Network Security - Week 3

Manuel E. Correia

DCC/FCUP

2025

Authentication Protocols - Examples

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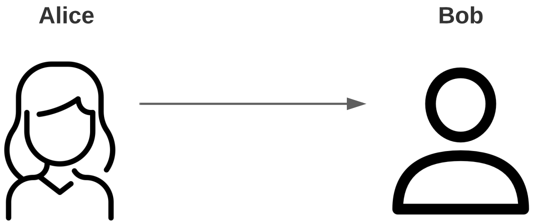
   - **NO** - Machine eats your card (eventually)

Authentication Protocols - For real now



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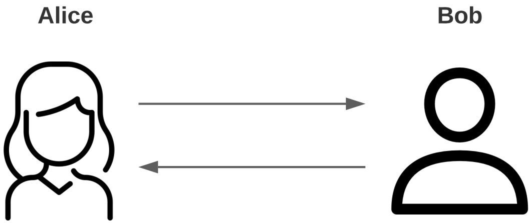

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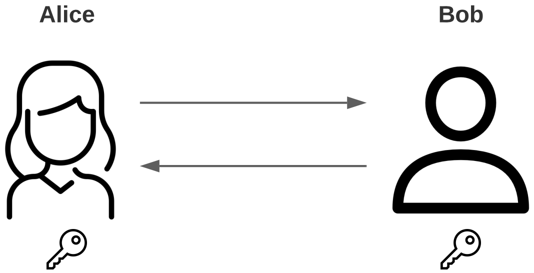

- Alice must prove her identity to Bob
  - They can be humans or computers
- May also require Bob to prove its identity to Alice
  - A.k.a. mutual authentication
- Often entails establishing a session key
  - For cryptographic purposes

Authentication Protocols - Challenges

Stand-alone computer

Relatively simple

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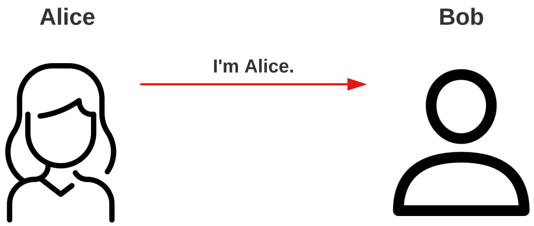
Over the network

Much more challenging

- Adversary can passively observe messages
- Adversary can replay messages
- Active attacks possible (insert, delete, change)

A Naive Authentication Protocol



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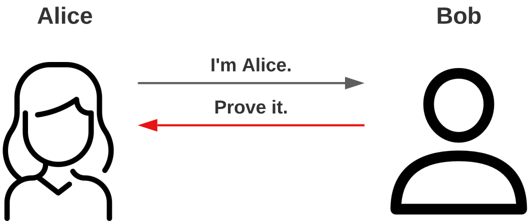

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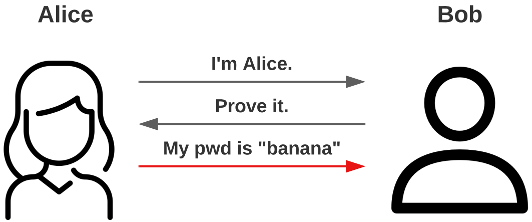

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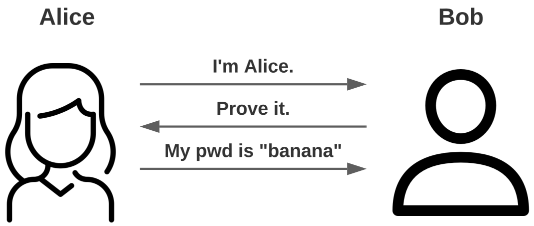

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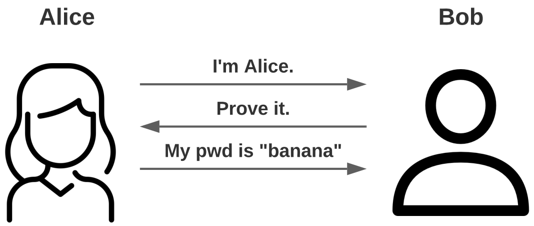
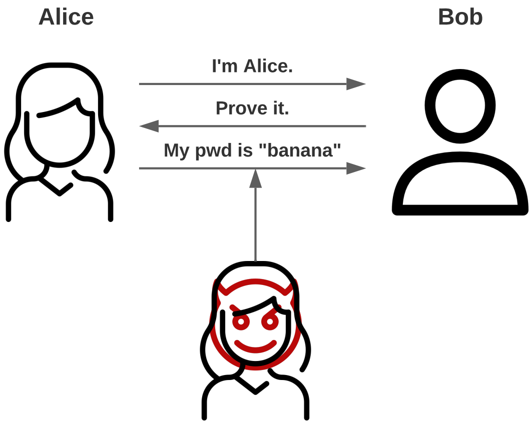
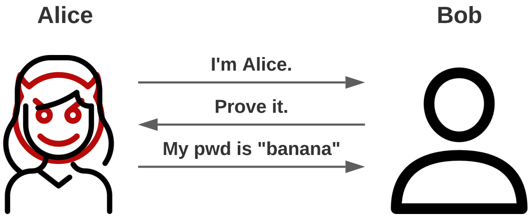


- Simple and (perhaps) OK for a stand-alone machine
- Highly insecure for a networked system
    - Subject to replay attacks
    - Bob must know Alice's password (explicitly)

The network is insecure!



Authentication Attack



- This is an example of a **replay** attack
  - The adversary observed the interaction
  - Used the messages to repeat a communication pattern

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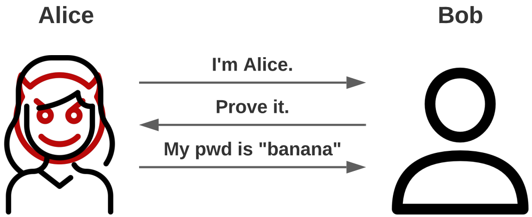

- This is an example of a **replay** attack
  - The adversary observed the interaction
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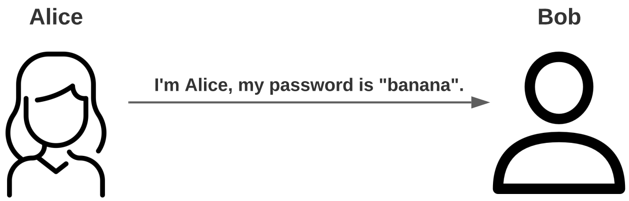
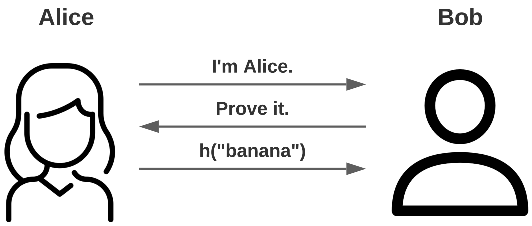
- How can we prevent replay attacks?

A (still pretty) Naive Authentication Protocol



- More efficient
- But doesn't solve the replay attack problems!

Hiding the Exact Password



- This approach hides Alice's password

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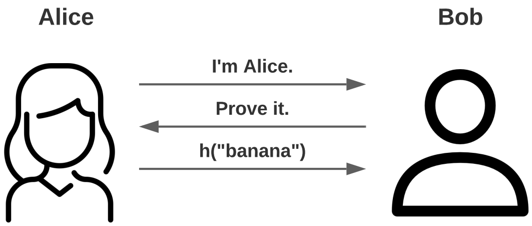

- This approach hides Alice's password
  - From both Bob, and the adversary!

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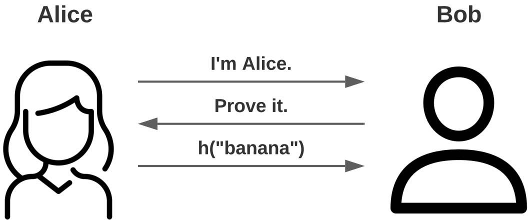

- This approach hides Alice’s password
  - From both Bob, and the adversary!
- But it’s still subject to replay attacks...

Freshness: challenge-response

To prevent replay, we leverage a technique called **challenge-response**

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- Suppose Bob wants to authenticate Alice (our setting)
- Bob sends a *challenge* to Alice
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Challenge

Challenge is chosen such that...

- Replay is not possible
- Only Alice can provide the correct response
- Bob can (efficiently) verify the response

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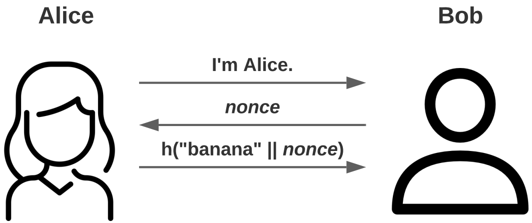
- How can Bob verify the nonce-enhanced response?

Using Nonces



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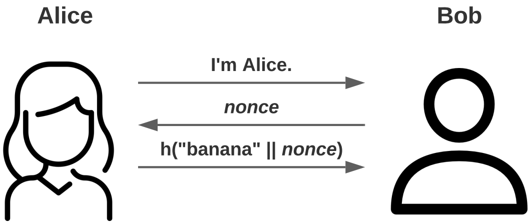

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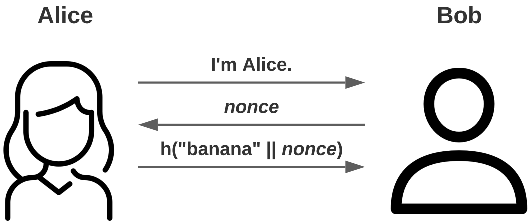

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Password not Necessary

An alternative design

- Alice and Bob share symmetric key k

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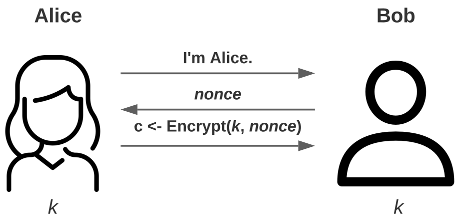

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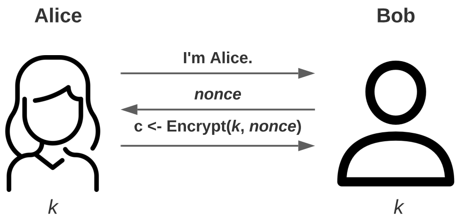

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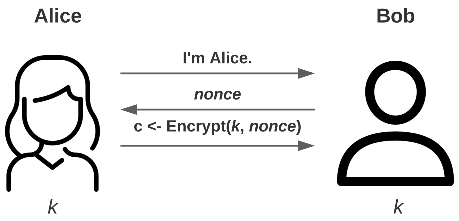

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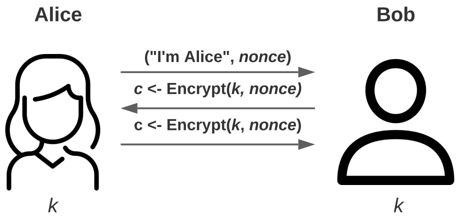
- How can we get mutual authentication?

Using Symmetric Keys - Mutual Authentication



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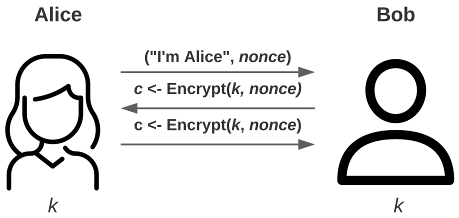

- Works... right?
- Anyone can repeat *c* to “prove” they are Alice.

Mutual Authentication

We have a secure one-way authentication protocol!

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One-way to Mutual

So all we have to do is do the protocol twice:

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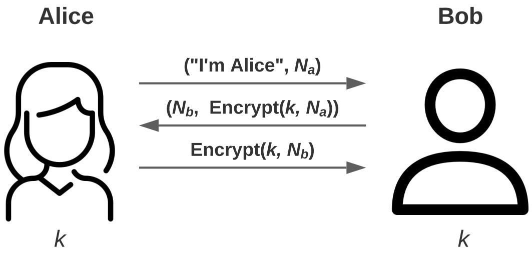
What could possibly go wrong?

Mutual Authentication - Naive Protocol



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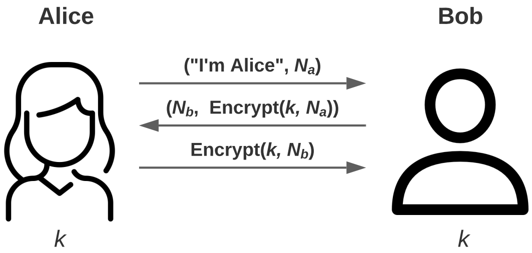
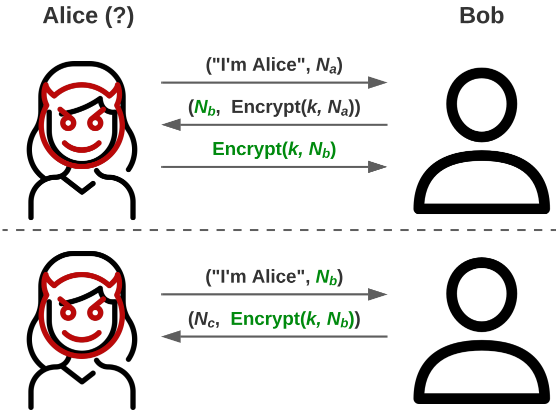


- Ok, now we have mutual authentication!
- Actually...
  - Subject to **reflection** attack

Mutual Authentication - Reflection Attack



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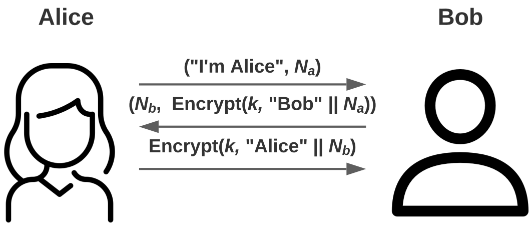
One-way to Mutual

One-way authentication protocol is **not** secure for mutual auth

- Subtle errors (told you!)
- In this case, the obvious solution is not secure

- Problem is related to the fact that the response is not bound to a specific protocol execution
- How can we enforce this one-to-one relation between responses, challenges and identities?

Mutual Authentication - Reflection-proof


Alice
Bob
("I'm Alice", N_a)
(N_b, Encrypt(k, "Bob" || N_a))
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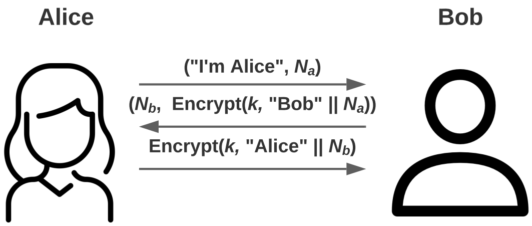

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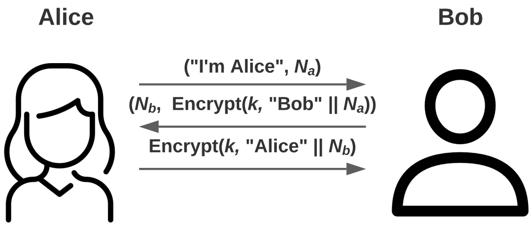
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- Apparently so...
  - At least for that type of attacks!

Using Public-key Cryptography

What if we use asymmetric keys?

- Alice has secret key *sk* and Bob knows public key *pk*

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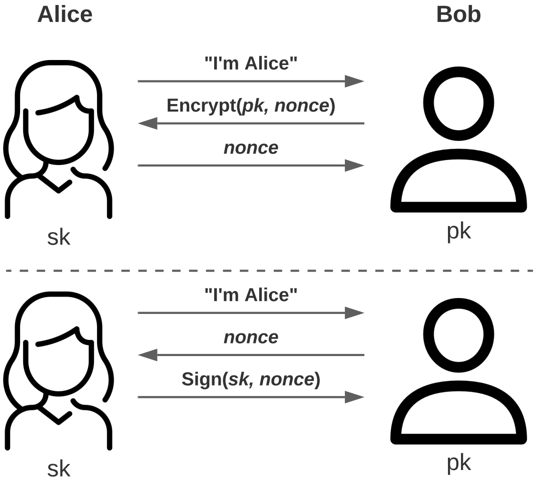
- Signature: $s = \text{Sign}(sk, m)$
- Verification: $T/F = \text{Verify}(pk, m, s)$

Mutual Authentication - PKC



Caution with keys...

It’s (generally) a bad idea to use the same key pair for encryption and signing.

- Keys get lost
- Keys get compromised

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Good practices

- Use one key pair for encryption/decryption or signing/verification
- Use another for authentication

Establish a secure channel

Session key

- A symmetric key for each session

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  - Ephemeral
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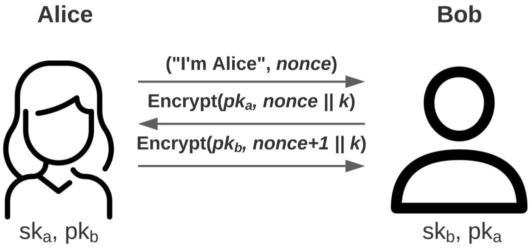
- A symmetric key for each session
  - Ephemeral
  - Used for confidentiality and/or integrity

Purpose

- Alice and Bob use session key to encrypt/authenticate data
- The adversary cannot determine the session key
- Limit amount of data encrypted with a given key
  - Limit damage (data loss) if one key is corrupted

PKC Mutual Authentication - Attempt #1



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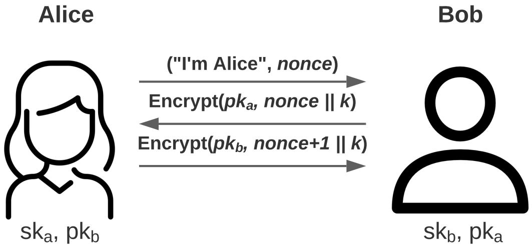
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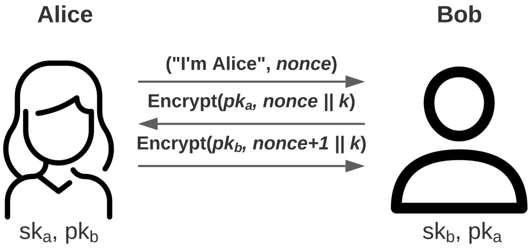
Encrypt(*pk$_a$*, *nonce* || *k*)
Encrypt(*pk$_b$*, *nonce*+1 || *k*)
sk$_a$, pk$_b$
sk$_b$, pk$_a$

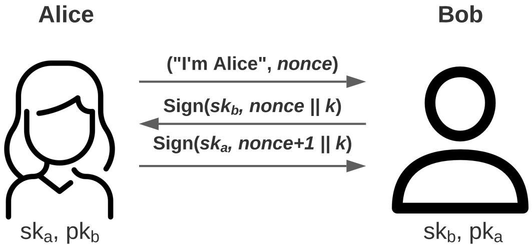
- Session key is secure

PKC Mutual Authentication - Attempt #1

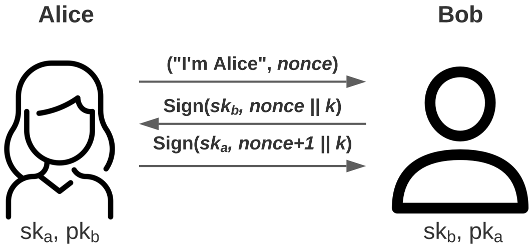

Alice
Bob
("I'm Alice", *nonce*)
Encrypt(pk_a, *nonce* || *k*)
Encrypt(pk_b, *nonce*+1 || *k*)
sk_a, pk_b
sk_b, pk_a

- Session key is secure
- Only Alice is authenticated...

PKC Mutual Authentication - Attempt #2

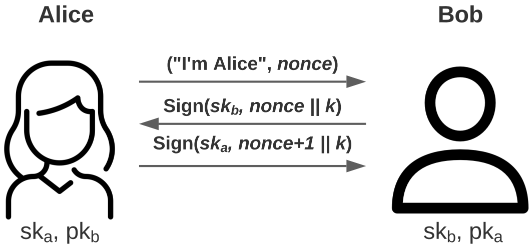


PKC Mutual Authentication - Attempt #2



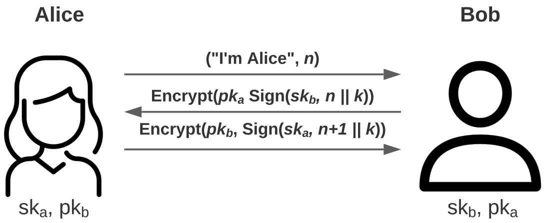
- Mutual authentication is ensured

PKC Mutual Authentication - Attempt #2

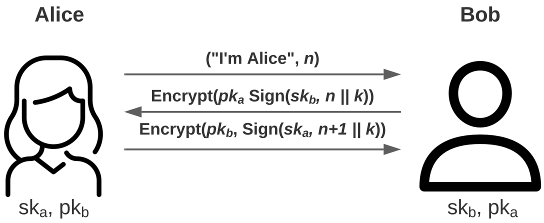


- Mutual authentication is ensured
- But the key is not protected at all!

PKC Mutual Authentication - Attempt #3

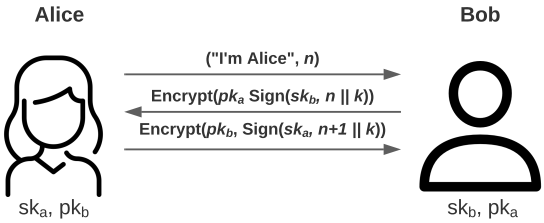

Alice
Bob
("I'm Alice", n)
Encrypt(pk_a Sign(sk_b, n || k))
Encrypt(pk_b, Sign(sk_a, $n+1$ || k))
sk_a, pk_b
sk_b, pk_a

PKC Mutual Authentication - Attempt #3


Alice
Bob
("I'm Alice", n)
Encrypt(pk_a Sign(sk_b, n || k))
Encrypt(pk_b, Sign(sk_a, $n+1$ || k))
sk_a, pk_b
sk_b, pk_a

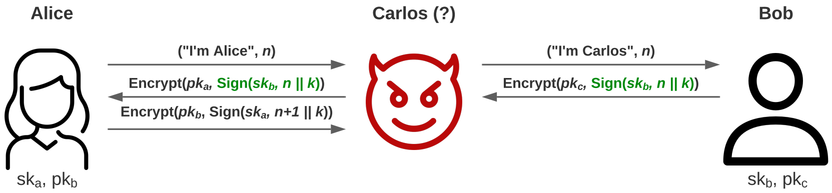
- Is this secure?

PKC Mutual Authentication - Attempt #3


Alice
Bob
("I'm Alice", n)
Encrypt(pk_a Sign(sk_b, n || k))
Encrypt(pk_b, Sign(sk_a, $n+1$ || k))
sk_a, pk_b
sk_b, pk_a

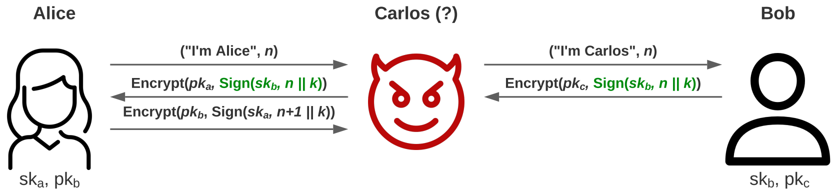
- Is this secure?
- Vulnerable to a MitM attack!

MitM attack



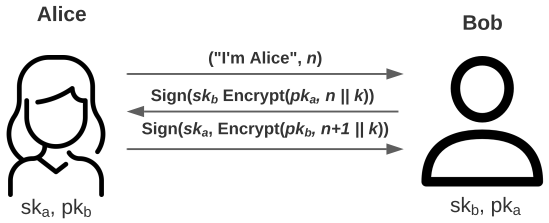
Alice
Carlos (?)
Bob
("I'm Alice", n)
Encrypt(pk_a, Sign(sk_b, n || k))
Encrypt(pk_b, Sign(sk_a, $n+1$ || k))
("I'm Carlos", n)
Encrypt(pk_c, Sign(sk_b, n || k))
sk_a, pk_b
sk_b, pk_c

MitM attack

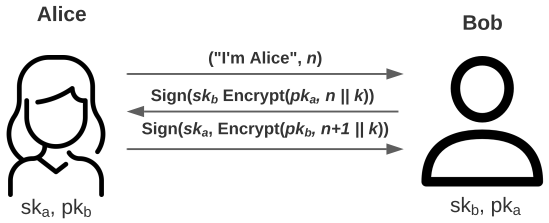

Alice
Carlos (?)
Bob
("I'm Alice", n)
Encrypt(pk_a, Sign(sk_b, n || k))
Encrypt(pk_b, Sign(sk_a, n+1 || k))
("I'm Carlos", n)
Encrypt(pk_c, Sign(sk_b, n || k))
sk_a, pk_b
sk_b, pk_c

- Carlos can get the session key in the clear
- Alice is convinced to use the same session key
- But she isn't talking to Bob!

PKC Mutual Authentication - Attempt #4

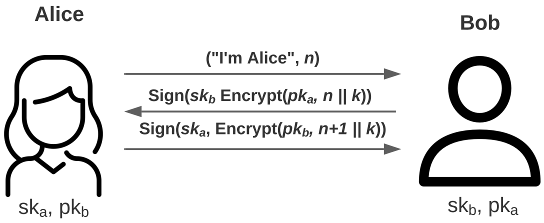

Alice
Bob
("I'm Alice", n)
Sign(sk_b Encrypt(pk_a, n || k))
Sign(sk_a, Encrypt(pk_b, $n+1$ || k))
sk_a, pk_b
sk_b, pk_a

PKC Mutual Authentication - Attempt #4


Alice
Bob
("I'm Alice", n)
Sign(sk_b Encrypt(pk_a, n || k))
Sign(sk_a, Encrypt(pk_b, $n+1$ || k))
sk_a, pk_b
sk_b, pk_a

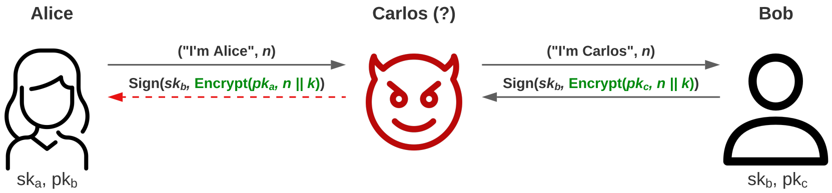
- Is this secure?

PKC Mutual Authentication - Attempt #4


Alice
Bob
("I'm Alice", n)
Sign(sk_b Encrypt(pk_a, n || k))
Sign(sk_a, Encrypt(pk_b, $n+1$ || k))
sk_a, pk_b
sk_b, pk_a

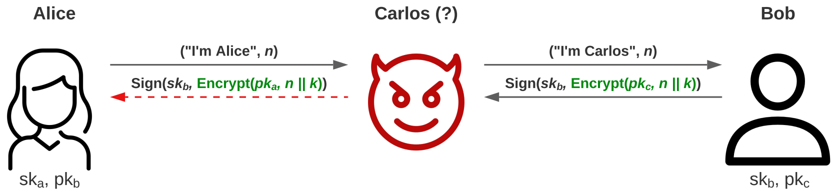
- Is this secure?
- All seems ok!

MitM attack?



- Carlos only has to send a valid signature to convince Alice

MitM attack?



- Carlos only has to send a valid signature to convince Alice
- ... but without knowledge of sk_b, it cannot produce it!

Network Security - Week 3

Manuel E. Correia

DCC/FCUP

2025