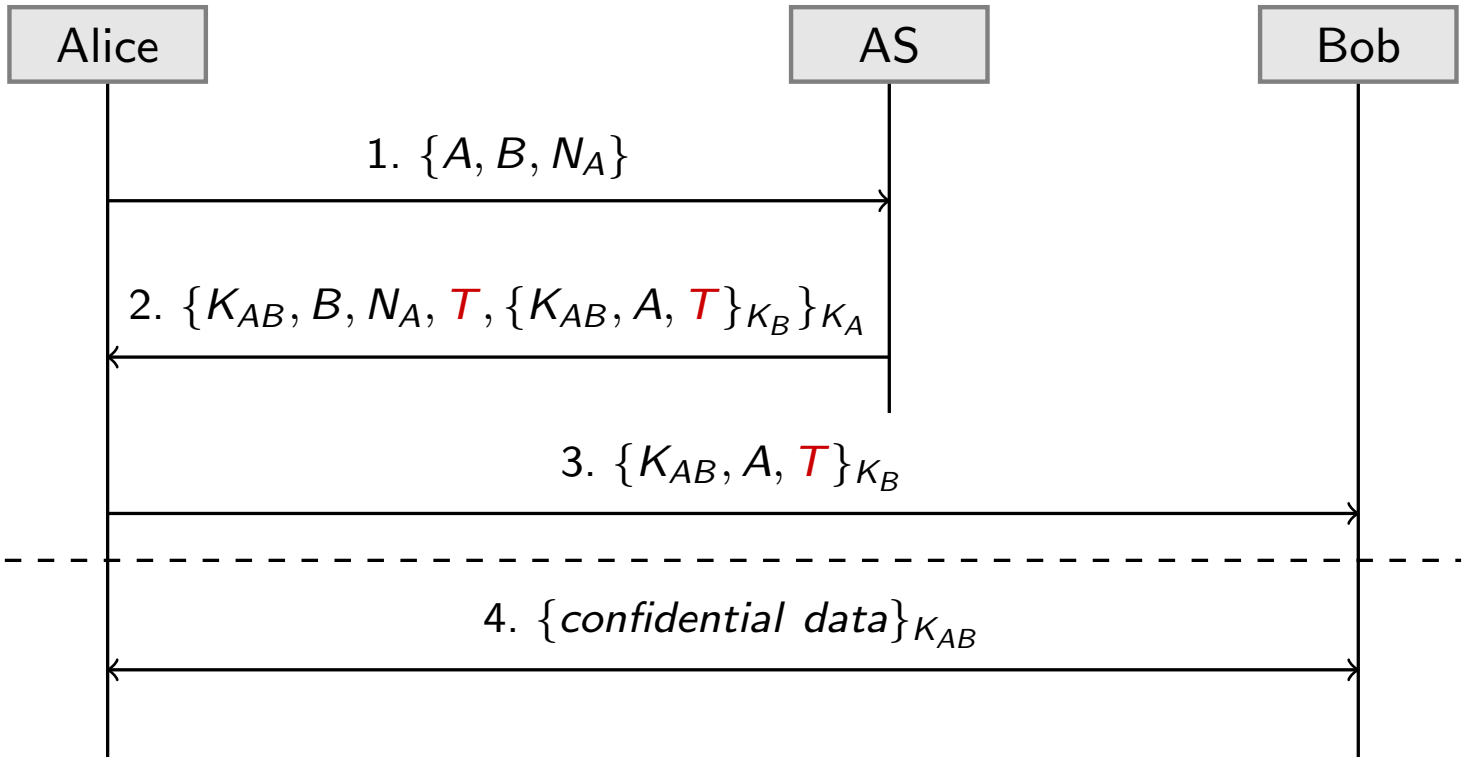

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➜ Is Bob protected now?

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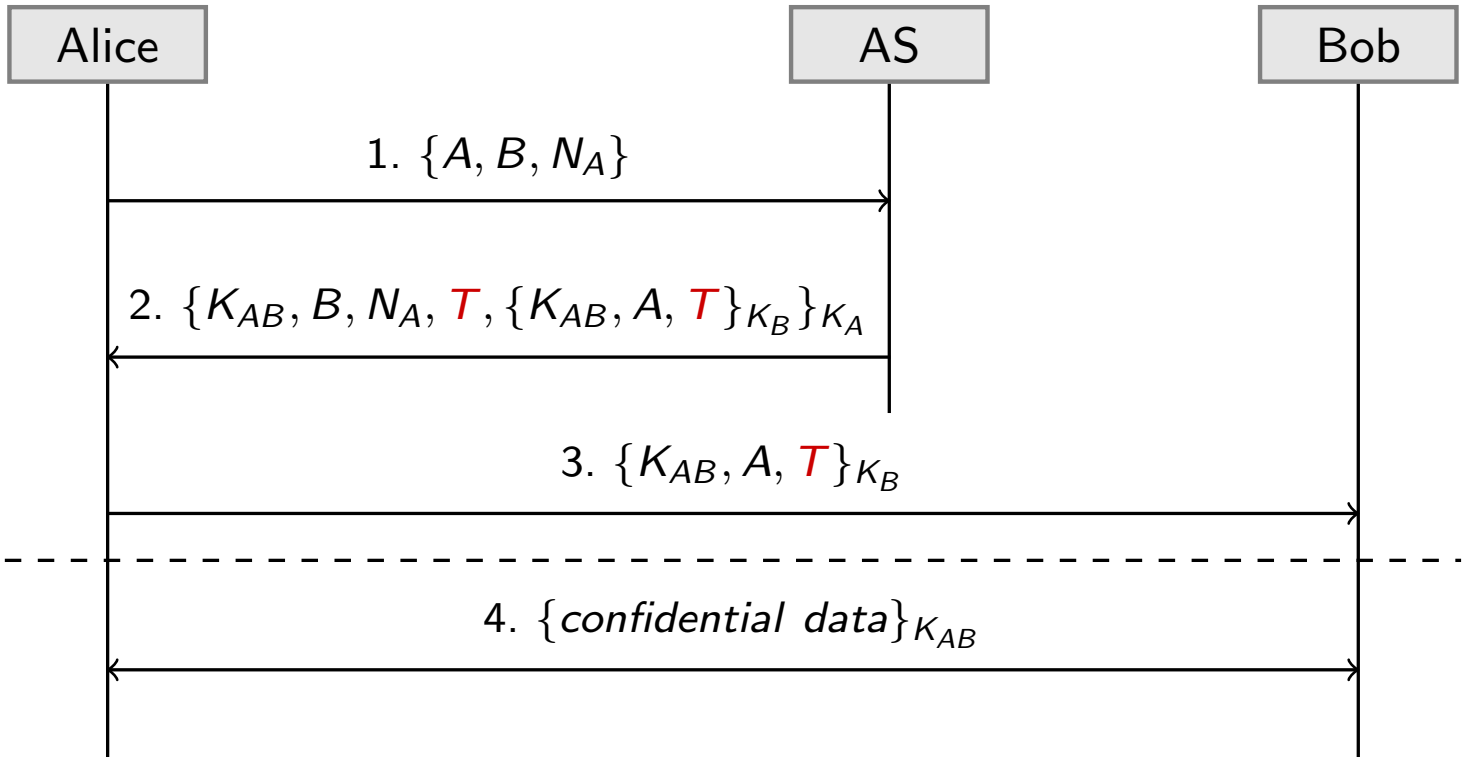


A time stamp T gives information about the freshness of tickets and enables Bob to detect replay attacks

➜ Is Bob protected now? No! You could also manipulate time!

Attacks on Protocols with Time Stamps

We assume that ...

- the local clock of the target system can be manipulated or
- a time service (e.g. of a time server) can be manipulated

Procedure

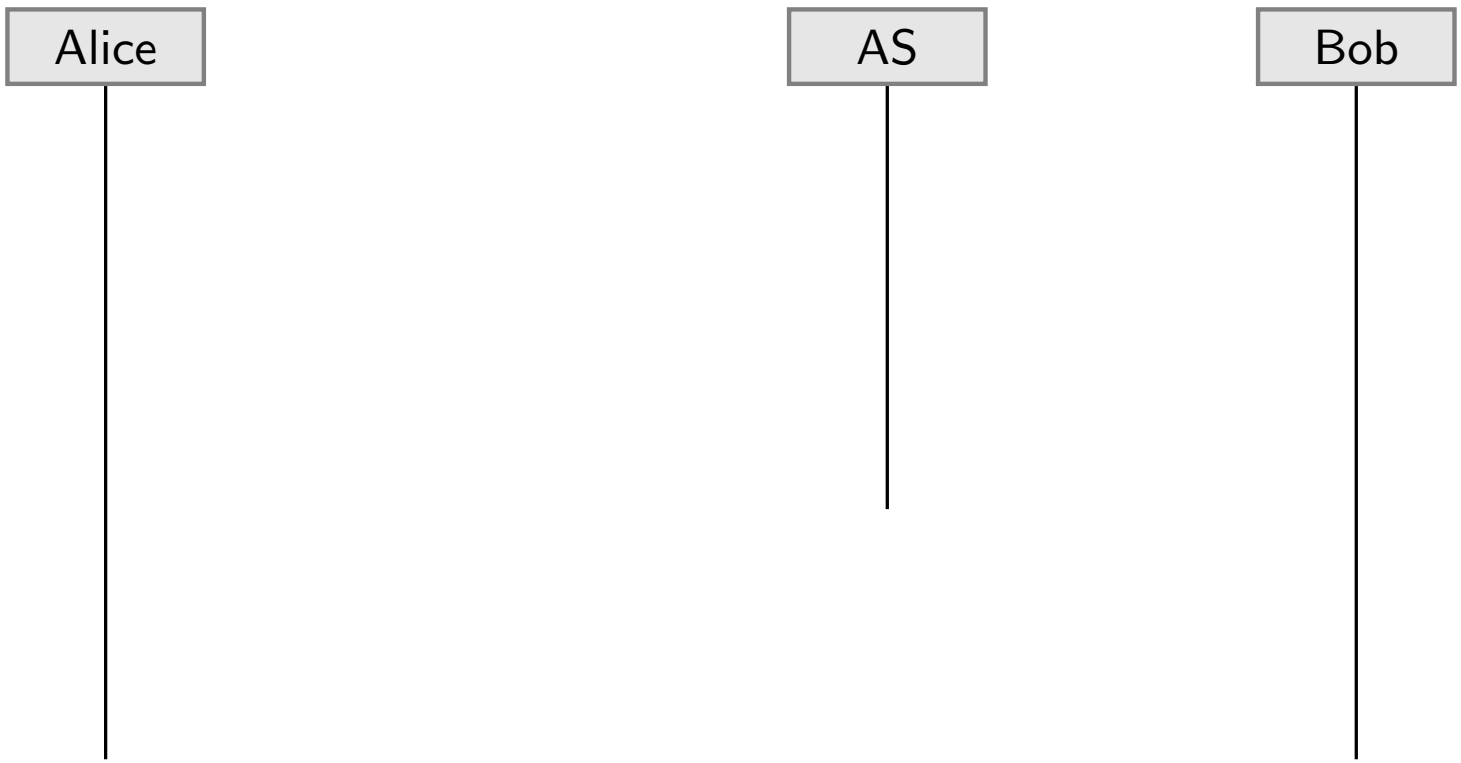
1. Modify the time of your target system
2. Perform a replay attack

How to protect?

➜ Use of previously negotiated nonces also for Bob

➜ Disadvantage: The protocol is getting more complicated

Variant 6 of the Symmetric NSP with Nonces



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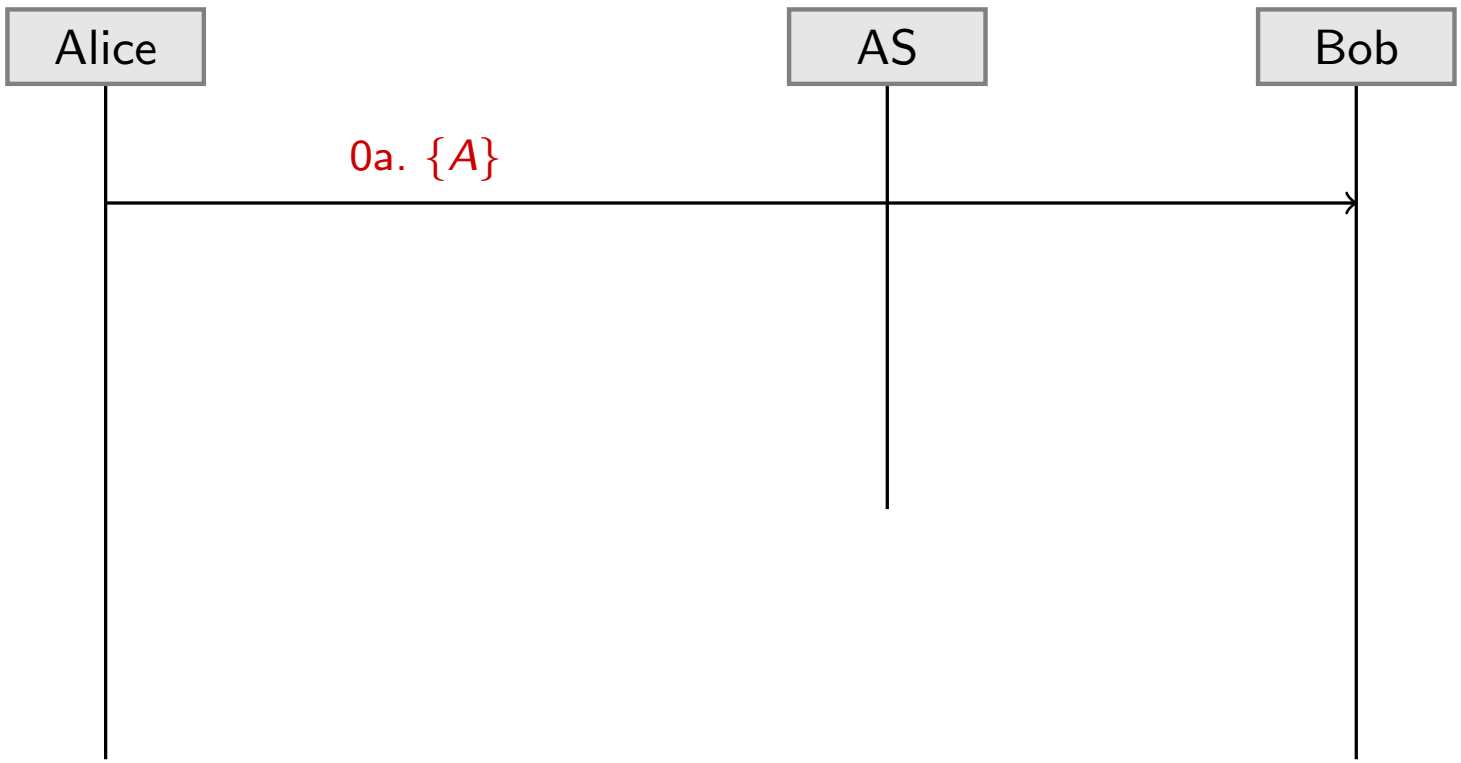

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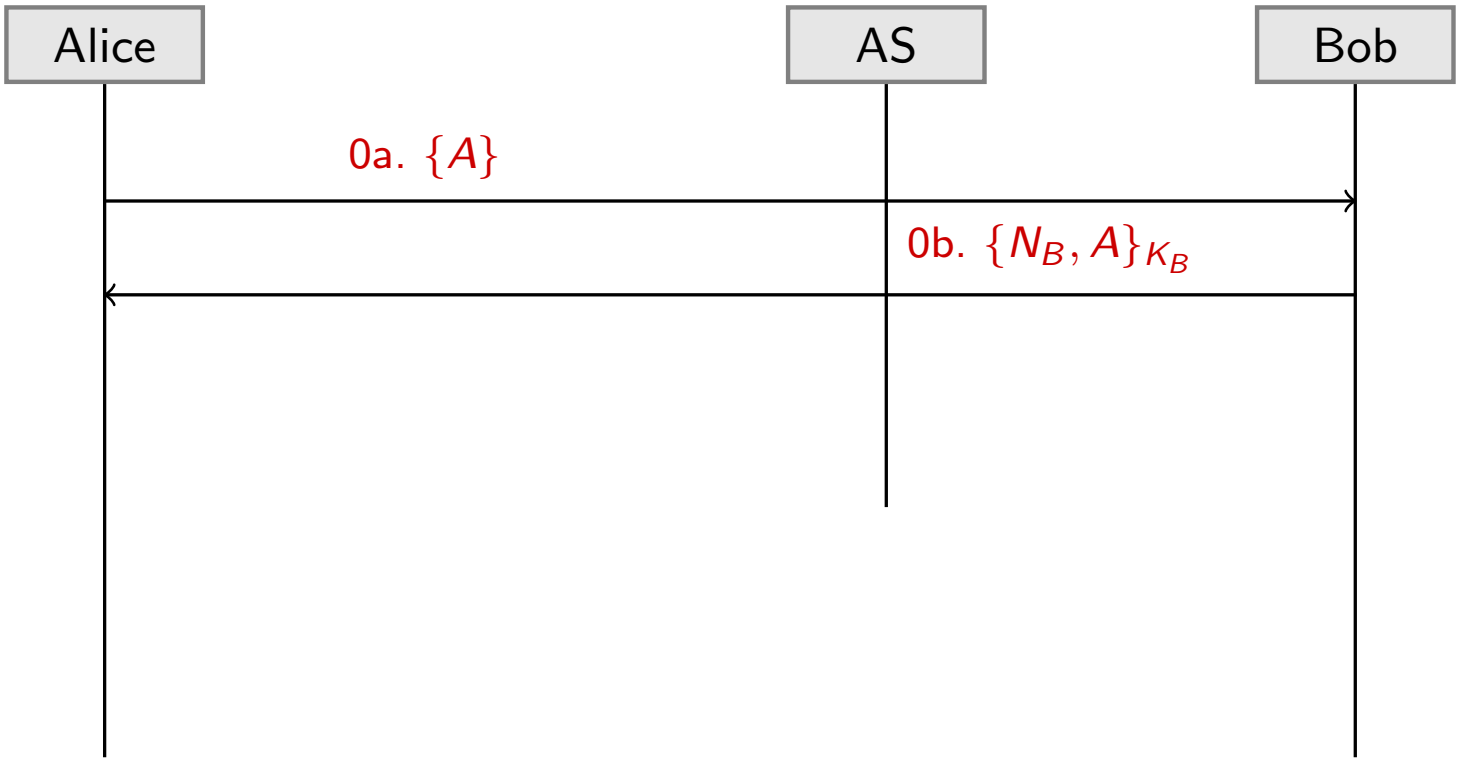

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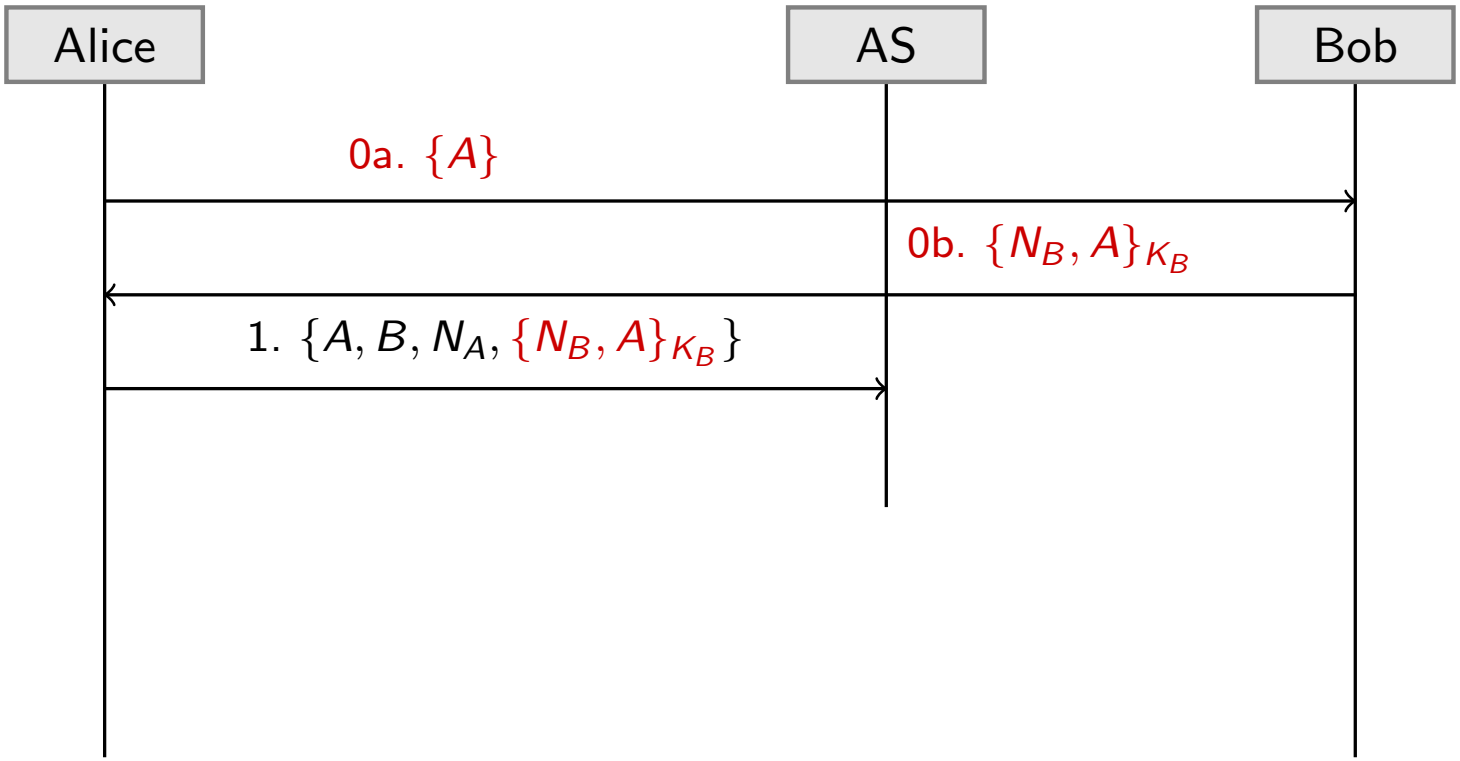

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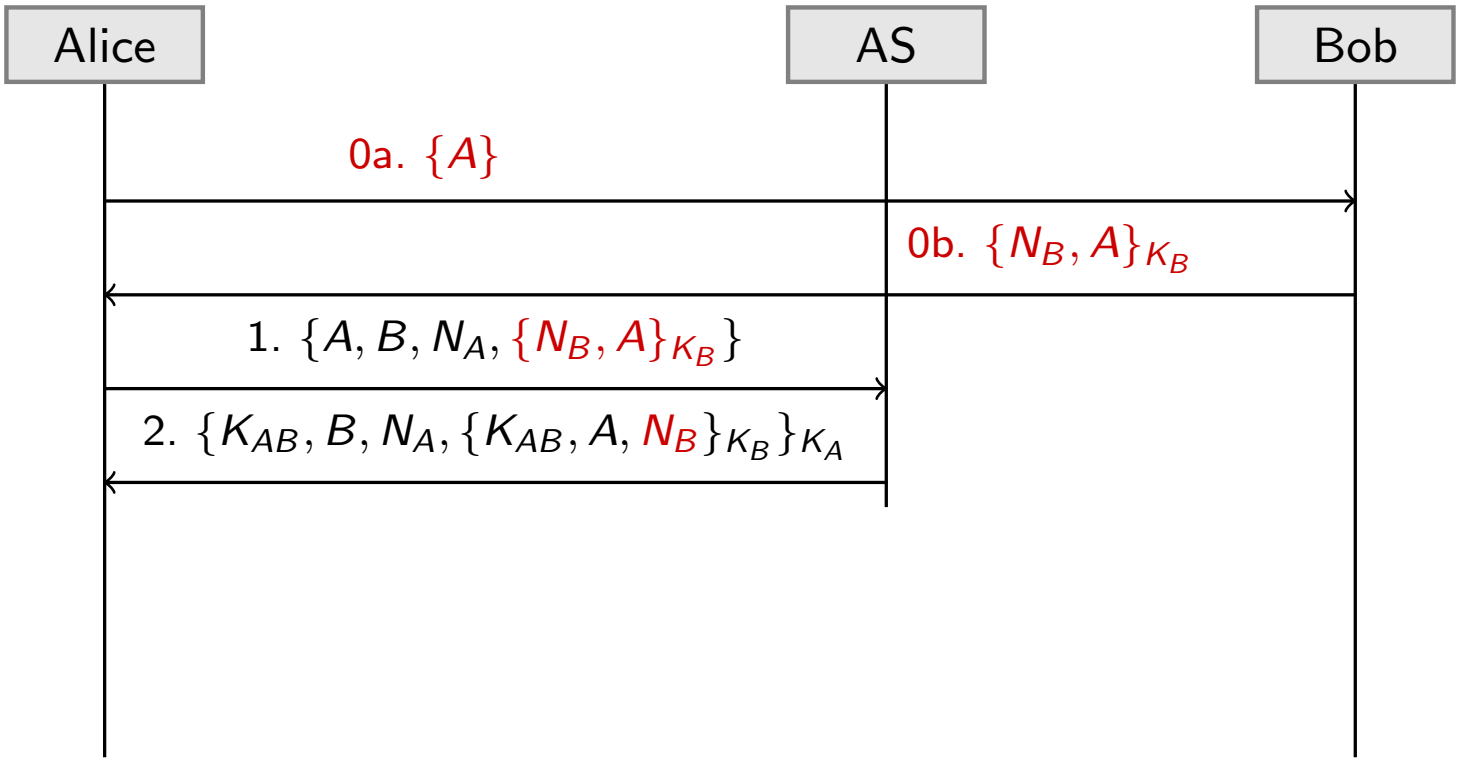

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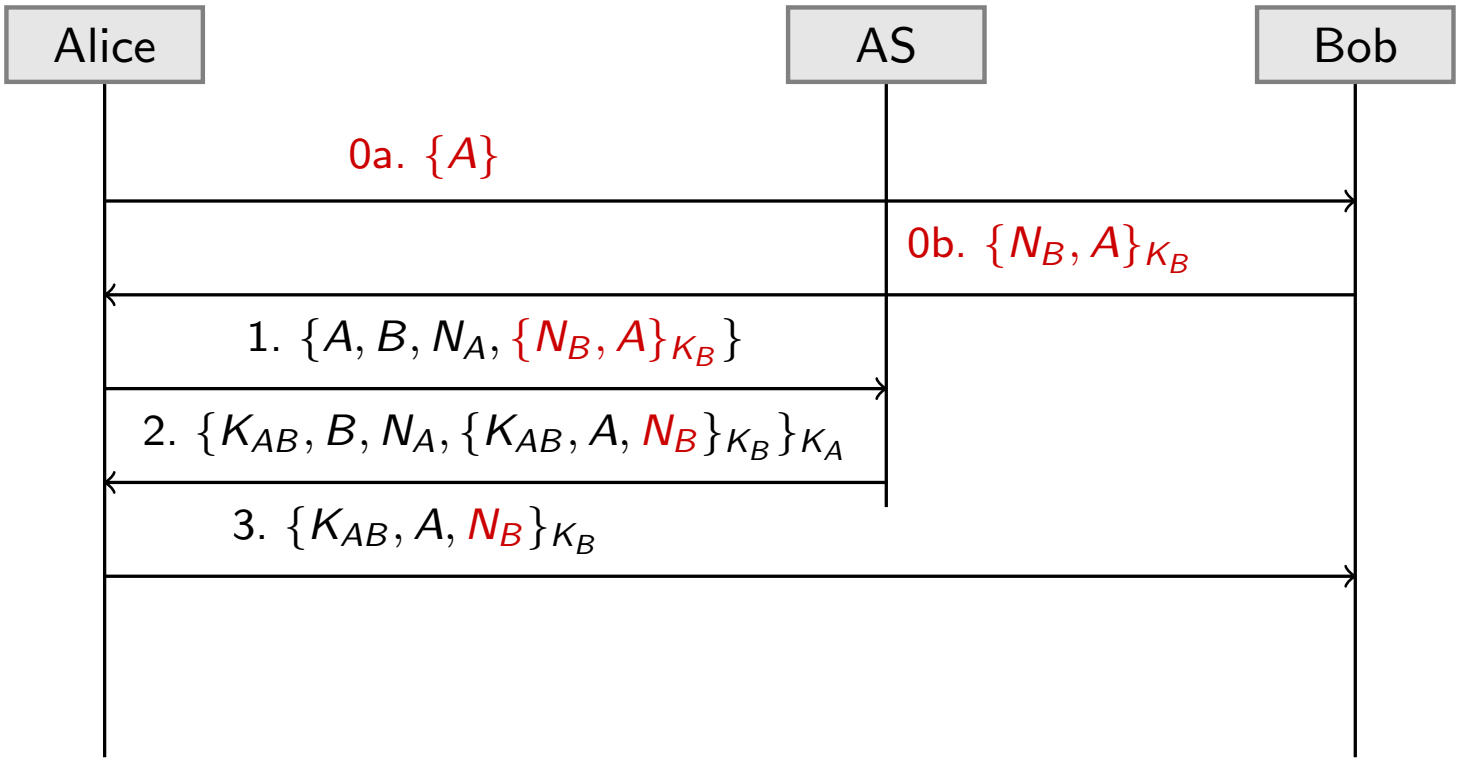

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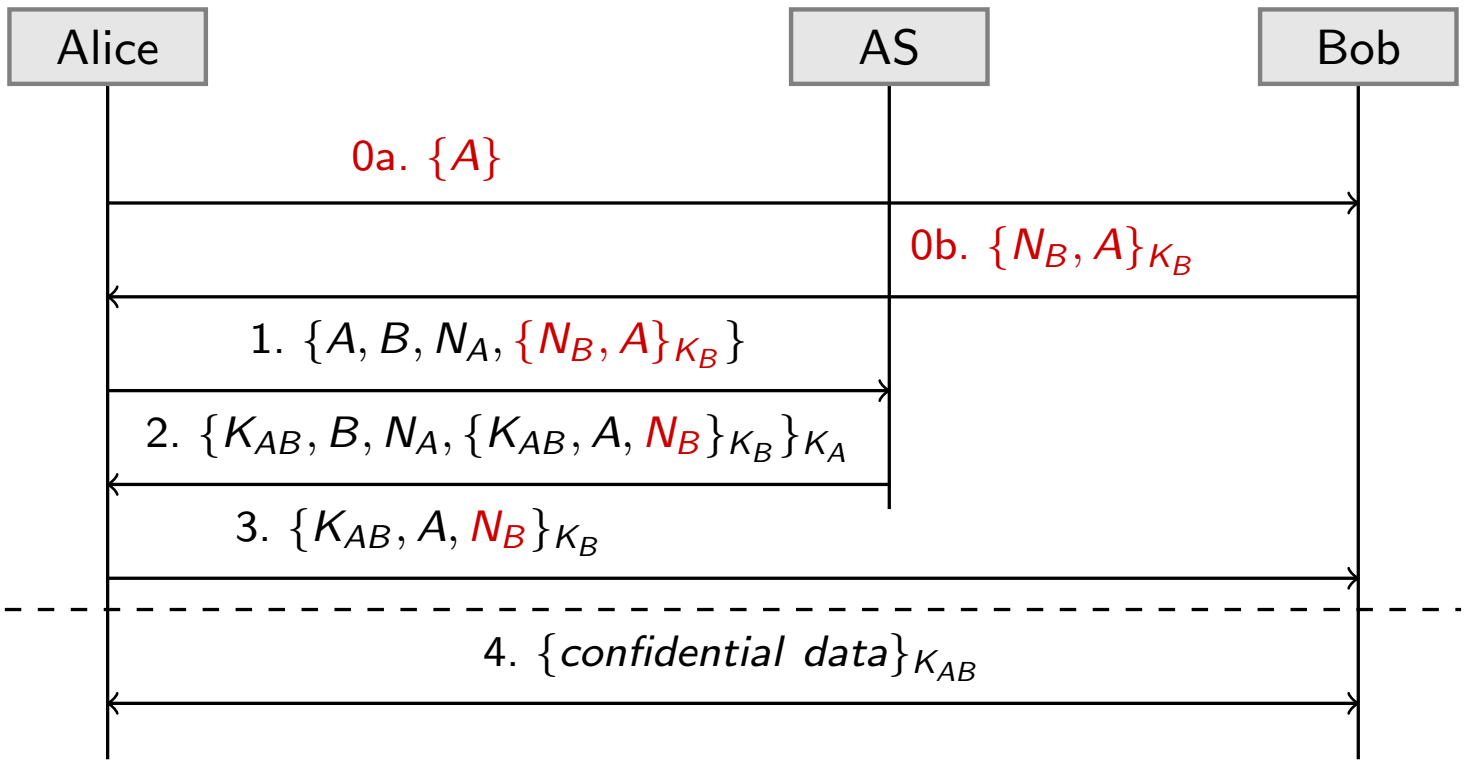

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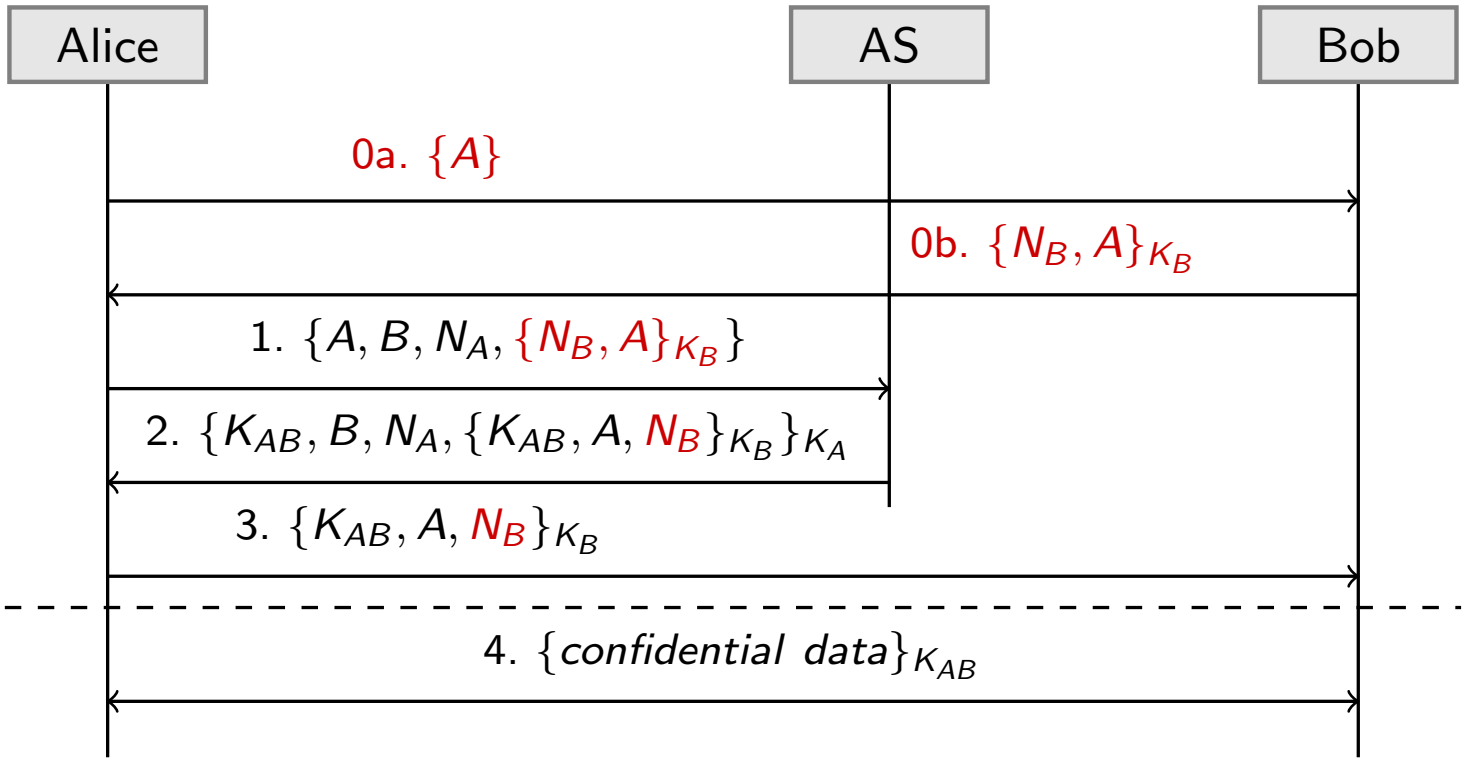

This variant of the NSP prevents replay attacks against Alice & Bob and allows to detect man-in-the-middle attacks

Which countermeasures exist to prevent these attacks?

Needham-Schroeder Protocols

– Asymmetric Variants –

Preliminary Specifications

Given Keys

1. PK_{AS}: Public key of the authentication server AS
2. SK_{AS}: Secret key of the authentication server AS
3. PK_A and PK_B: Public keys of Alice and Bob
4. SK_A and SK_B: Secret keys of Alice and Bob

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Assumptions

- AS knows the public keys of all participants
- All participants only know the public key PK_{AS} before the protocol is started

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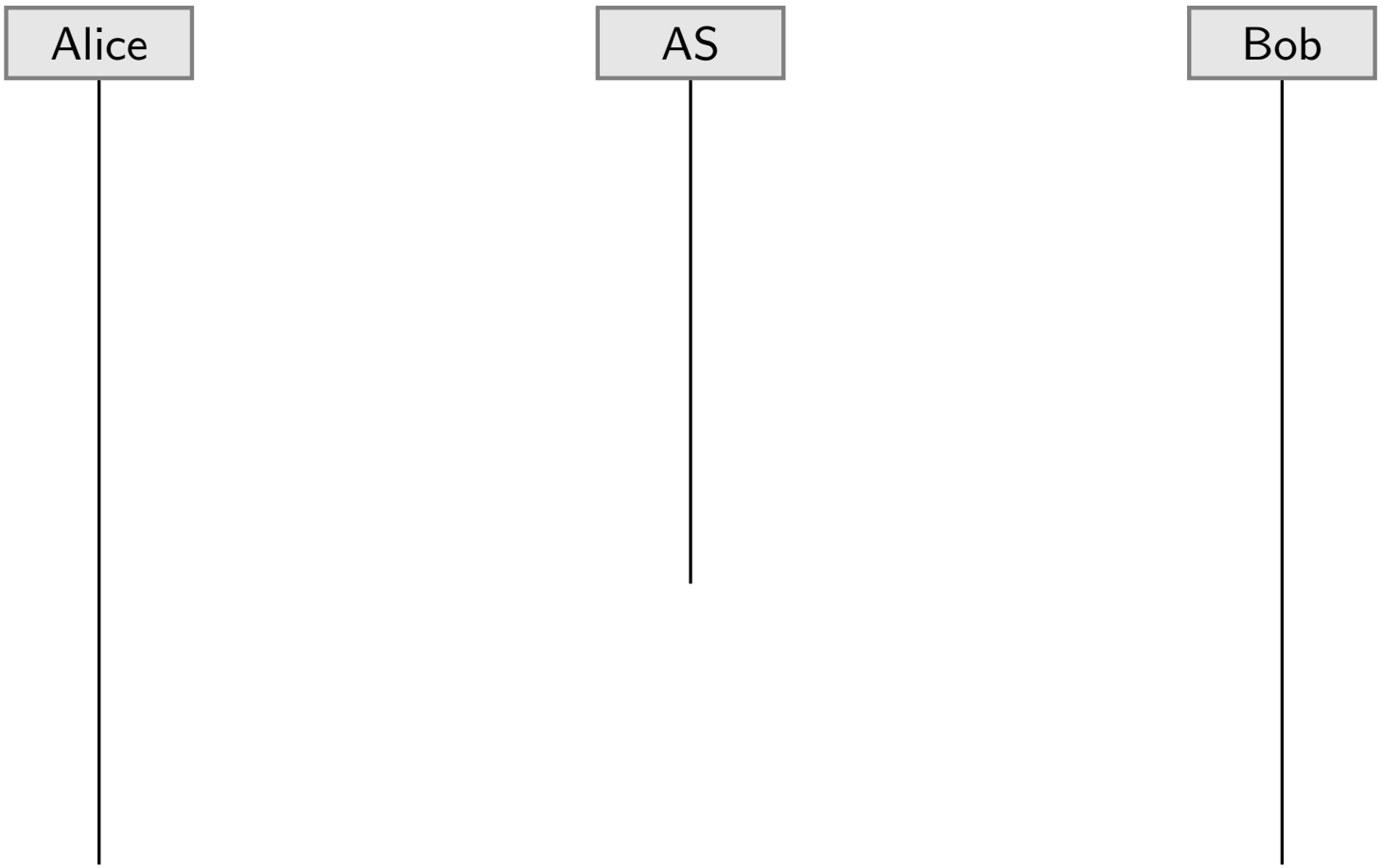
➜ Participants must request all other required keys from AS

Asymmetric Variant of the NSP



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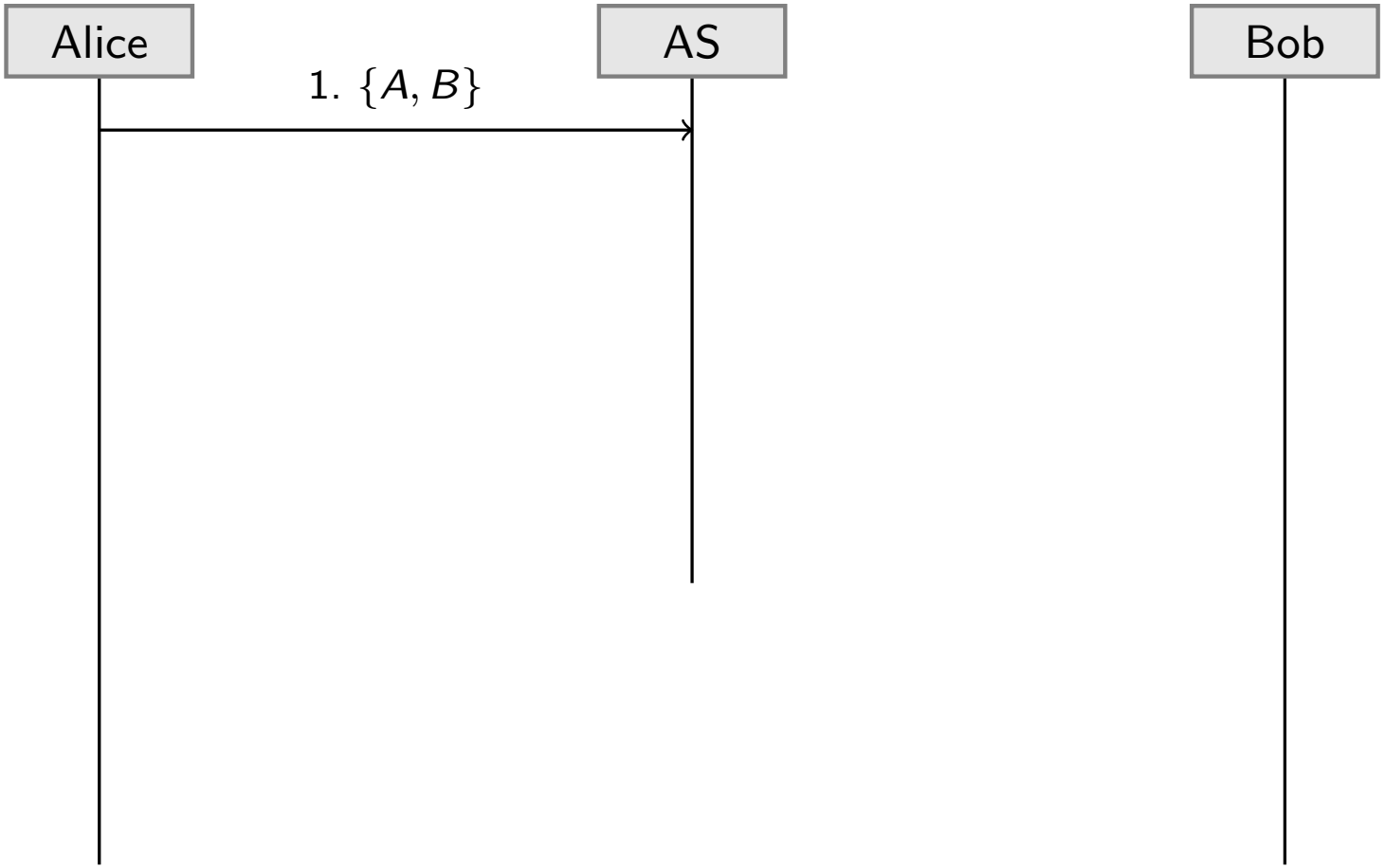

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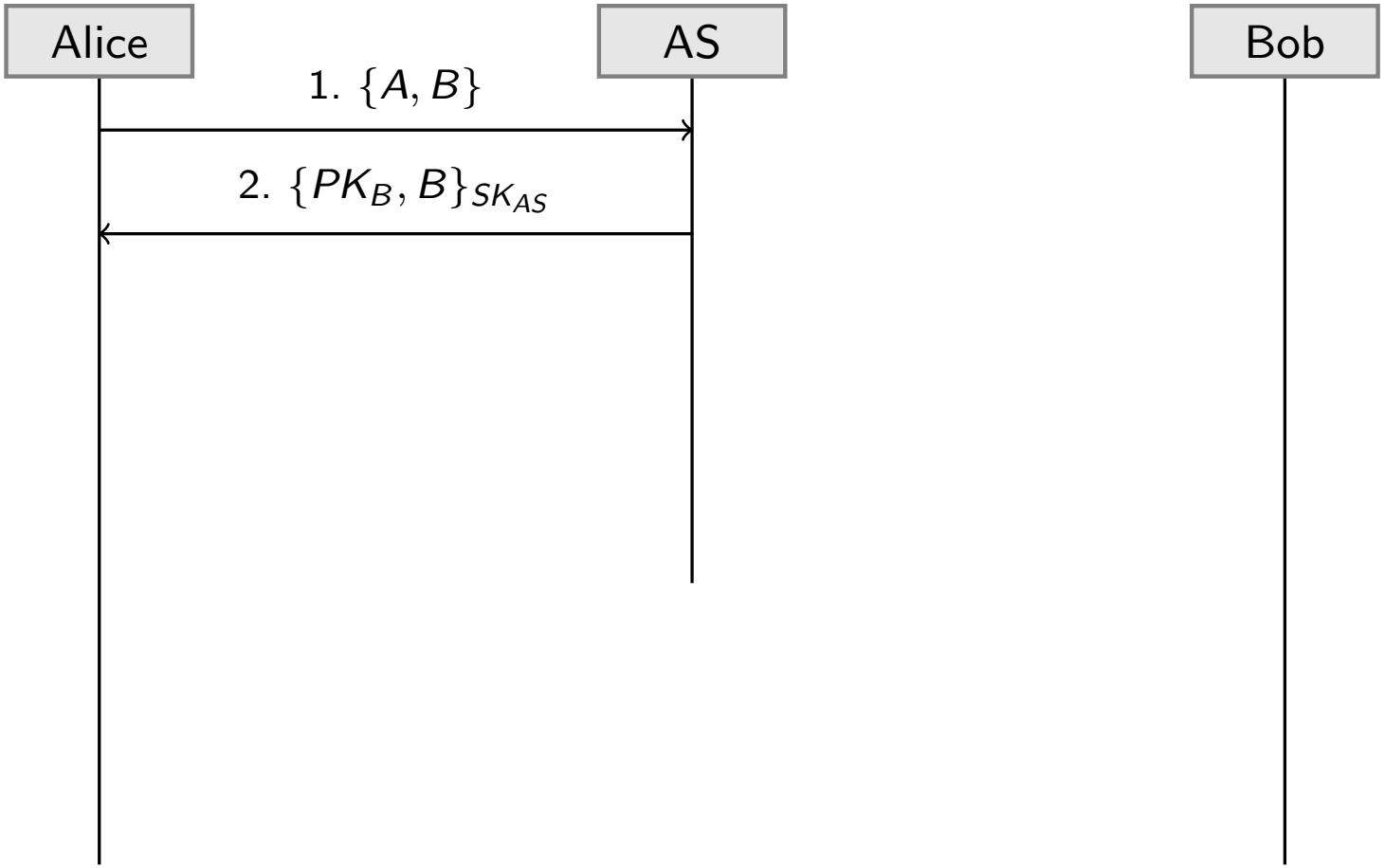

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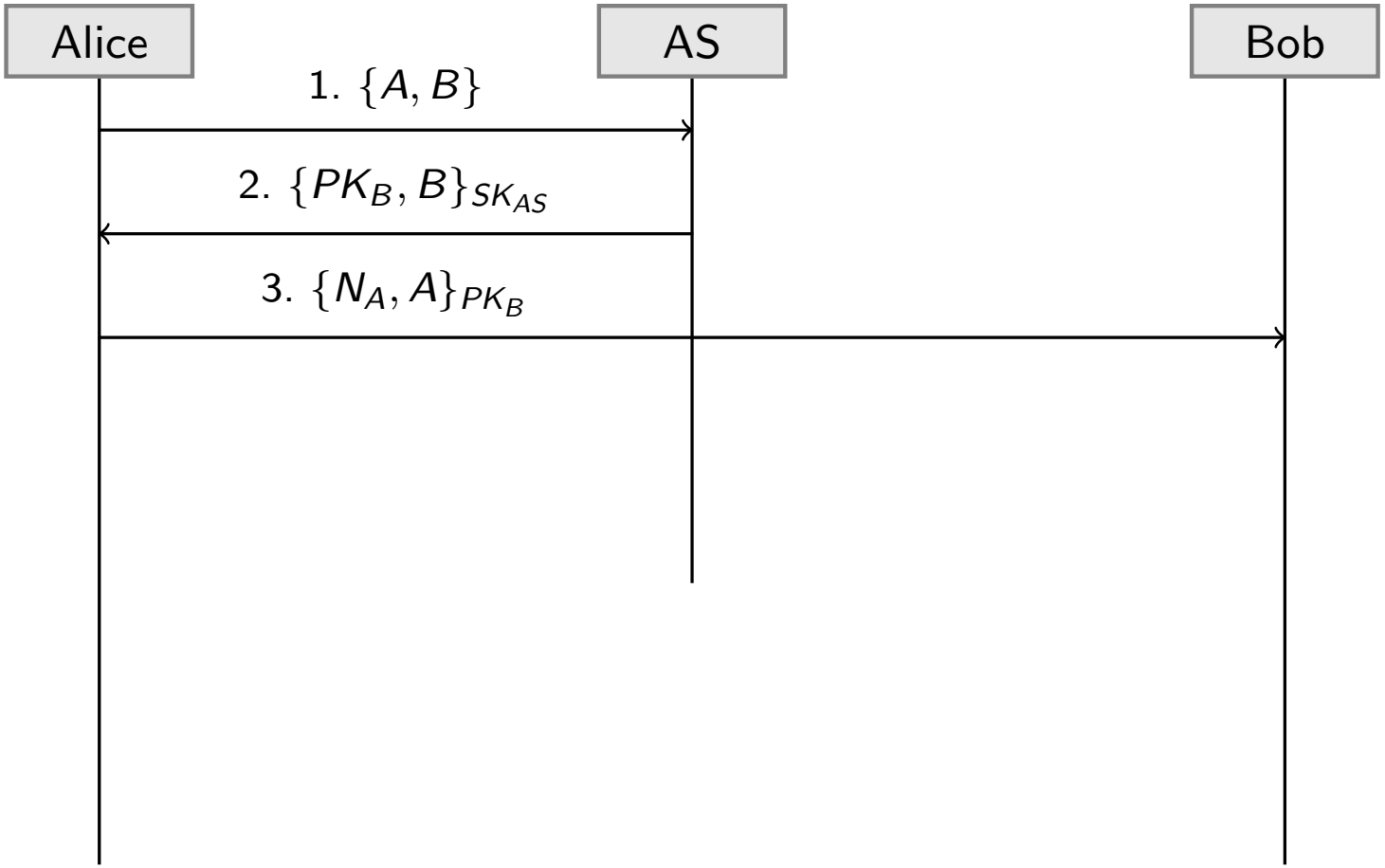
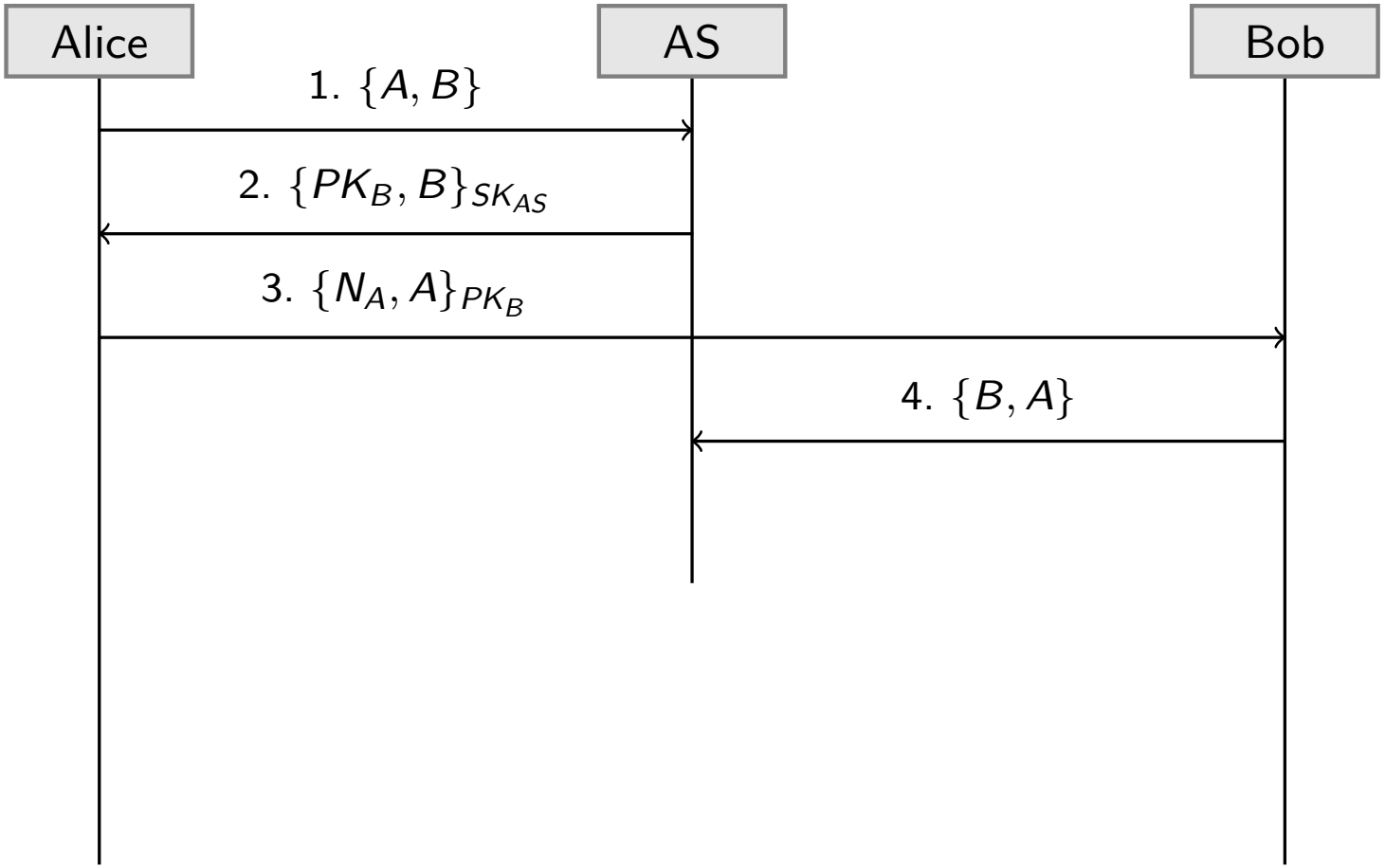


Asymmetric Variant of the NSP



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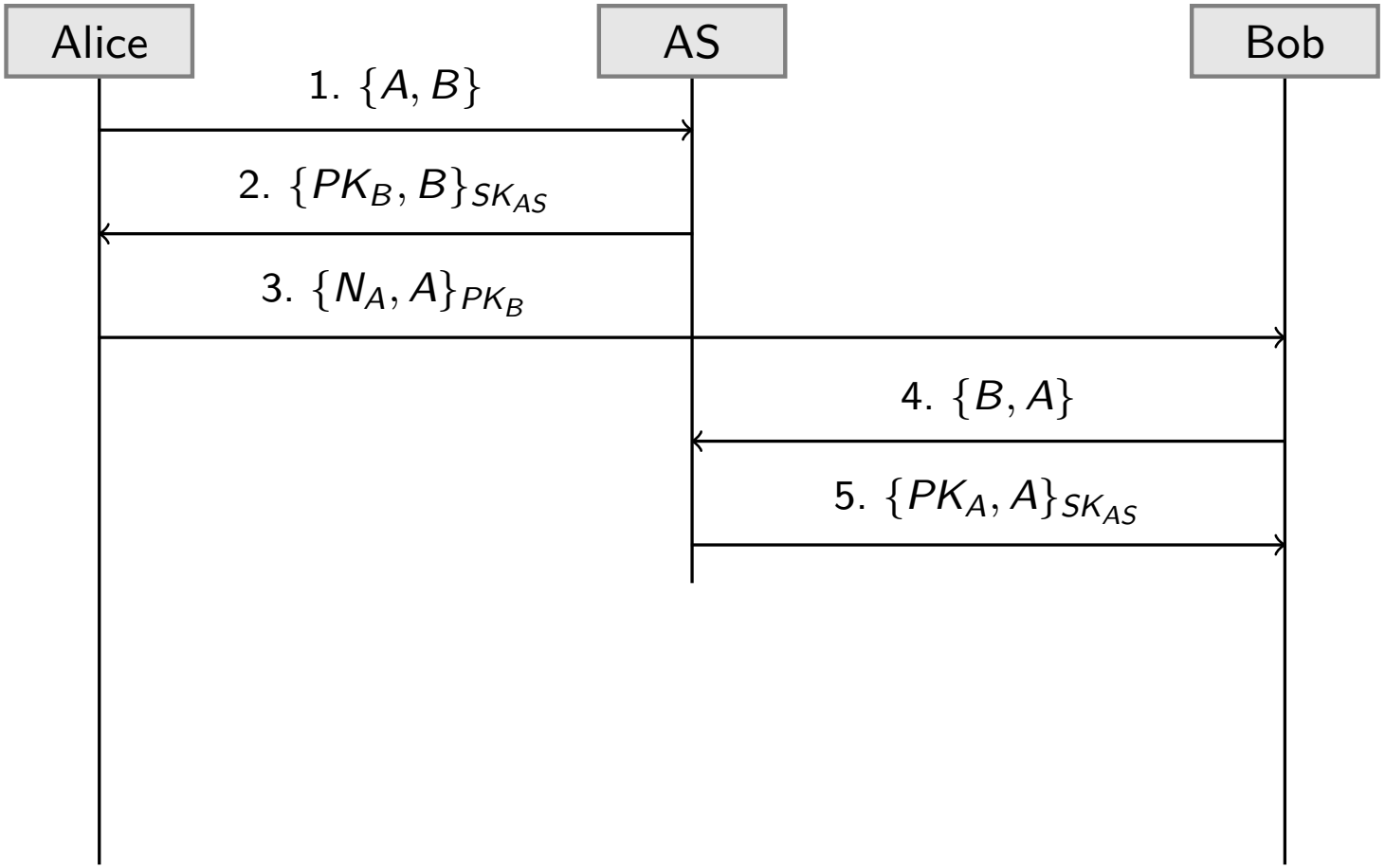

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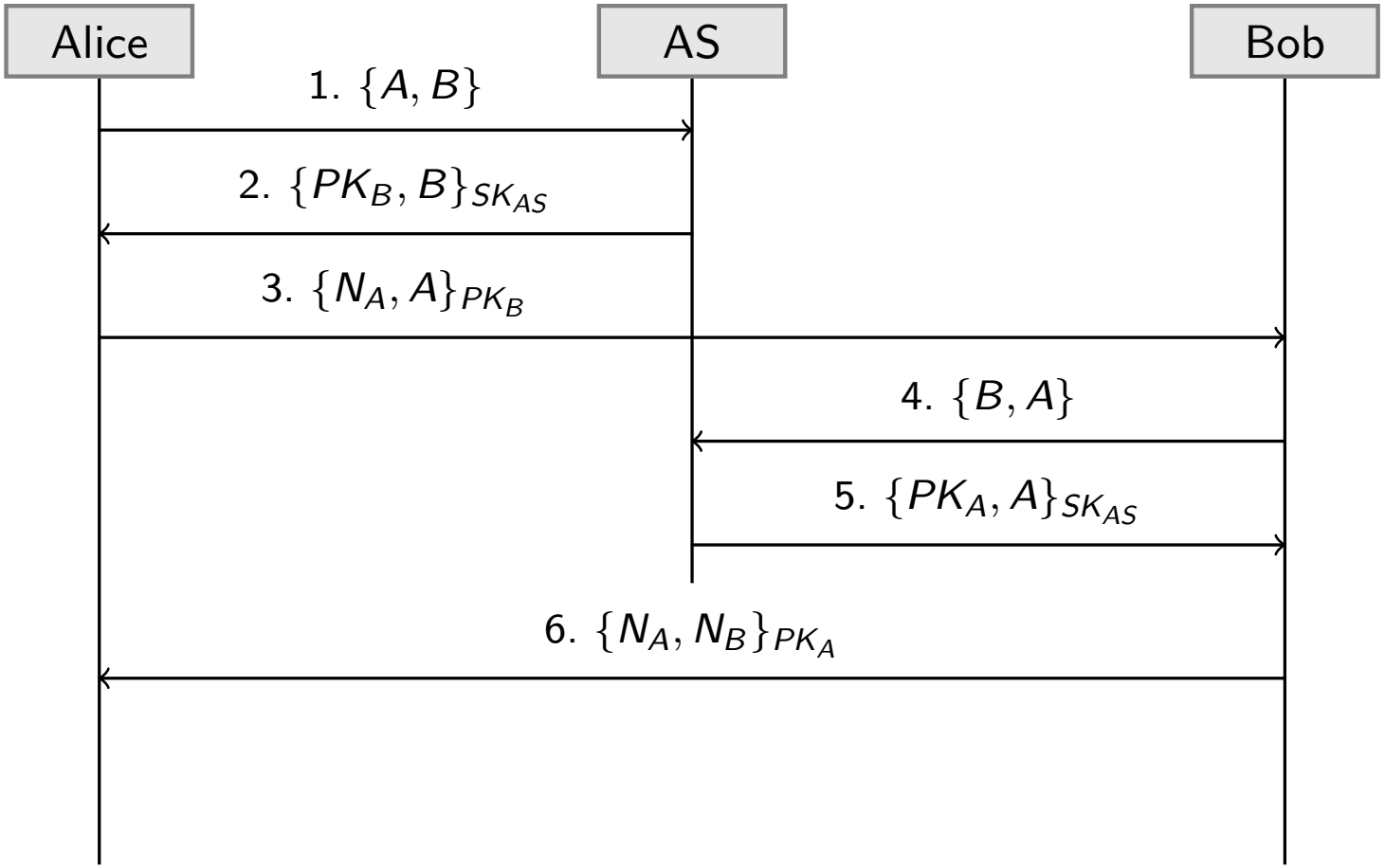

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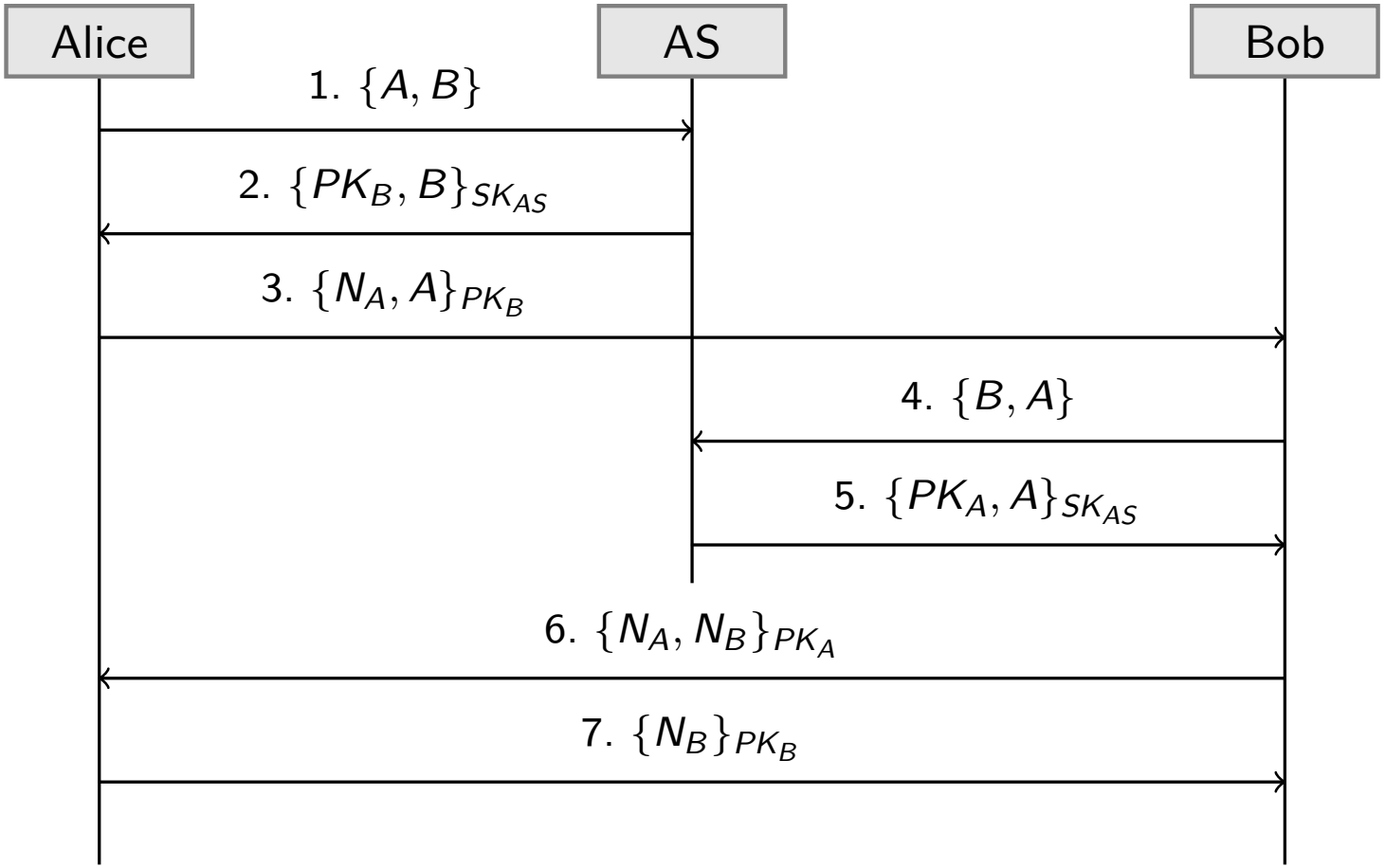

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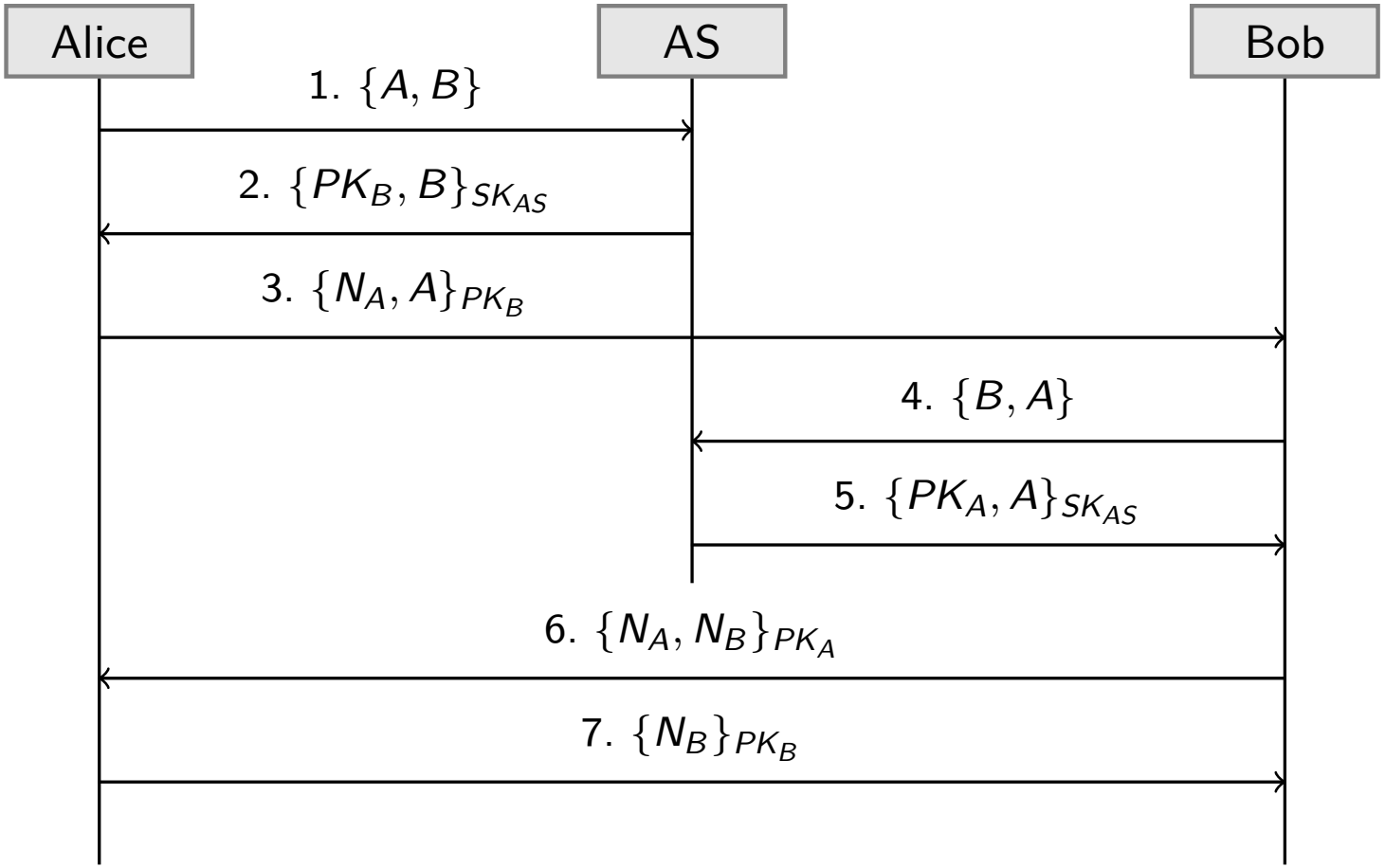

The protocol is not secure against man-in-the-middle attacks!
Why? Find the attack scenario!

Specify the asymmetric variant of the Needham-Schroeder protocol. What attack for NSP has not been detected for many years?

Simplified Version of the Asymmetric NSP

- ➜ Assumption: Participants have already received all required public keys from the AS
- ➜ Therefore, Steps 1,2,4 & 5 can be omitted

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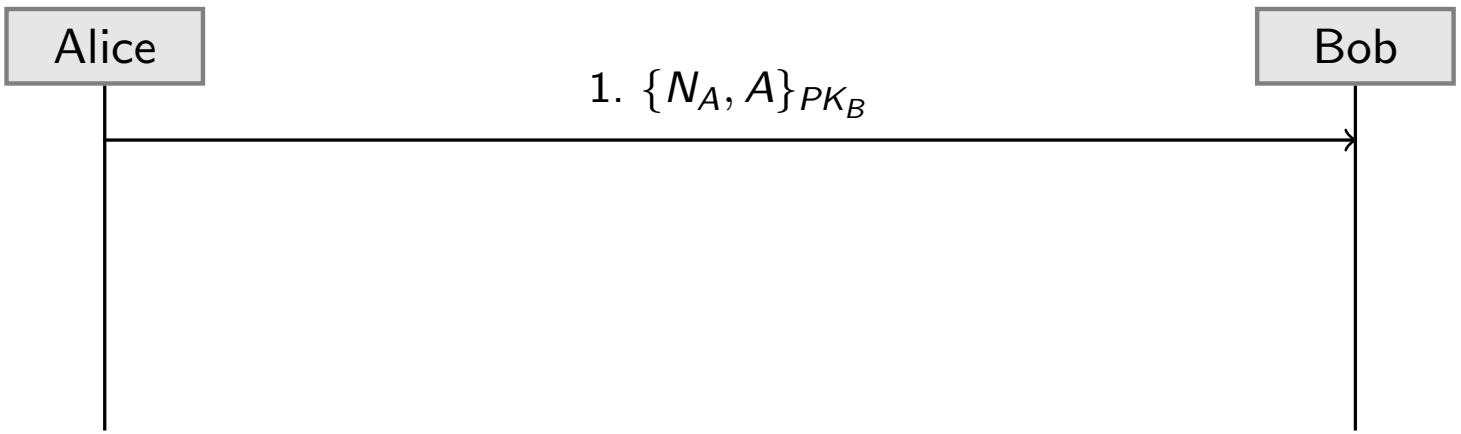

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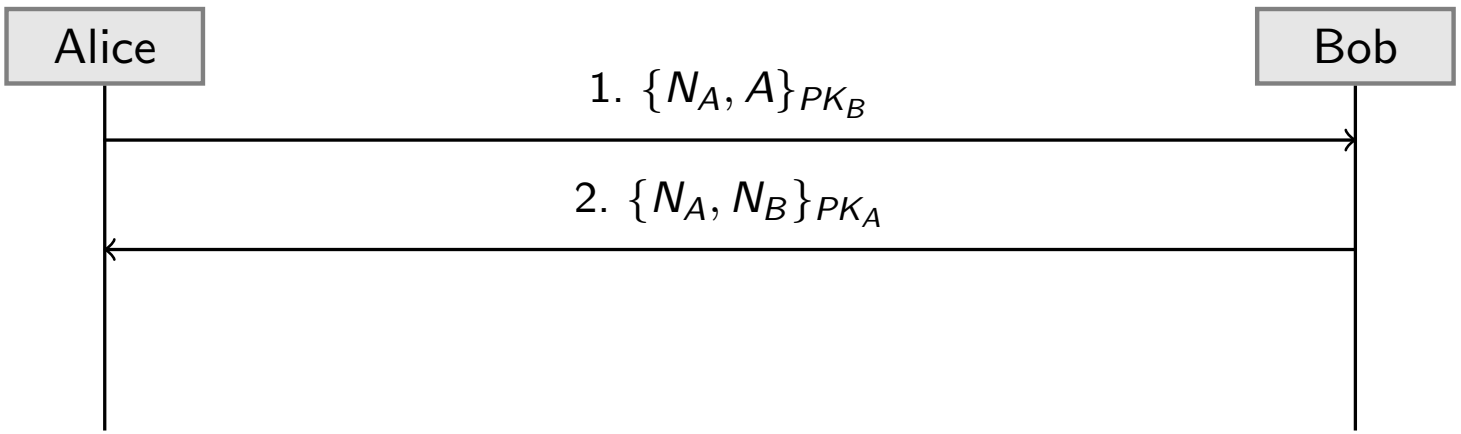

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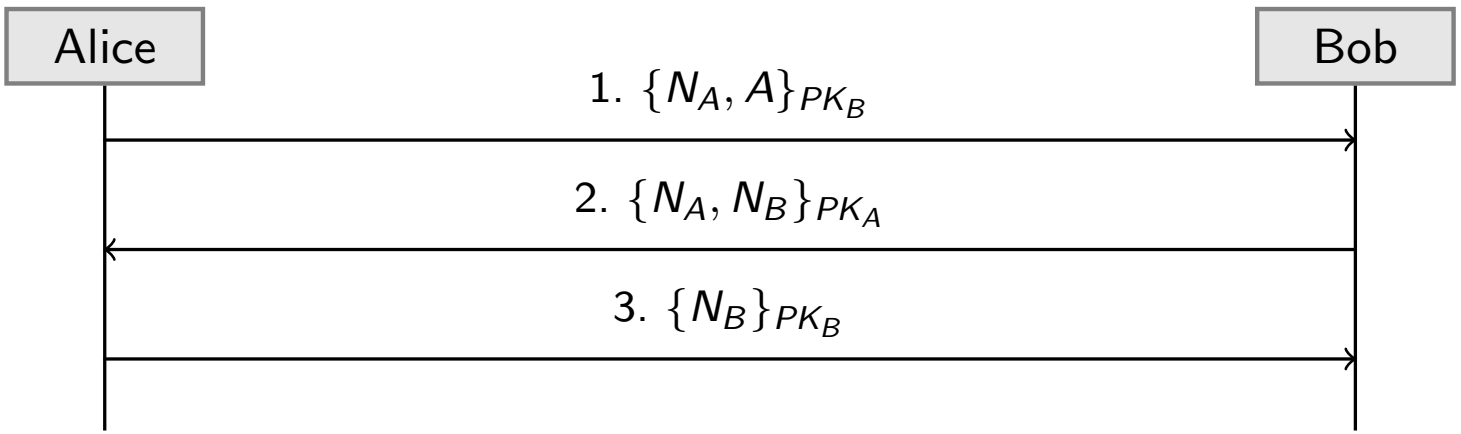

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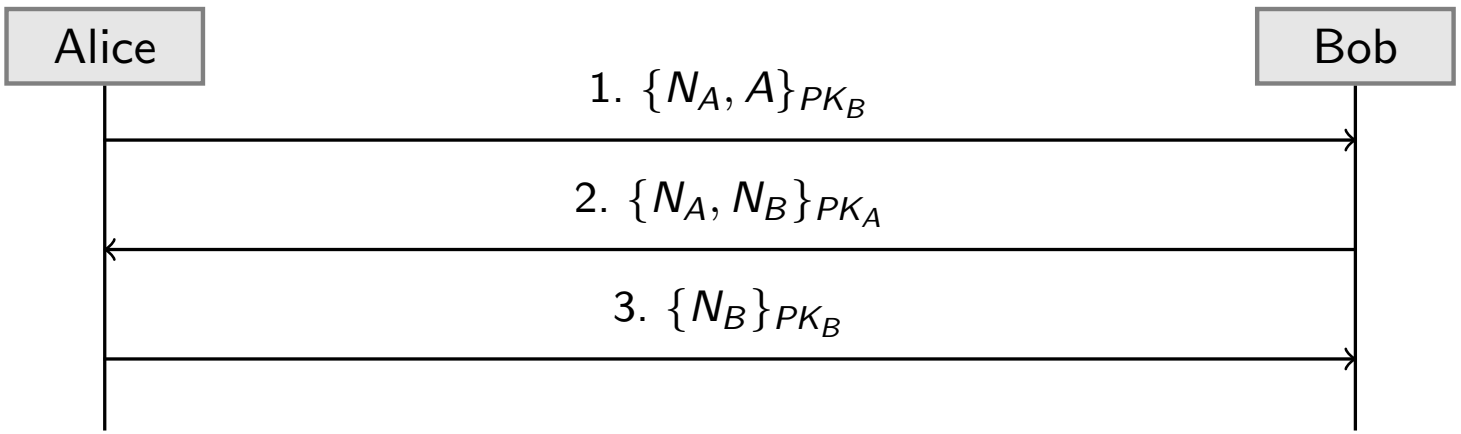
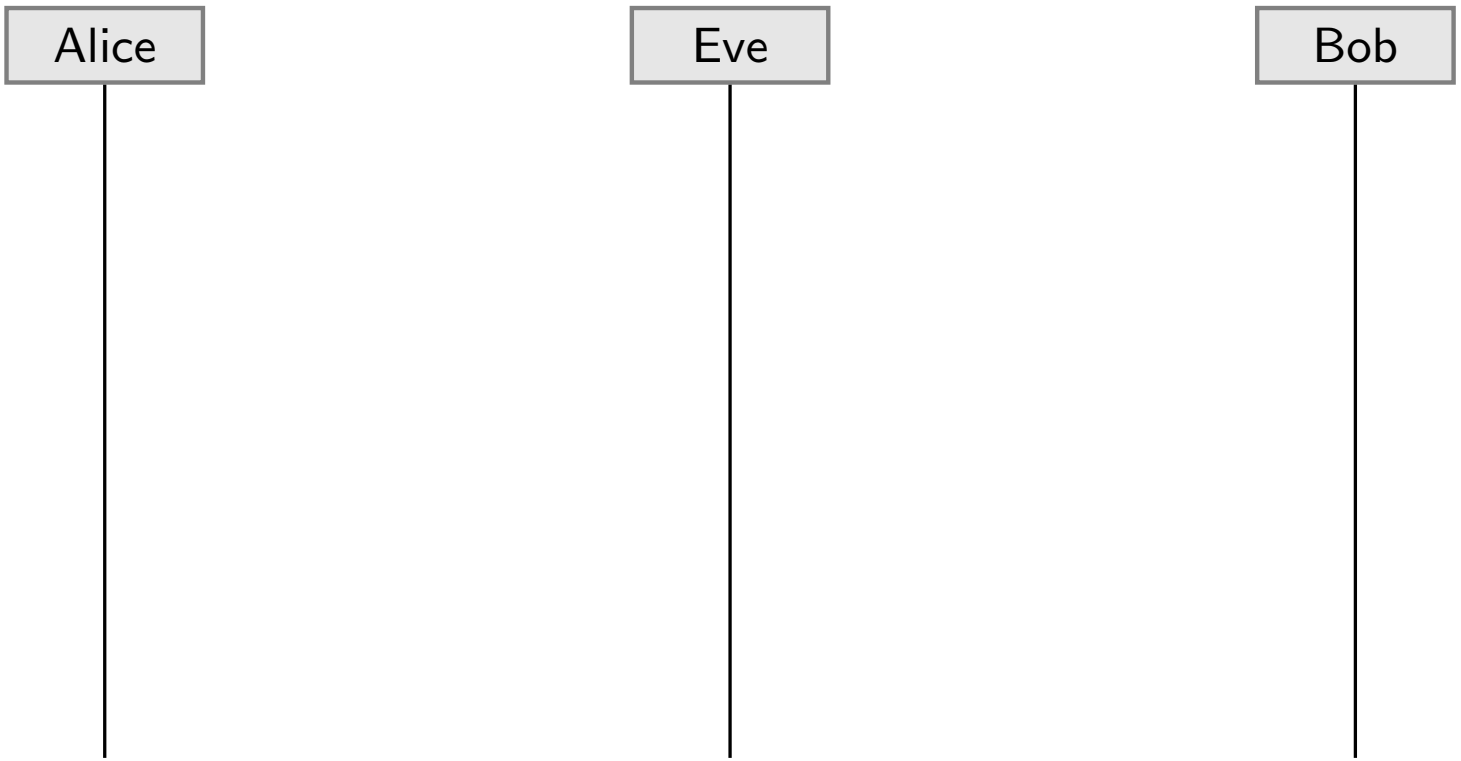


Note: The attacker Eve executes two of these protocol sessions in parallel to perform the attack!

Attack for the Asymmetric Variant of the NSP



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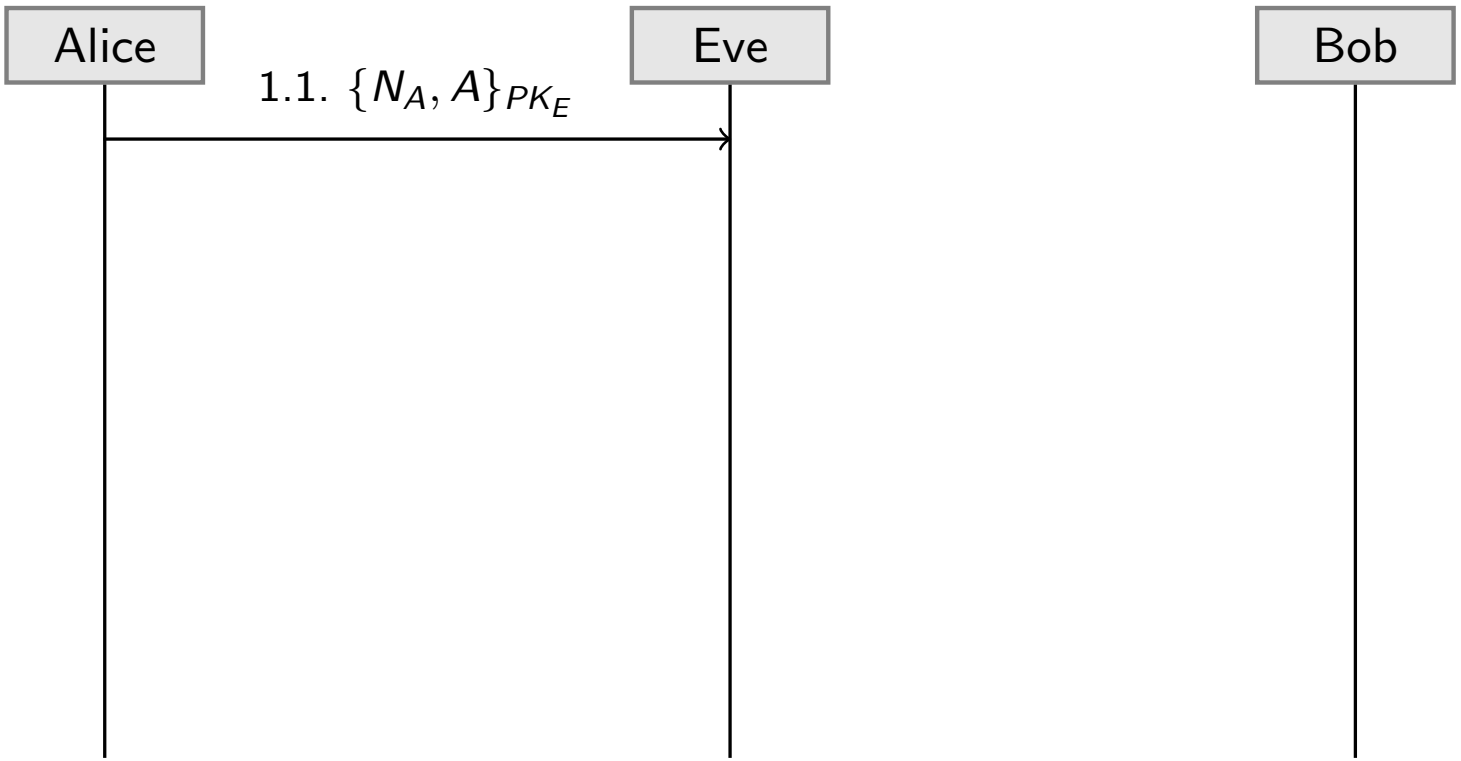

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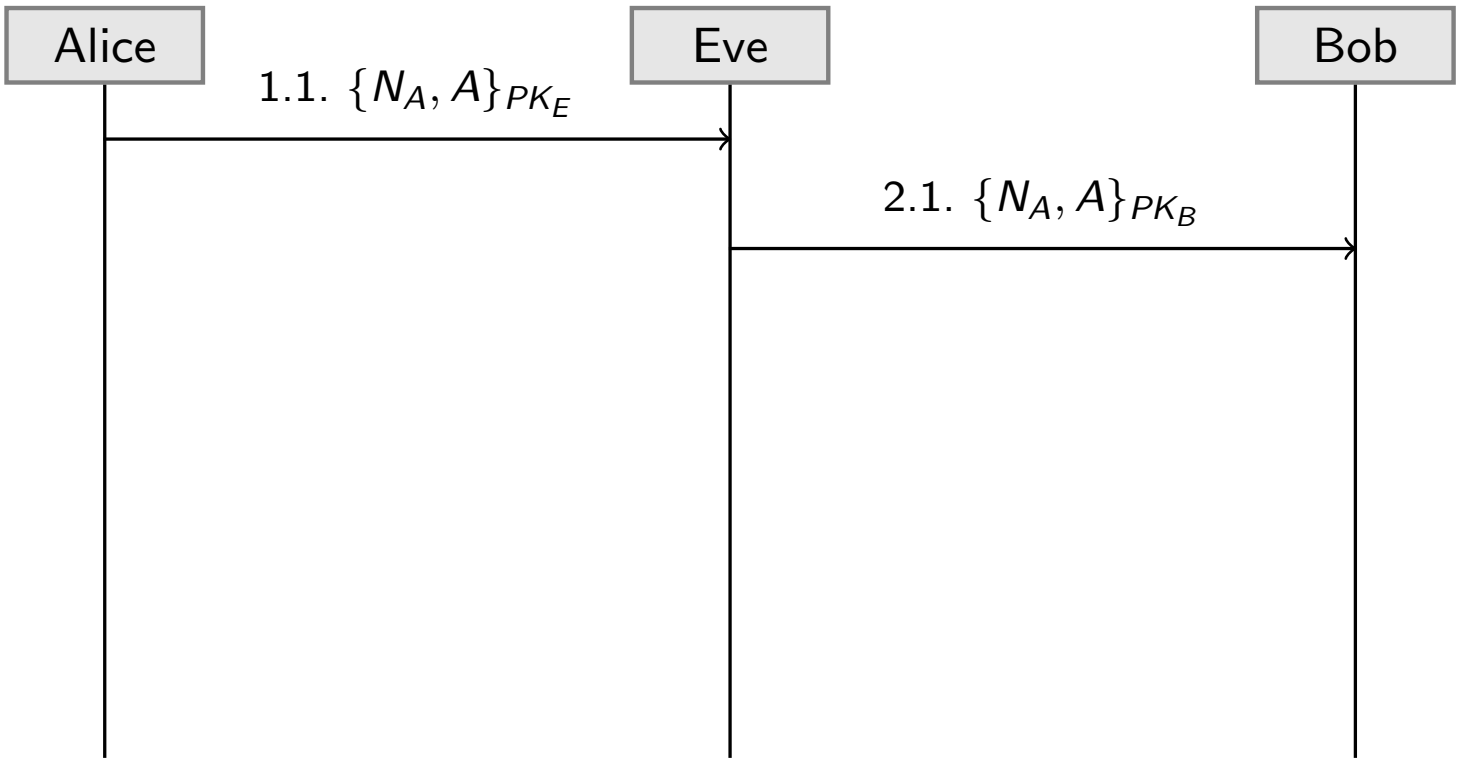

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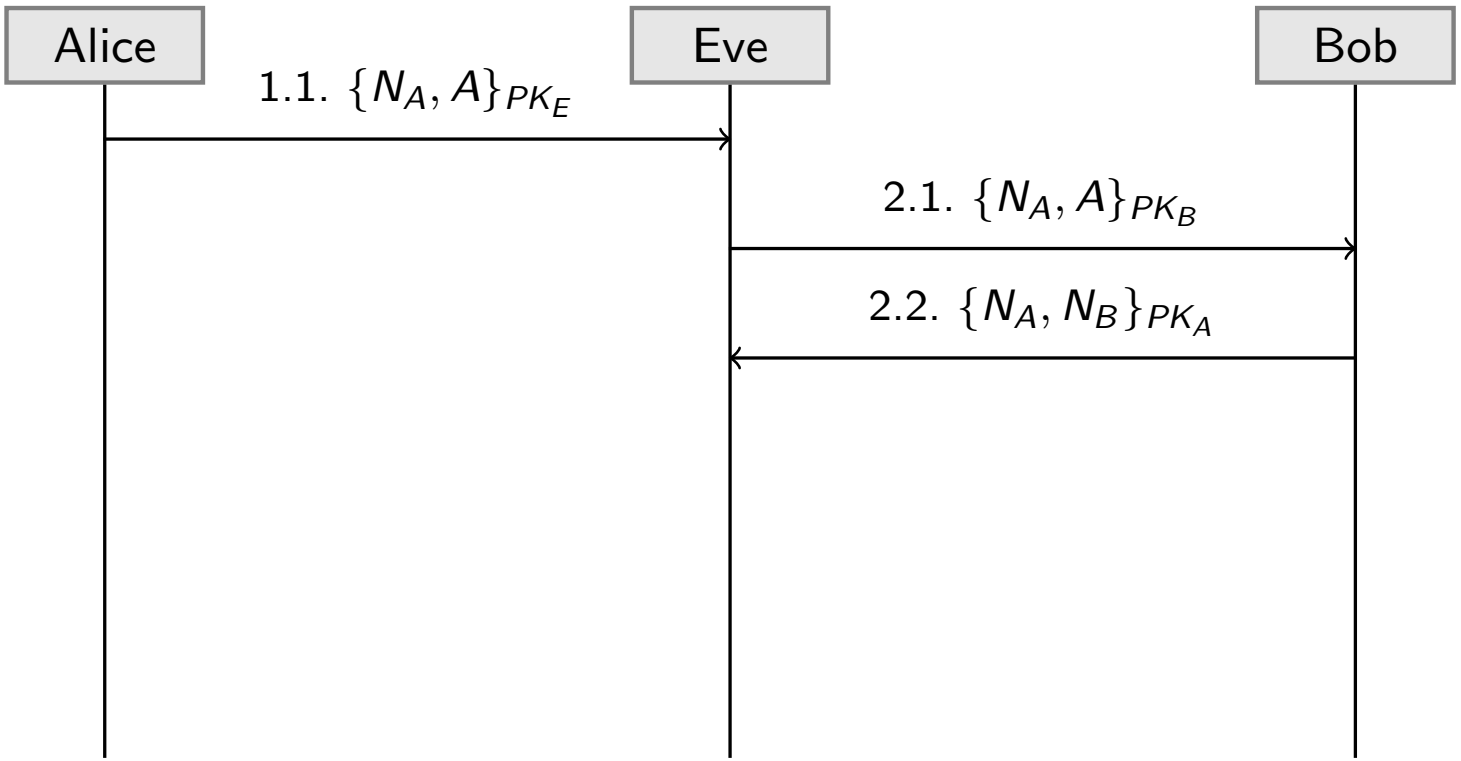

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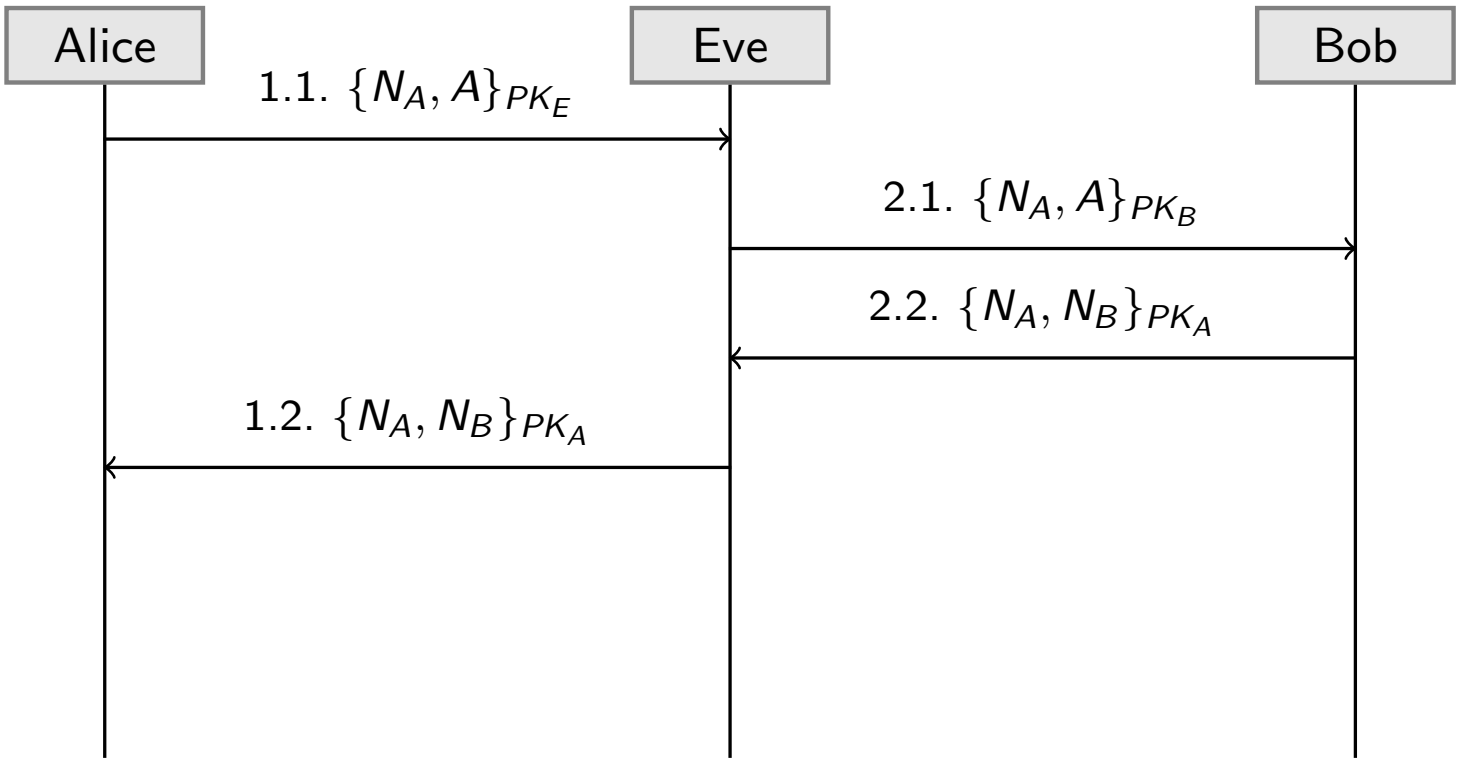

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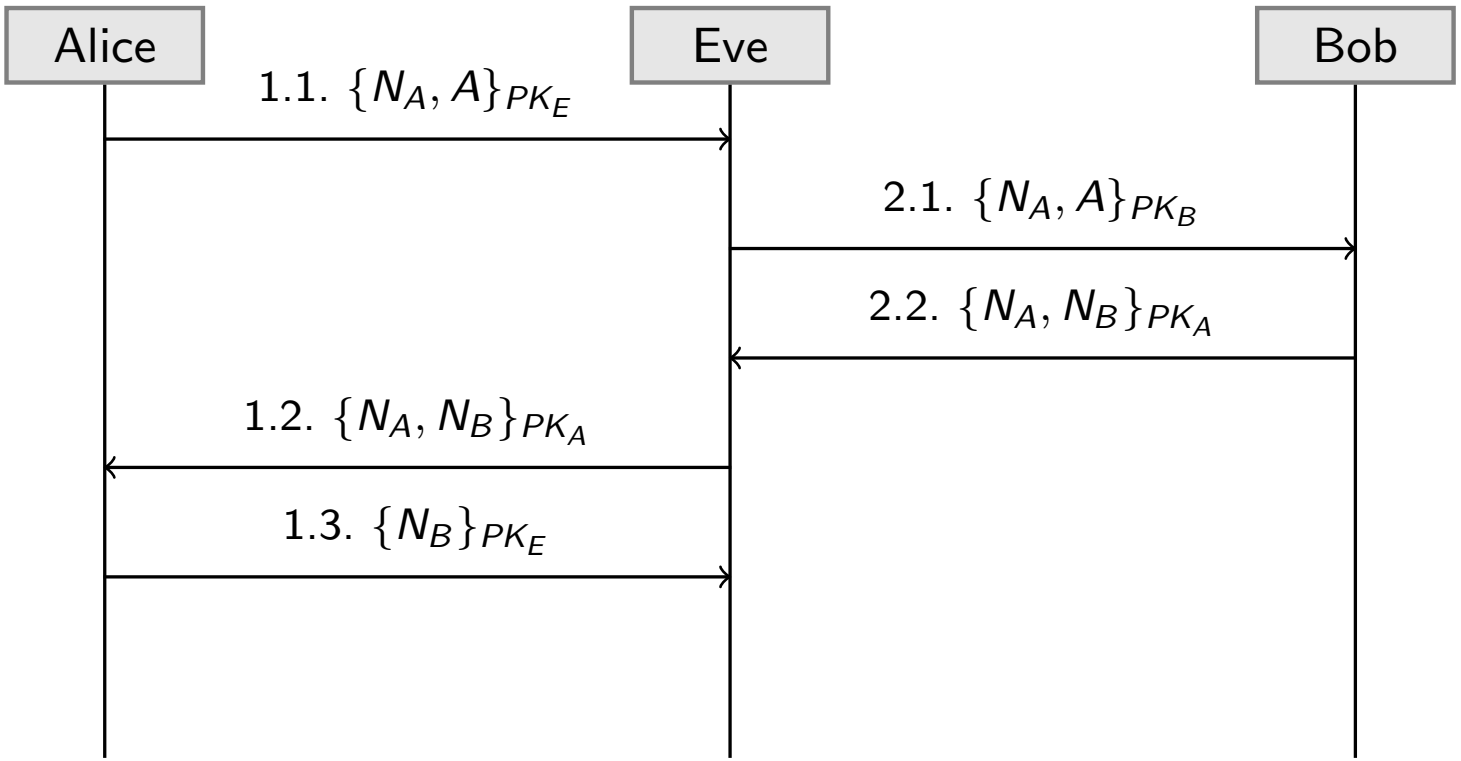

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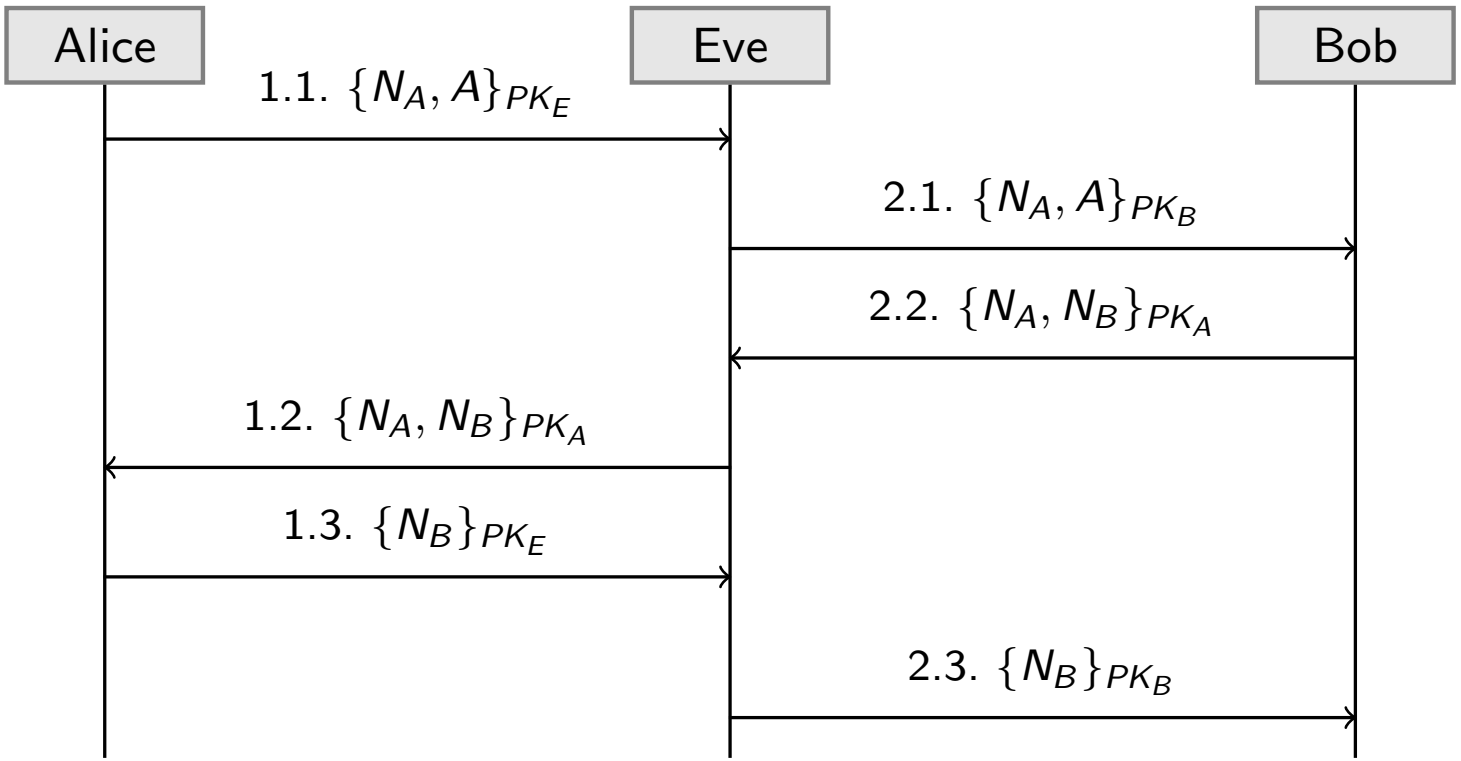

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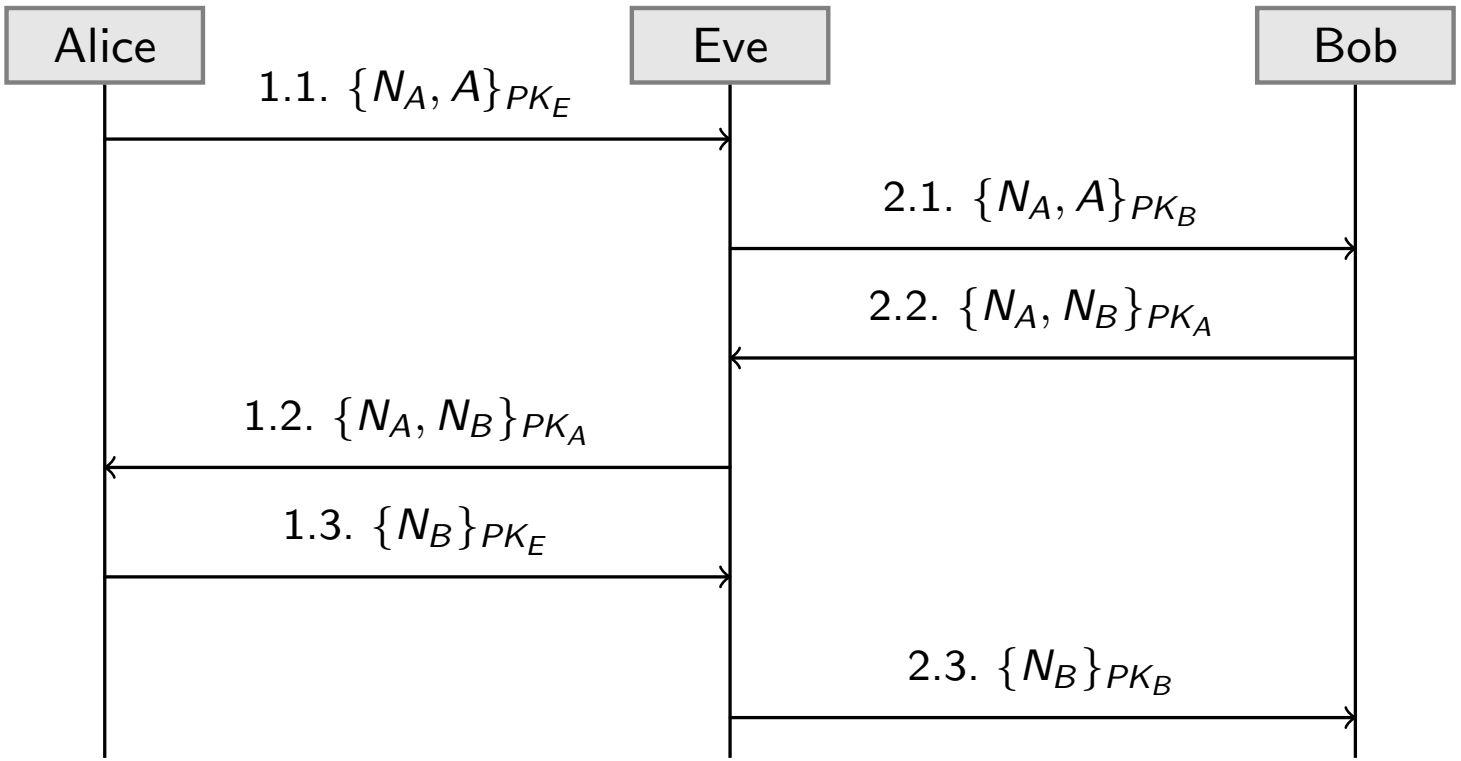
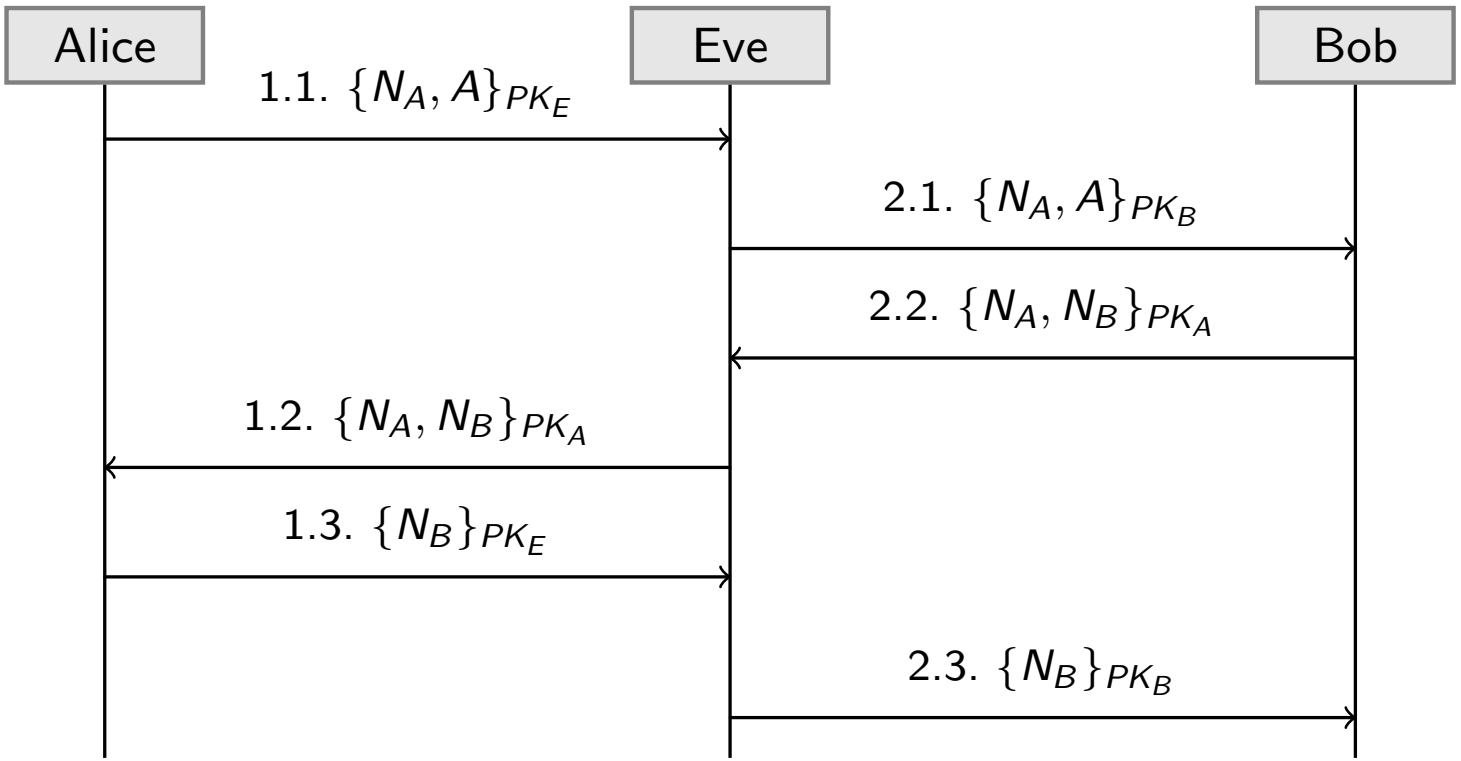


Eve cheats on Bob. She pretends to be Alice in reality.

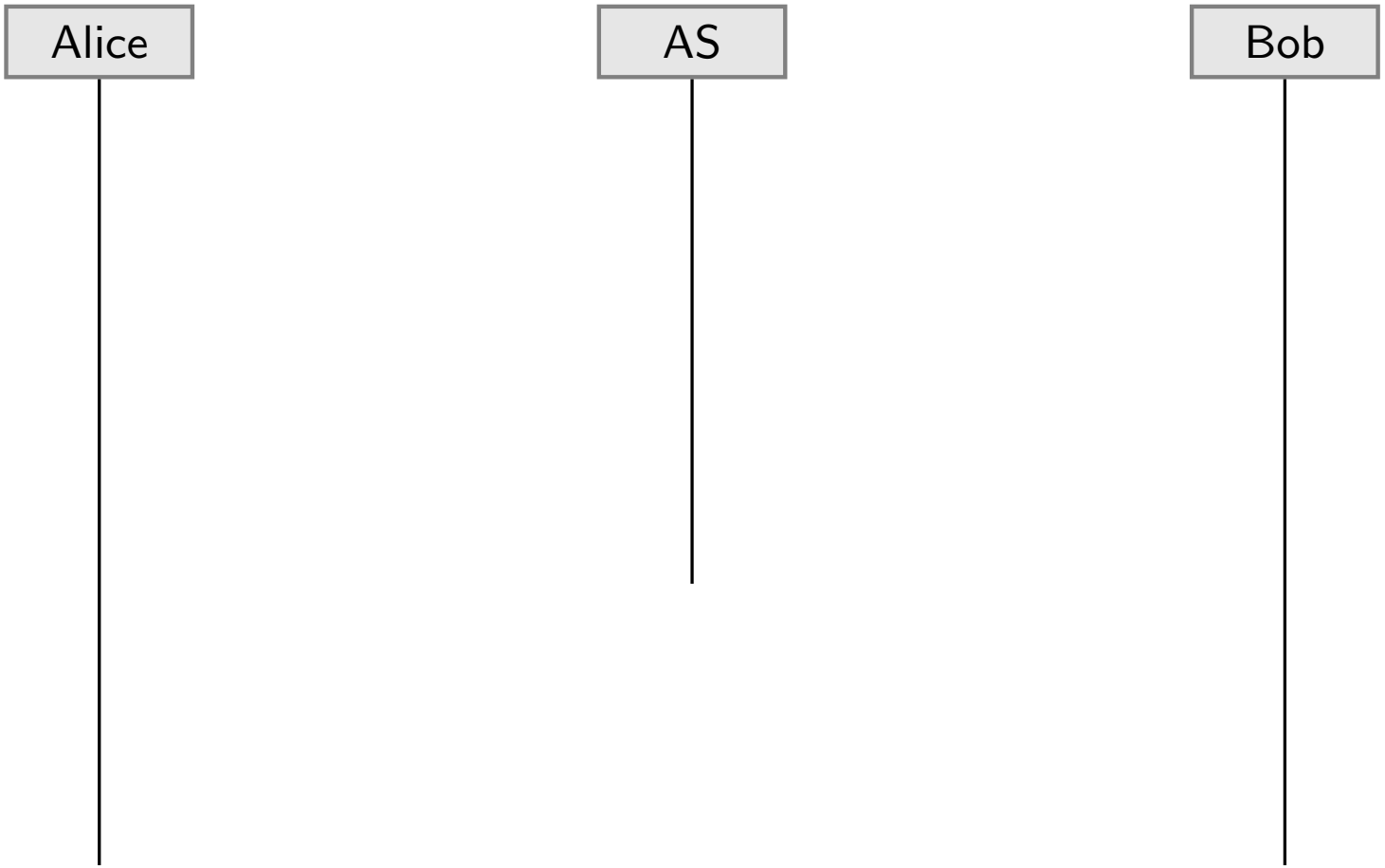
Attack for the Asymmetric Variant of the NSP



Eve cheats on Bob. She pretends to be Alice in reality.

➜ How to protect Bob? How to adapt the protocol?

Corrected Variant of the Asymmetric NSP



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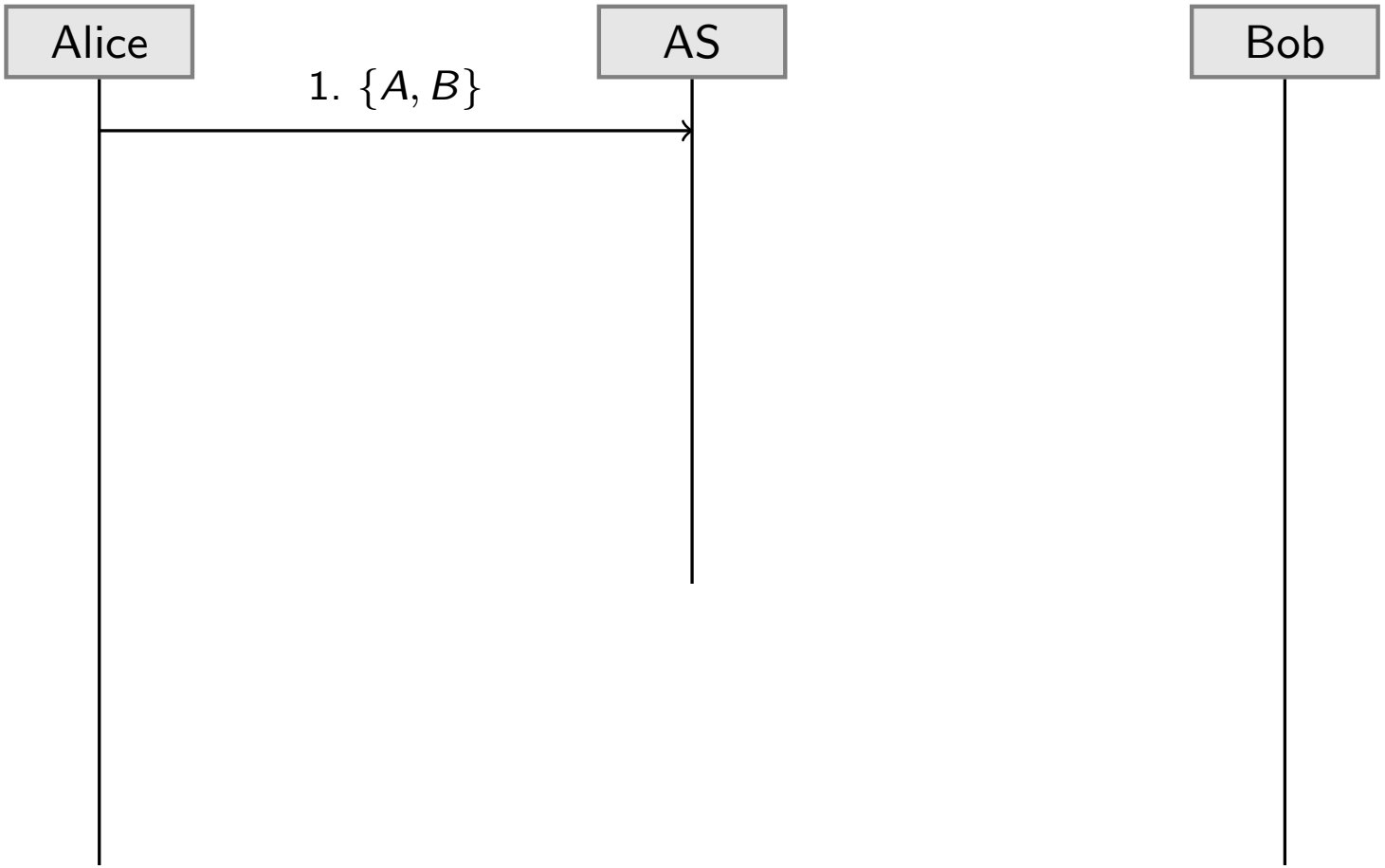

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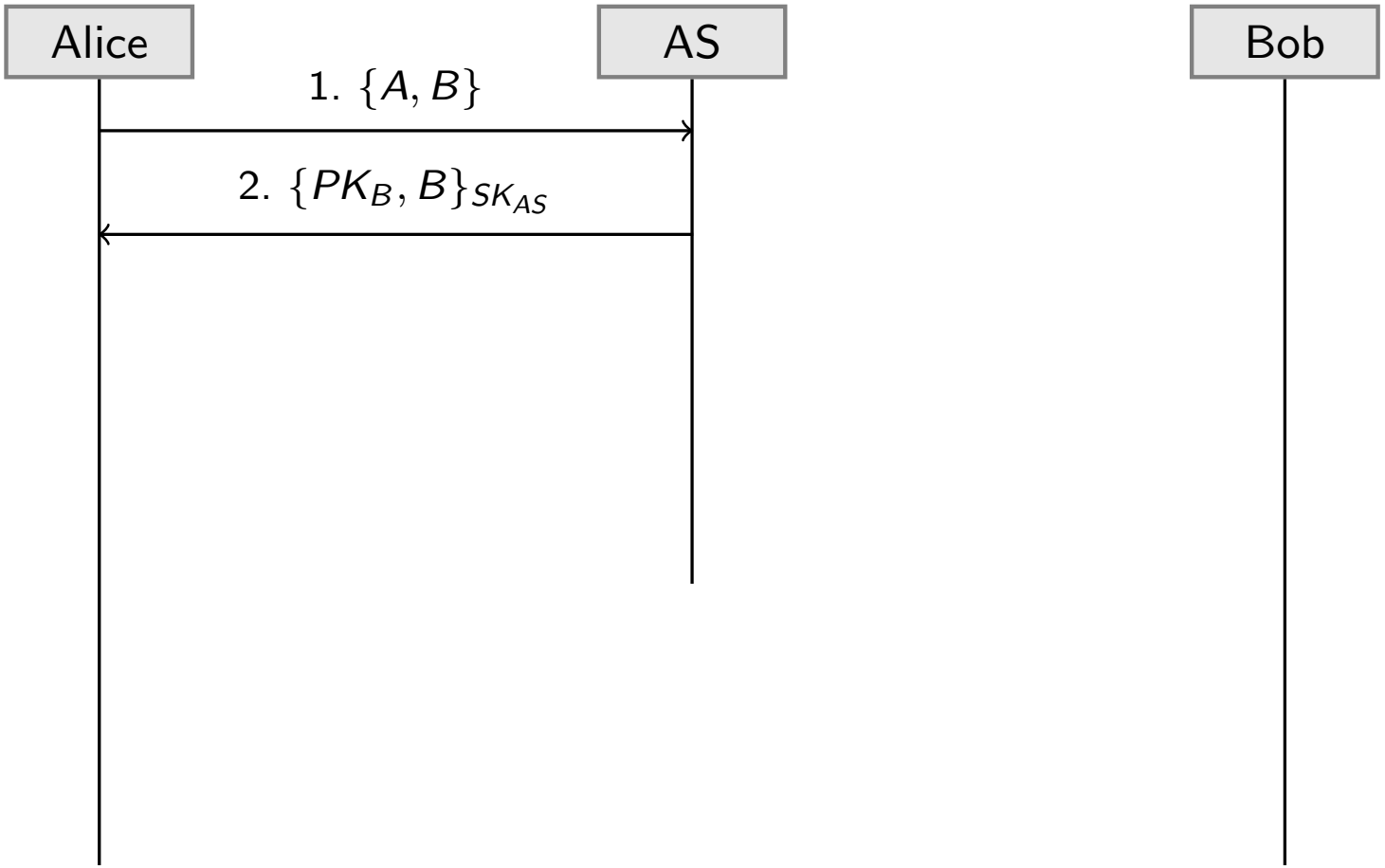

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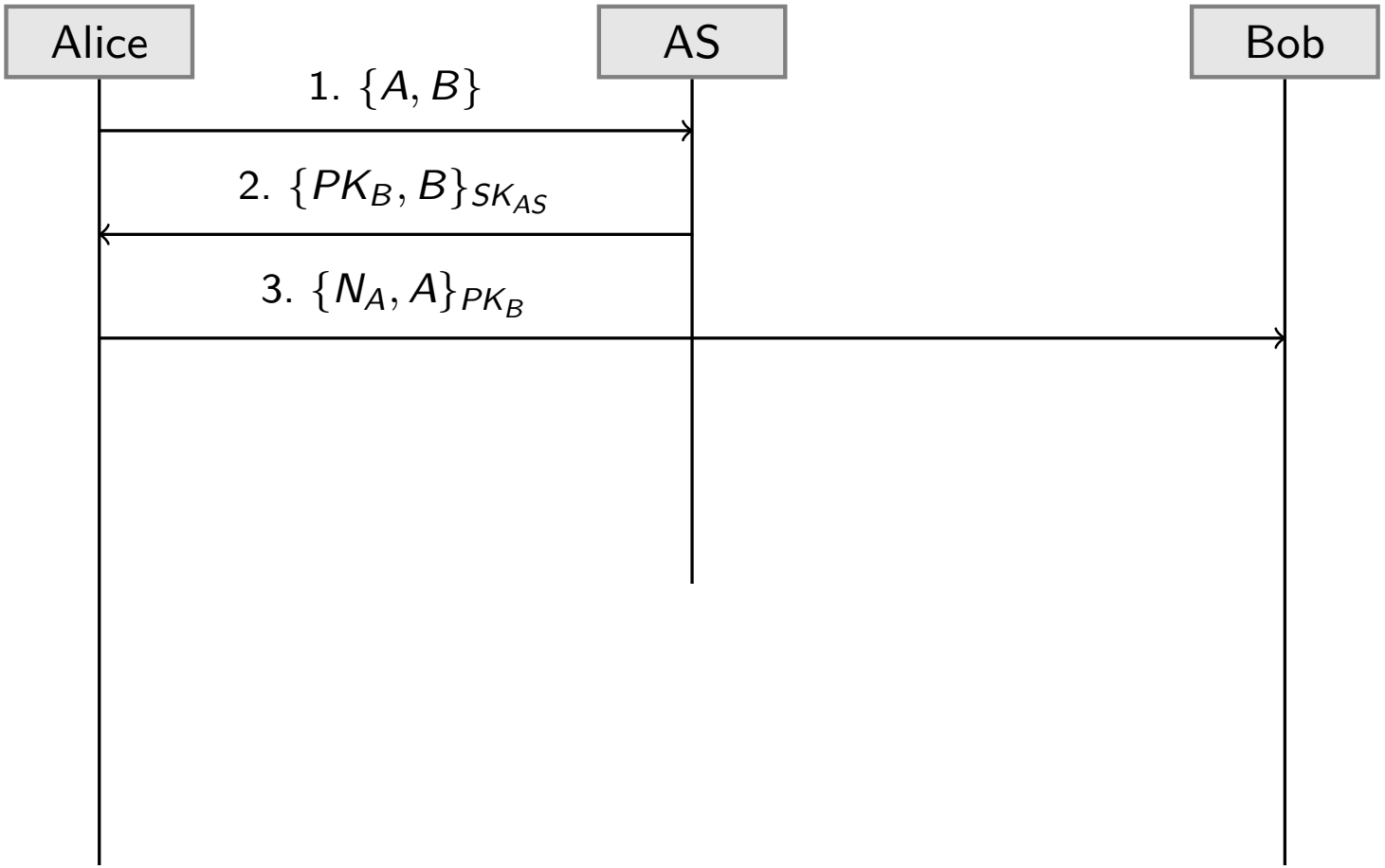

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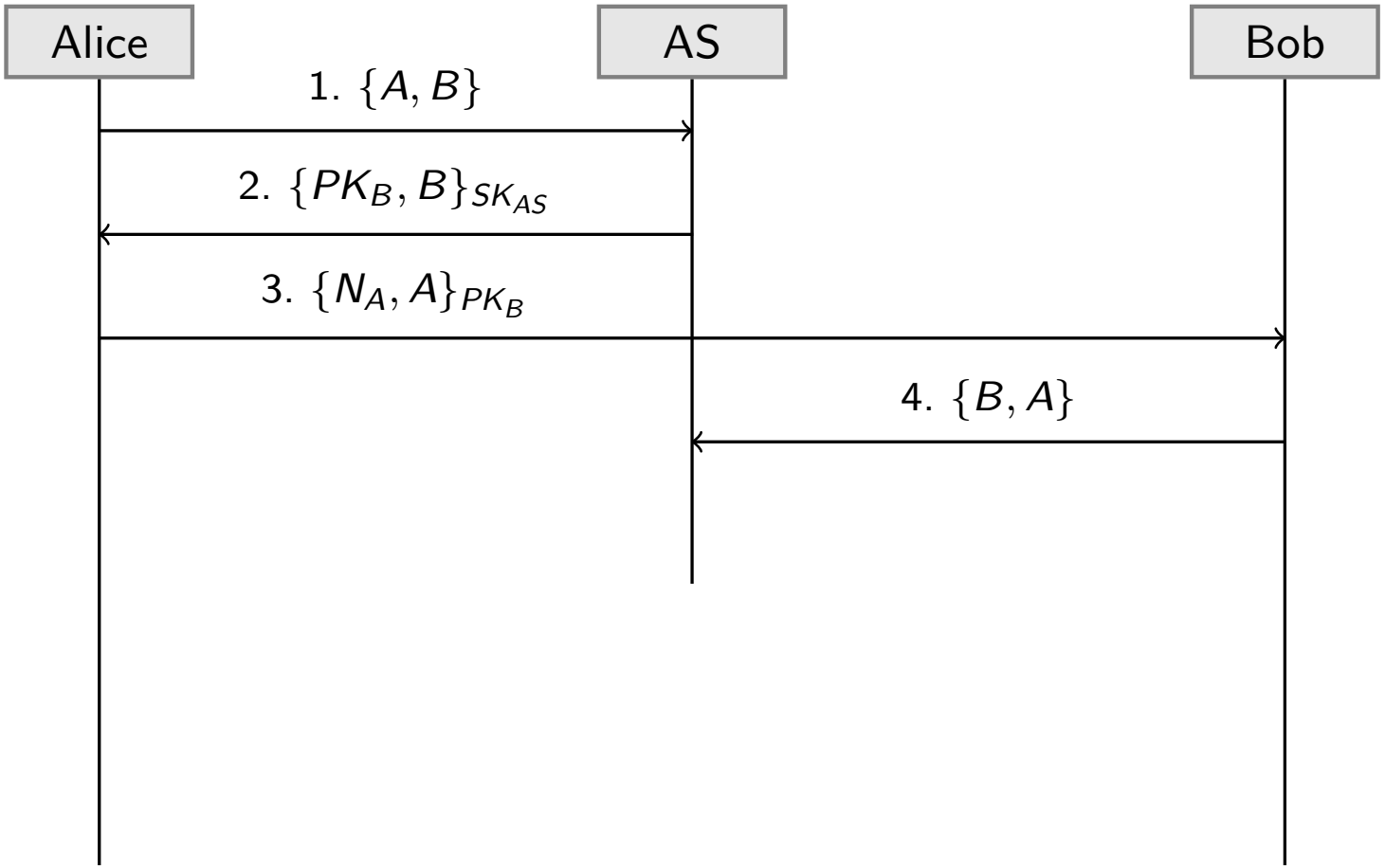

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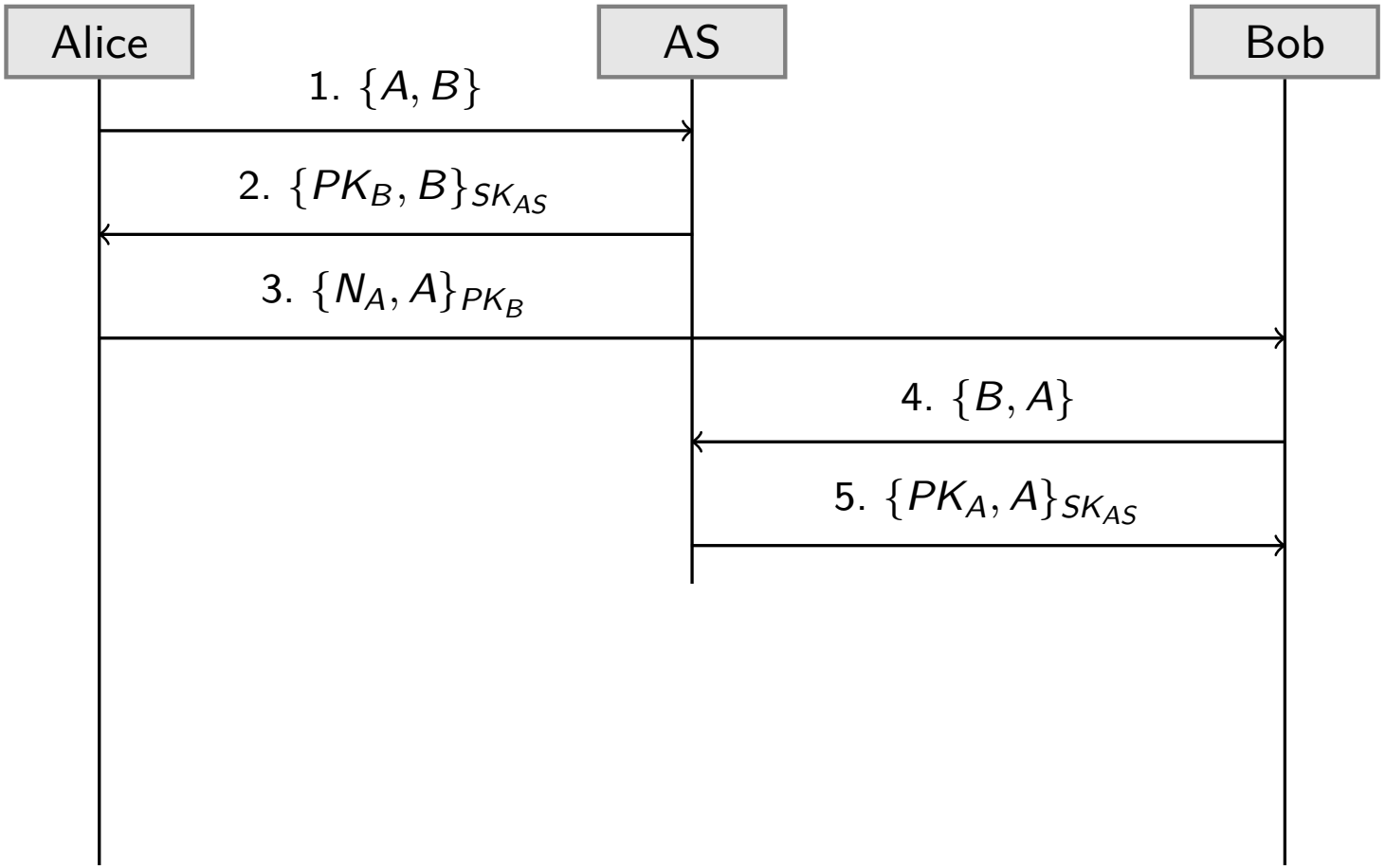

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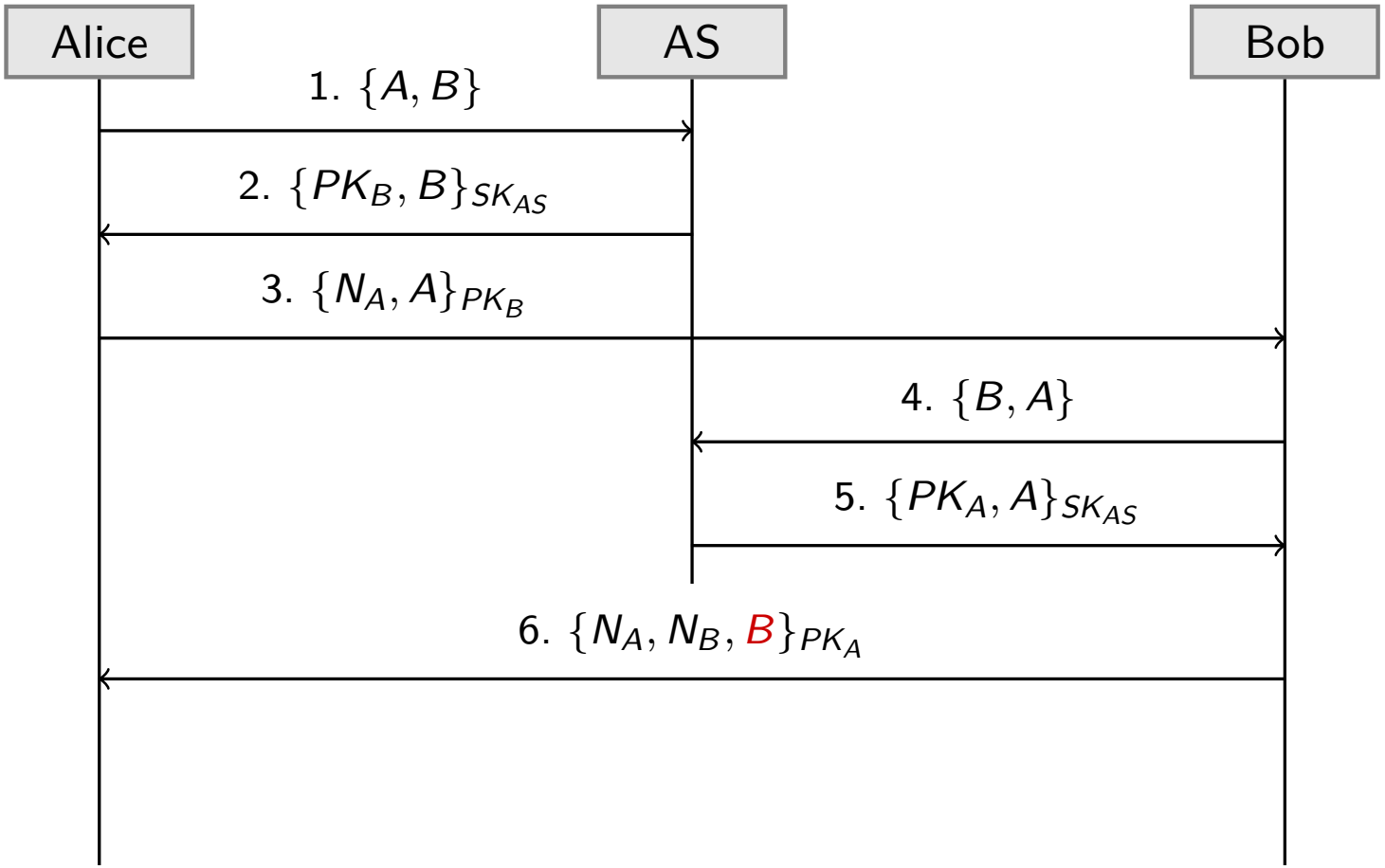

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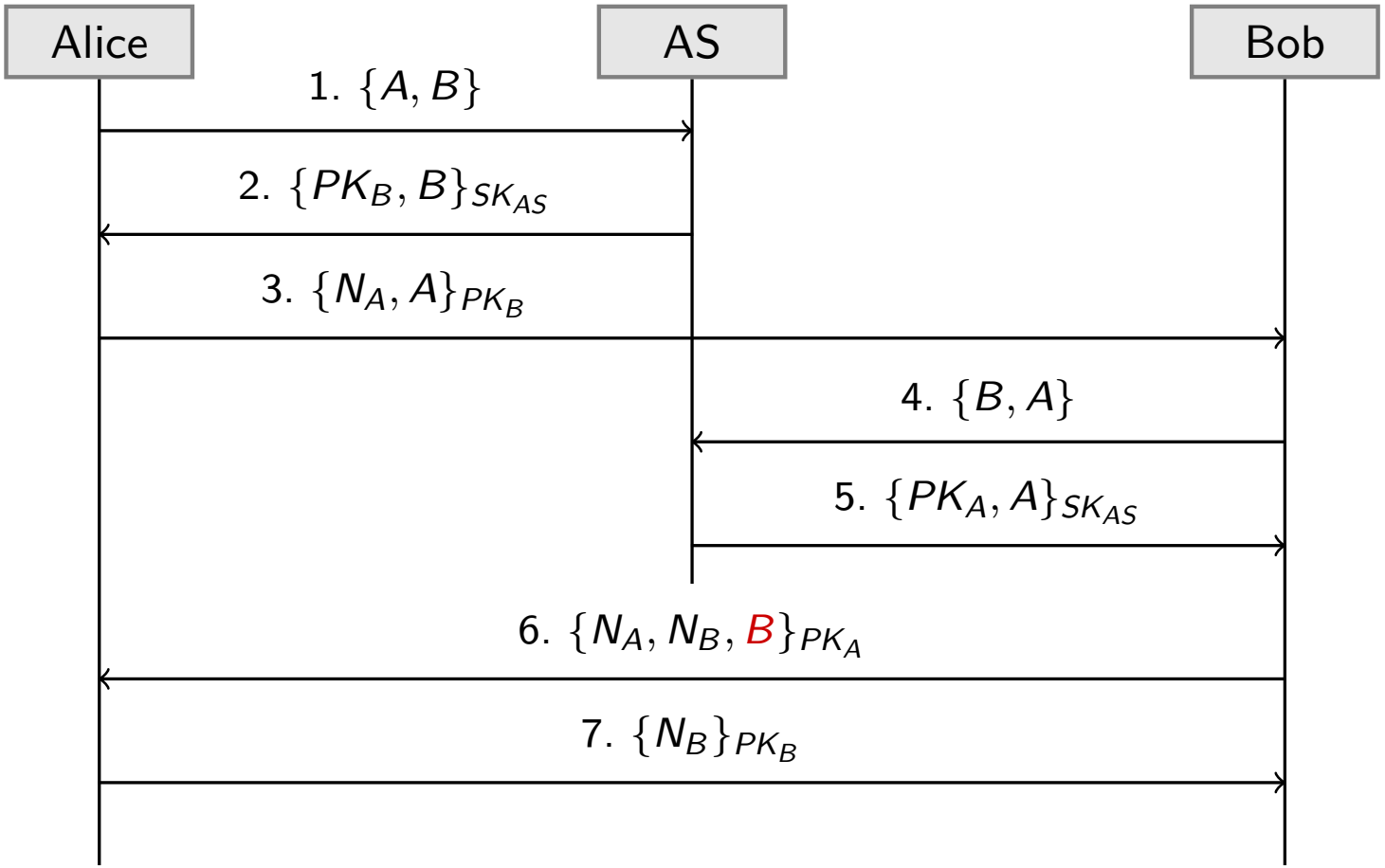

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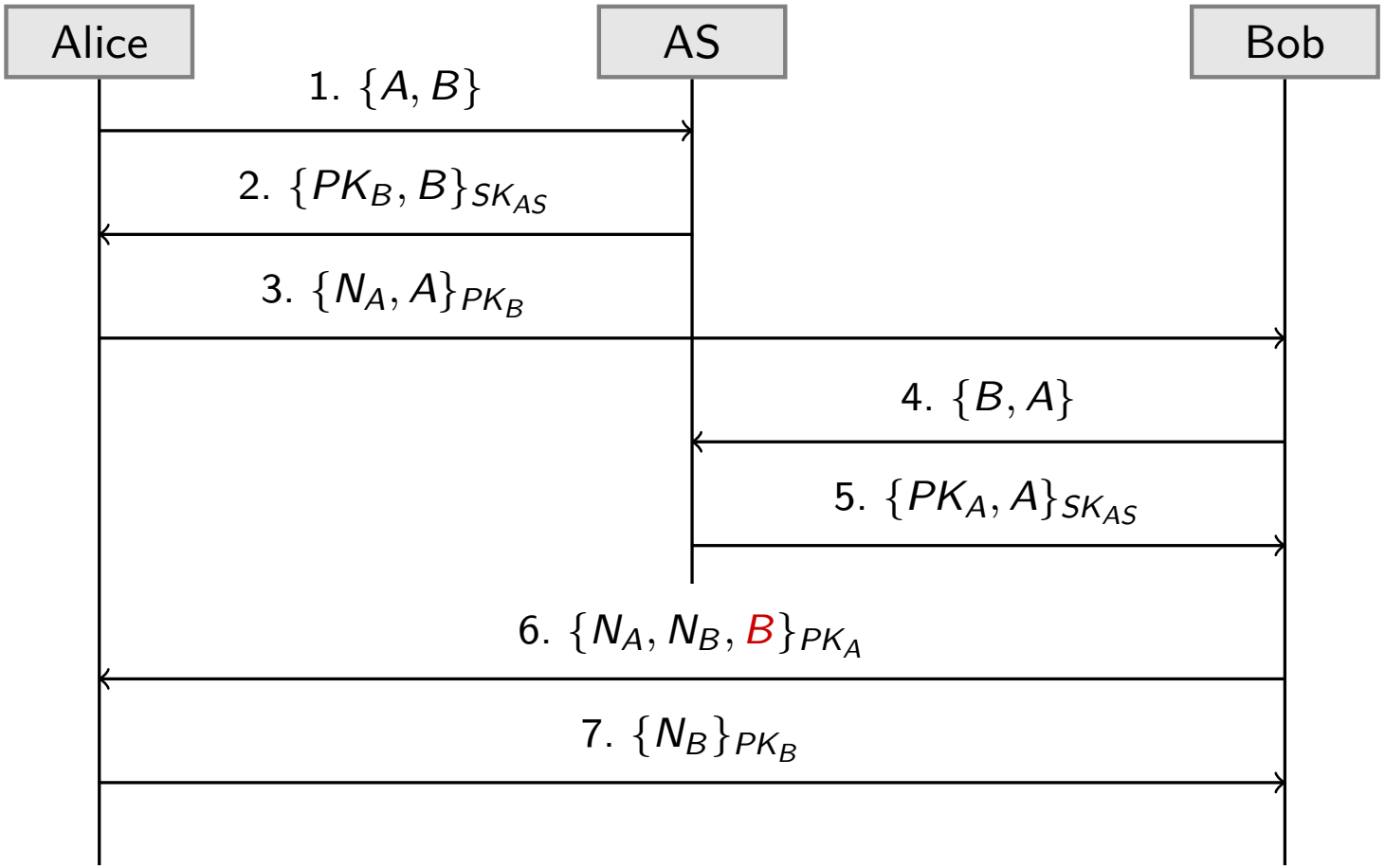

Sending Bob's identity in Step 6 enables Alice to detect the man-in-the-middle attack