Secure Communication Channels

March 21, 2021

Roadmap

Roadmap

Secure Communication Channels

- Many network security problems can be mitigated with the help of **secure channels**, which can guarantee:

  Authentication of the communicating parties, i.e. that the entities at the ends of the channel are who they claim to be

  Integrity/Authenticity i.e. that the messages were not modified in transit

  Confidenciality i.e. that an attacker cannot observe the contents of a message
- Usually, integrity or confidentiality do not make sense without authentication
  - And authentication does not make much sense without integrity

Authentication

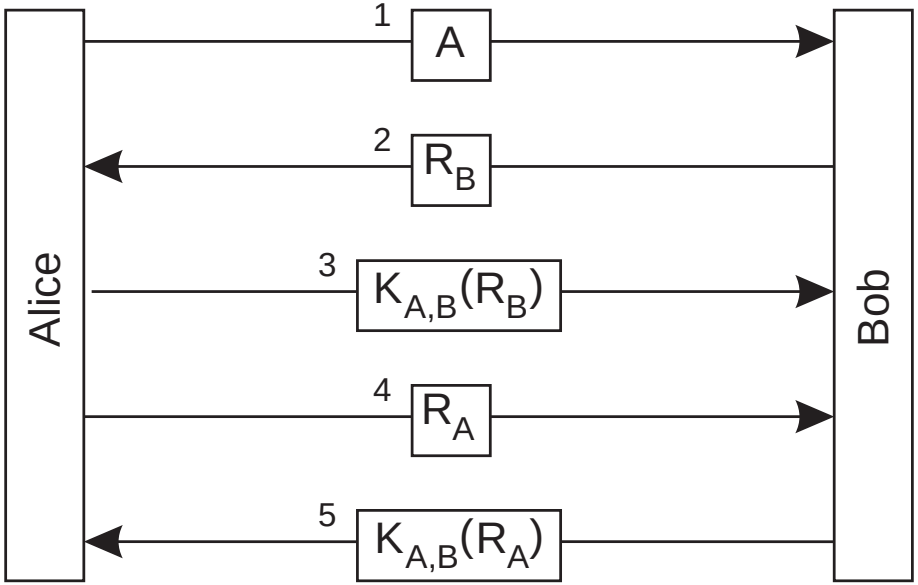
- Usually, during the setting up of a secure (communication) channel the two entities authenticate each other
  - Actually, on the Web, most often only one of the entities is authenticated
- Often, the channel set up phase includes also the establishment of a **session key** that is used to ensure integrity or confidentiality
- Passwords are not appropriate for authentication while setting up a secure channel
  - Instead, one often uses *challenge/response* protocols

Roadmap

Shared Key Authentication Protocols

Assumptions The parties (Alice/A e Bob/B) at the two ends share a secret key ($K_{A,B}$)

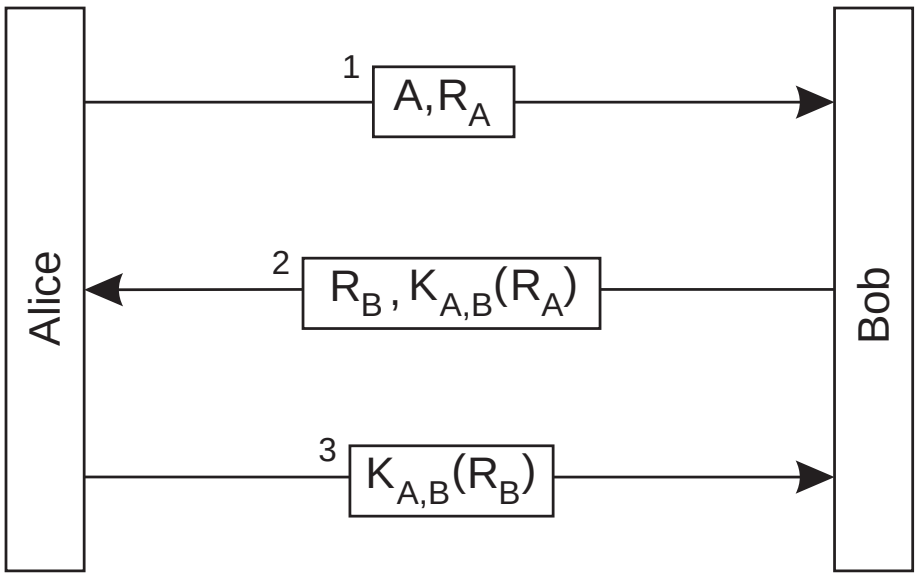
- How they can get the secret key, will be discussed shortly



- Messages 2 and 3 allow B to authenticate A;
- Messages 4 and 5 allow A to authenticate B;

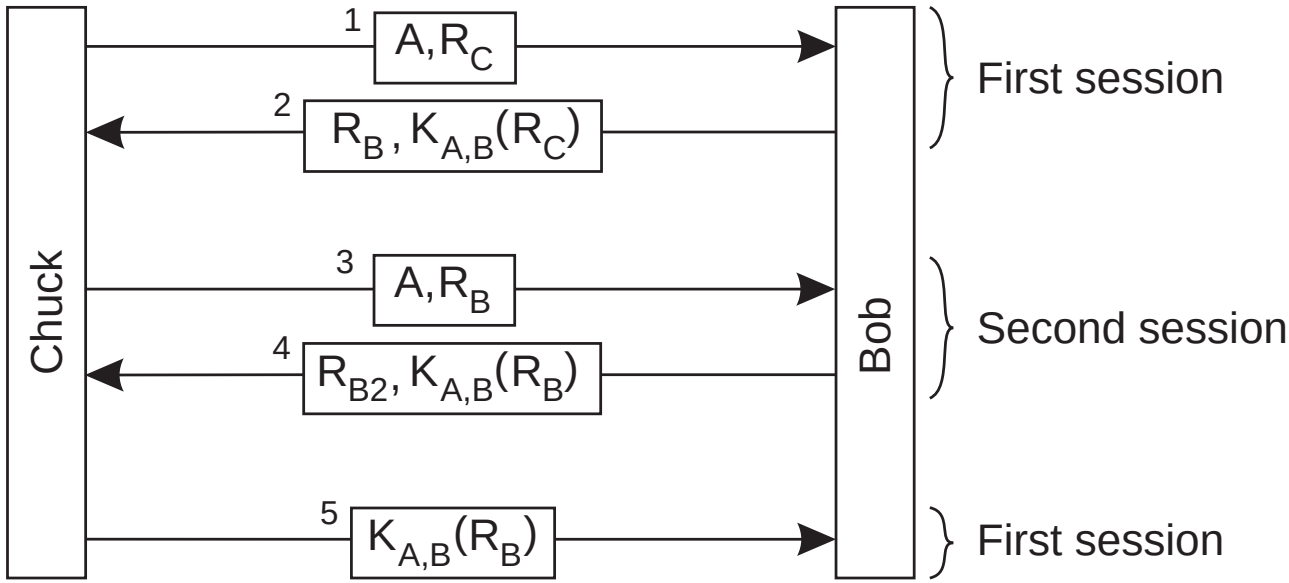
"Optimized" Authentication Protocol with Shared Key

- We could ***optimize*** this protocol as follows:



- But this is vulnerable to a **reflection attack**.

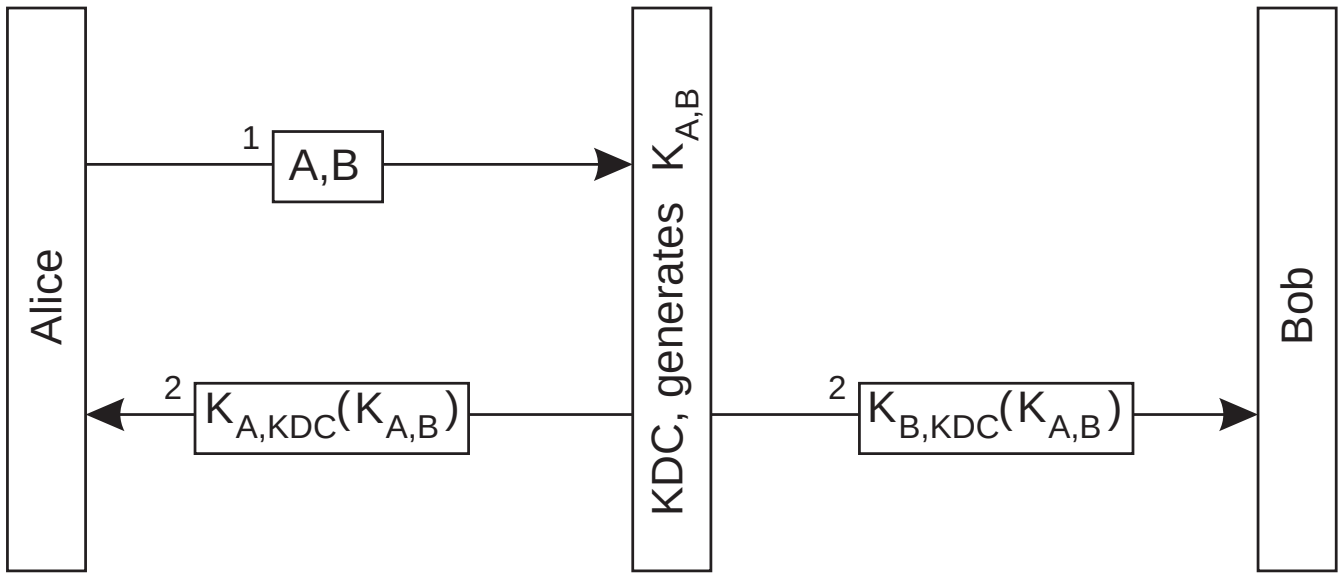
Reflection Attack



- The problem is that the 2 parties use the same challenge in two different executions
- A principle to avoid reflection attacks is to make the protocol asymmetrical:
  - E.g. require one party to use an odd challenge and the other one an even challenge

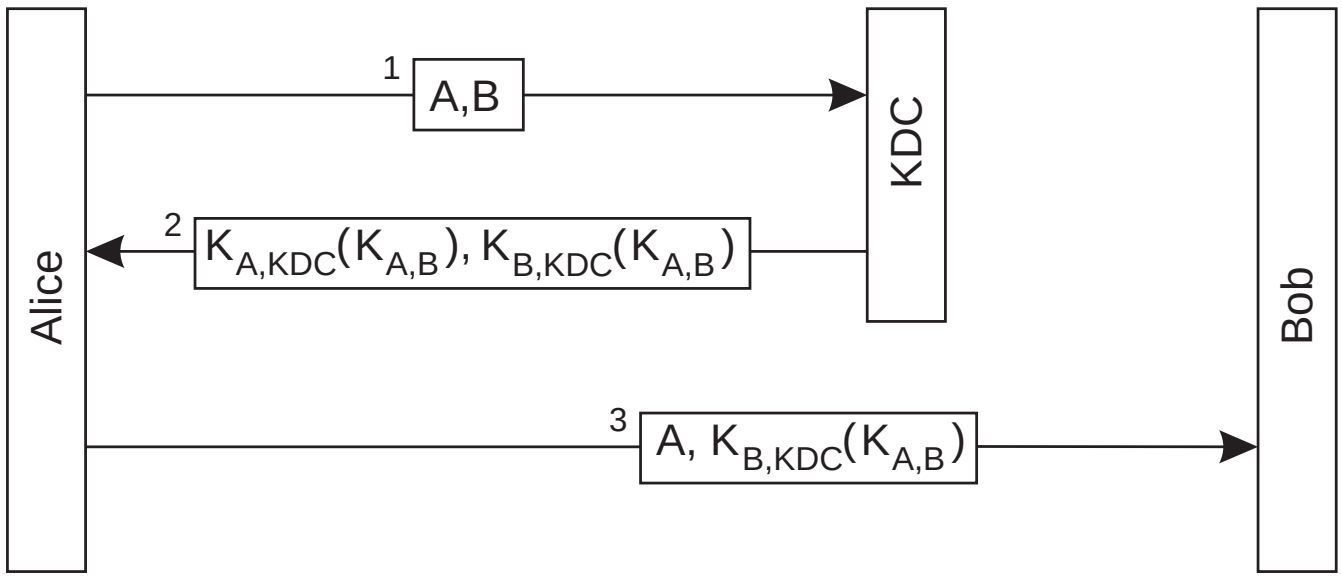
Mediated Athentication (with KDC) (1/2)

- Shared key authentication (without a KDC) is not scalable:
  - Each pair of principals must share a secret key.
- A solution is to use an mediator, the *Key Distribution Center (KDC)*, in which all principal must **trust**.
  - The KDC shares a secret key with each principal
  - Upon request, the KDC generates secret keys for sharing between principals that wish to communicate securely



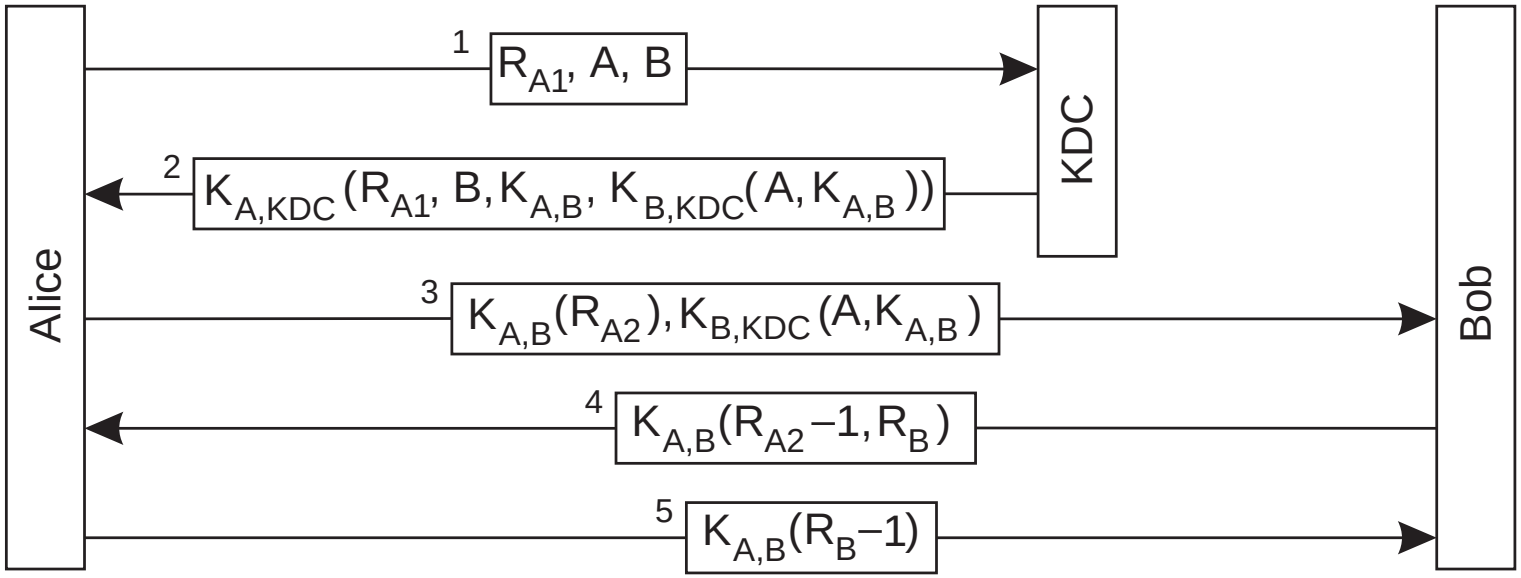
Mediated Athentication (with KDC) (2/2)

- What if B receives A's first message to B, before it receives the key from the KDC?



- This protocol is not complete:
  - A e B must authenticate mutually
    - I.e. prove that they know $K_{A,B}$

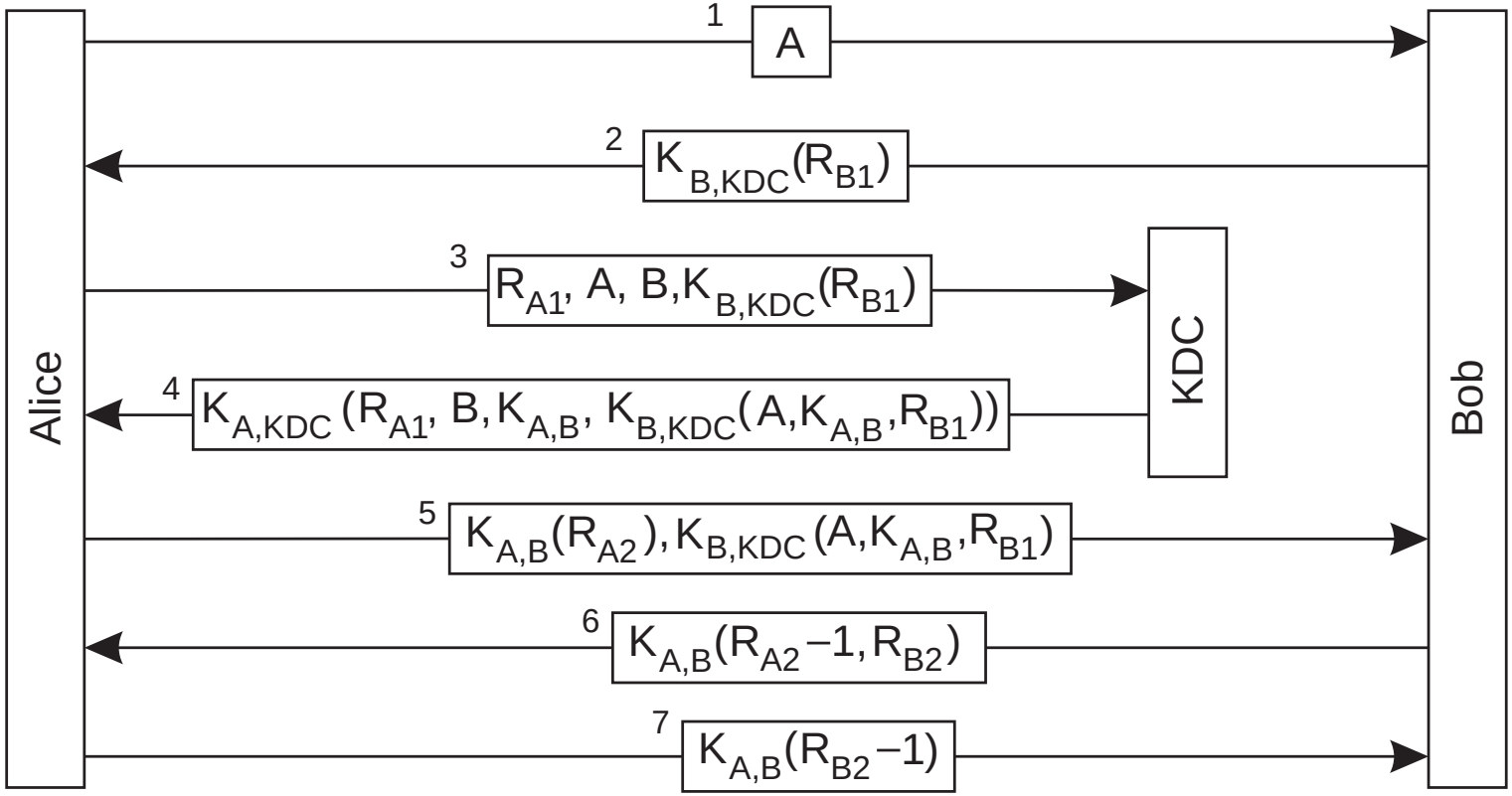
Needham-Schroeder's Protocol (1/2)



- The *nonce* (R_{A1}) is used to ensure that A comunicates with the KDC (it prevents *replay attacks*).
- The KDC includes B's identity in the response, to prevent C from impersonating B, by replacing B with C, in message 1.
- Messages 3 and 4 allow A to authenticat B
- Messages 4 and 5, allow B to authenticate A
- $K_{B,KDC}(A, K_{A,B})$ in message 2 is known a the *ticket to Bob*

Needham-Schroeder's Protocol (2/2)

- In 1981, Denning and Sacco found a vulnerability, if C learns A's key ($K_{A,KDC}$), even if it has been replaced:
  - In this case, C may impersonate A, in its communication with B
- In 1987, Needham and Schroeder published a new version of the protocol that fixed that vulnerability



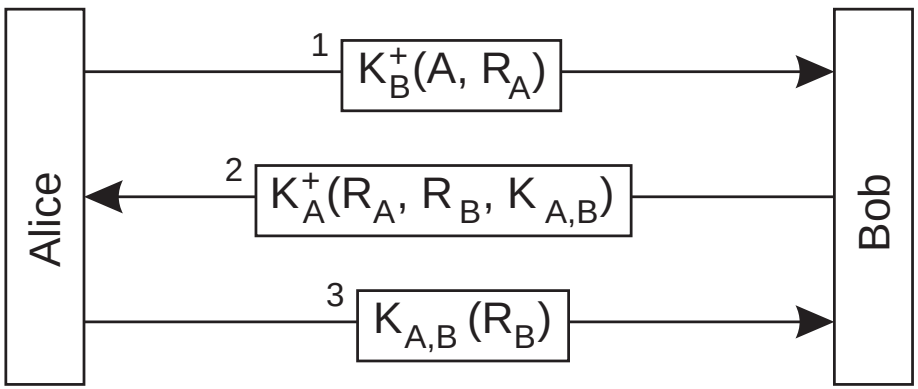
Roadmap

Public-key Authentication

Assumptions

1. The principals (Alice/A and Bob/B) know the public keys of one another
   - Below, we discuss how one can learn the public key of a principal
2. Private keys are *known exclusively* by the respective principal

Basic Protocol

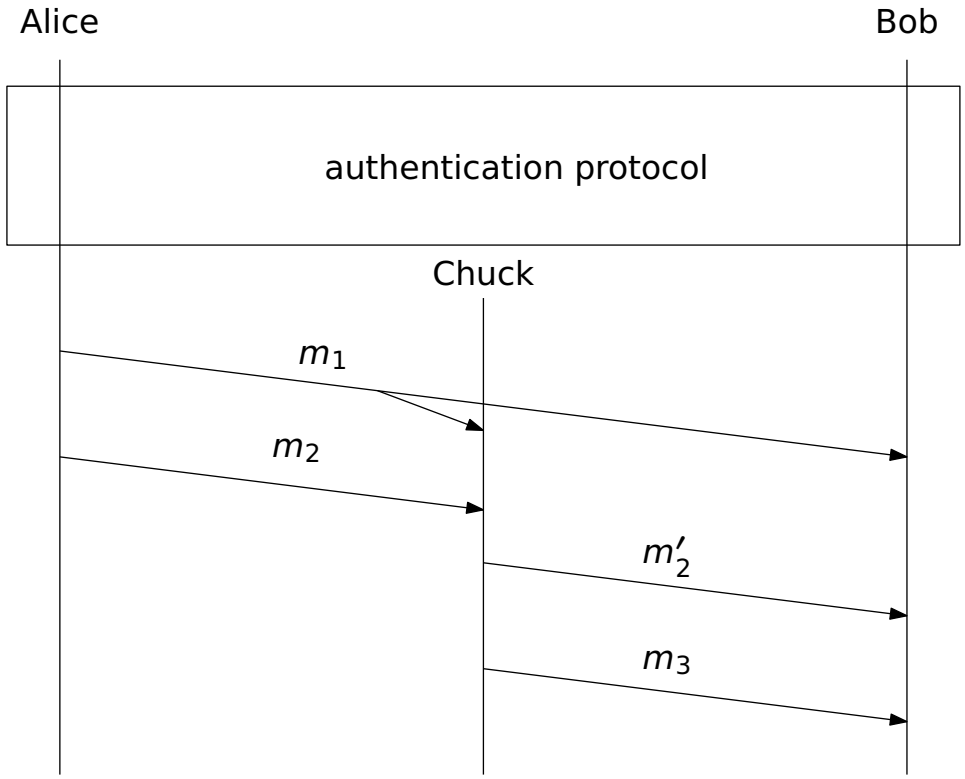


- In addition to authenticate both principals, this protocol also negotiates a **session key**
  - The share key can be used to ensure confidenciality and integrity

Roadmap

Data Integrity/Confidentiality (1/2)

- Authentication upon setting up a secure channel is not enough
  - If after authentication no measures are taken, i.e. the messages are exchanged in the clear, an attacker can not only intercept these messages but also modify them or even fabricate them



- To ensure authenticity/integrity and confidentiality of the messages exchanged after authentication, A and B can use cryptography

Data Integrity/Confidentiality (2/2)

- Although encrypting a message can ensure confidentiality, it may not be sufficient to ensure integrity
  - In secure communication, by **integrity** we mean that the channel should be able to detect modification of the messages
  - But the secure channel may not have enough context information to determine whether or not the message has been modified

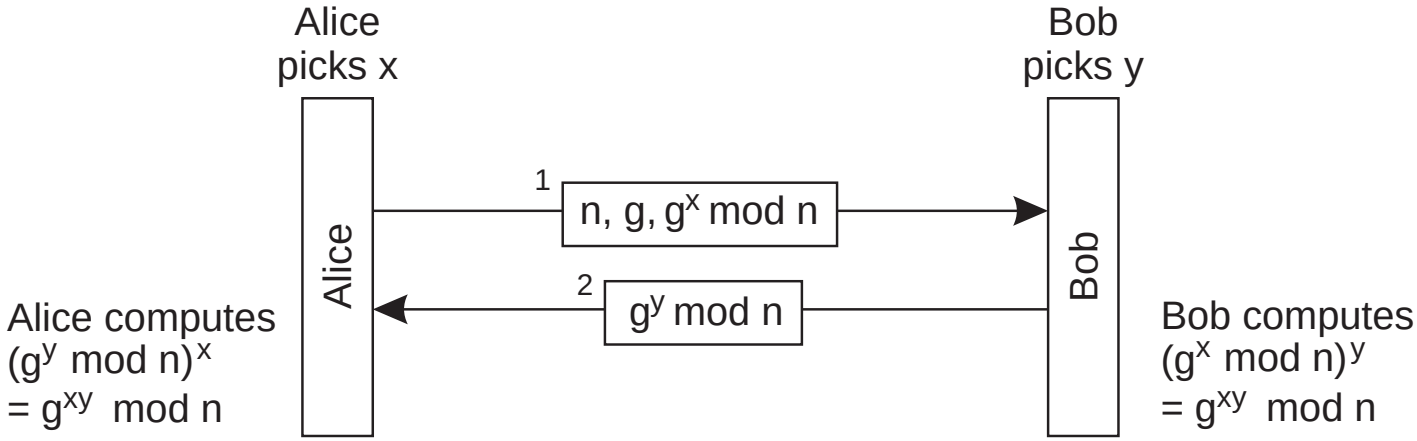
  One needs to use **authenticated encryption**
  - An obvious approach is **Encrypt-then-MAC (EtM)**, i.e. first encrypt the message then compute a MAC of the ciphtertext (note that different keys should be used)
  - But there are approaches that use a single key

Session Key

- To ensure confidentiality, it is important to use a **session key** that is different from the key used for principal authentication:
  - Public key encryption is less efficient the shared key encryption
  - Keys *wear out* with use: the more ciphertext an attacker has, more likely it is she will succeed finding the key
  - The use of the same key over multiple sessions, makes *replay attacks* more likely to succeed
  - If a session key is compromised, the attacker will not be able to decrypt messages exchanged in other sessions
- Actually, most secure channels have provisions to change keys in the middle of a session
  - This prevents compromising the key or replay attacks in long running sessions

Diffie-Hellman Key-Agreement Protocol (1/2)

- Let n be a large prime and g a number less than n with some properties (for additional security)
  - These number must be known *a priori*, and may be public
- Each principal chooses a private and secret large number, x and y and executes the following protocol:



- The session key can be computed as $g^{xy} \bmod n$

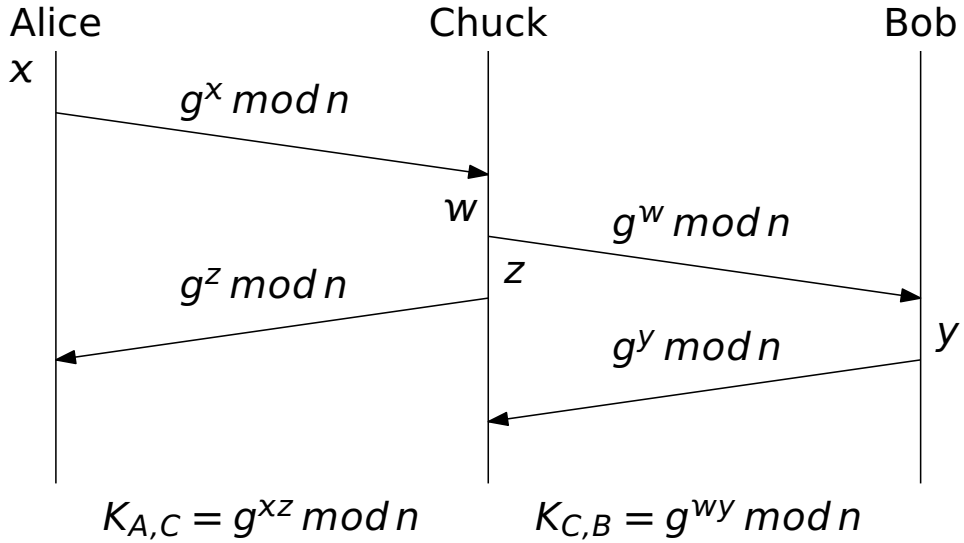
Question Why can't an attacker overhearing the communication do the same?

Answer It would have to compute the discrete logarithm, which is considered computationally tractable

  - However, there are known efficient algorithms for special cases

Diffie-Hellman Key-Agreement Protocol (2/2)

- As described, the DH protocol is vulnerable to a man-in-the-middle attack:



- To defend it against such an attack, we can use:

  Published DH numbers e.g. *A* would publish $g^x \bmod n$ somewhere, and always reuse x for computing the session key (same for *B*)

  Authenticated DH i.e. messages of the DH-protocol are authenticated to prevent tampering. This requires:
  - Either a secret key shared among *A* and *B*
  - Or a public-keys (and private) for *A* and *B*

Perfect Forward Secrecy

Question Why do we need yet another protocol (DH)?

- It is possible to generate a secure session key from the nonces, i.e. random numbers, that are usually exchanged by the authentication protocols
  - If we follow certain rules

Answer **Perfect forward secrecy**, i.e. an attacker will not be able to decrypt a recorded session even if (s)he later

- Breaks into both A and B
- Steals their long-term secrets

as long as A and B delete their secret numbers (x and y, respectively)

Watch out Schor has invented polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer

- DH and RSA will become insecure when quantum computing becomes practical
  - According to the Wikipedia, the largest integer factored using a quantum computer was 291 311, a 19-bit value, in 2017

Session Key for Unidirectional Authentication

- The Web (SSL/TLS) uses mostly public key cryptography **unidirectional** authentication:
  - Clients authenticate Web servers using public key cryptography
  - Servers do not authenticate clients
    - Public key management at Internet scale is nof easy
- In this case, the session key can be computed as follows:
  1. The client can generate (randomly) the session key and send it to the server encrypted with the latter's public key
  2. Client and server can execute Diffie-Hellman, but only the server's messages are authenticated
- In any case:
  - The client is guaranteed (under some assumptions) that it has set up a secure channel with the server
  - The server
    - has **no** idea who is on the other end of the channel
    - is guaranteed that on the other end of the channel is always the same client

Roadmap

Secure Channel Implementation Layer

- In principle, it is possible to implement a secure channel at any layer of the communication stack:

  Data Link e.g. Wi-Fi Protected Access (WPA)
  - Protects only the communication in one "segment".

  Network - e.g. IPSec
  - Usually this is implemented by the OS
  - Uses IP addresses for identification – and authentication

  Transport - e.g. SSL/TLS
  - Requires applications to be modified – (*sockets*);

  Application - e.g. `ssh`, SMIME, PGP
  - Protects application-specific *objects*, e.g. email messages stored on servers

Roadmap

Key Distribution

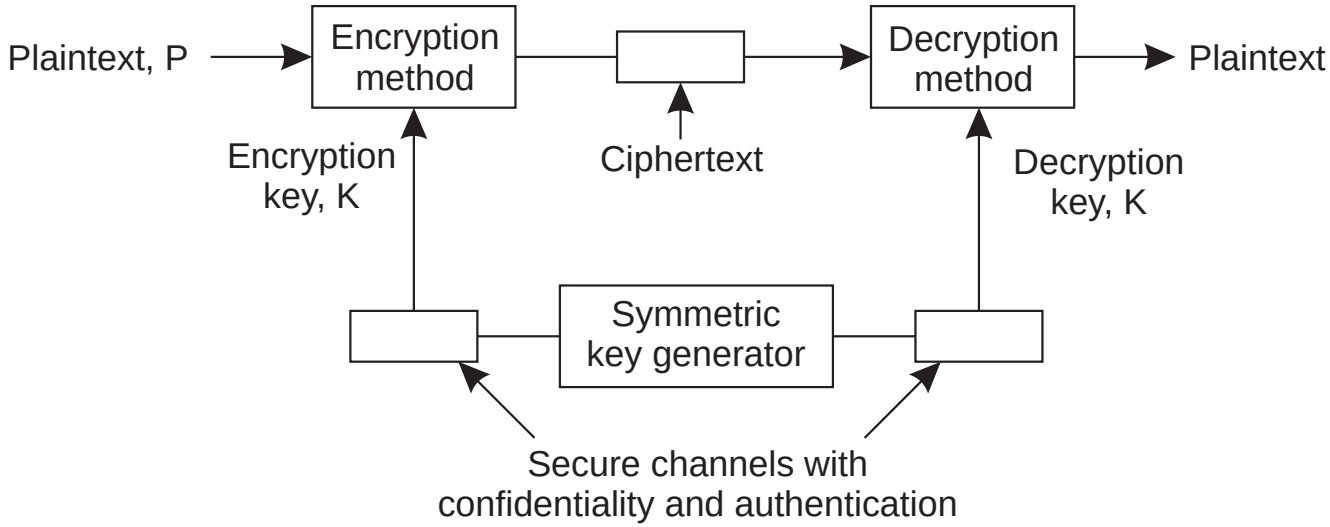
Problem How to get the keys required by the authentication protocol?

- All protocols assume that a principal knows a key bound to the other principal

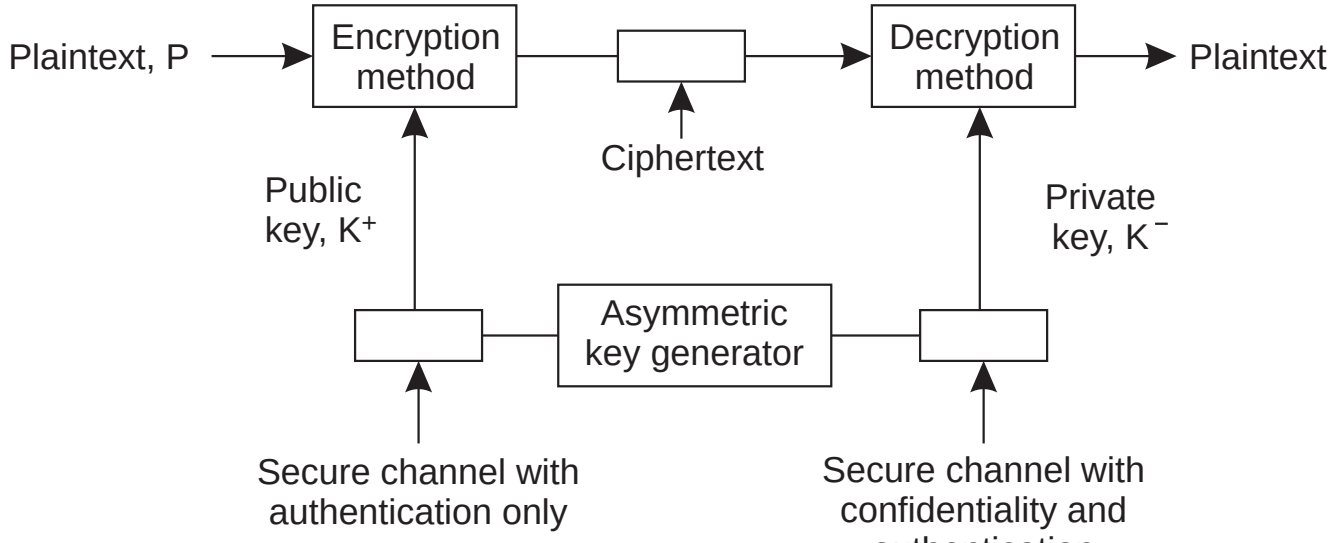
  Shared key in the case of symmetrical cryptographic systems;
  Public key in the case of asymmetrical cryptographic systems

Solution Depends on the type of cryptographic system

Authentication Key Distribution



(a)



(b)

Public Key Certificates (1/3)

- The challenge with shared keys is to ensure that they are kept secret
- The challenge with public keys is to ensure the binding between a public key and a principal
  - Cryptographic protocols can only check whether a public key matches a private key
  - If *C* convinces *A* that *B*'s public key is a key matches a private key *C* knows, then *C* can impersonate *B*
- The solution to address this challenge is based on **public-key ceritificates/digital certificate**, which contain:
  1. The subject's (principal's) name
  2. A public key that matche's the subject's private key
  3. A signature of the remaining information by a **Certification Authority (CA)**
  4. The name of the CA

Public Key Certificates (2/3)

- The assumption is that the CA's public keys are well known
  - Web browsers are shipped with the public keys of (too) many CAs
- When a browser validates/accepts a certificate, the user **trusts** that the principal's it wants to communicate with has the public key in the certificate
  - But CAs can be tricked into issuing certificates for someone else to attackers (e.g. Verisign issued a certificate for Microsoft)
- On the Web, the trust model used by digital certificates is not only oligarchic but also hierarchical
  - A CA can delegate on other CAs, i.e. issue a certificate vouching for their trustworthiness
- PGP uses the "anarchy model"
  - Each user can choose which public-keys it trusts (**trust-anchors**)
  - A user can sign certificates for anyone else
  - To get a key's certificate, one needs to find a path starting on some trust anchor
- A key issue in this scheme is naming: is the John Smith whose key I need the John Smith in some certificate?

Public Key Certificates (3/3)

- Digital certificates have expiration dates, often of several months or even years:
  - Browsers typically warn the user when a server presents an expired certificate

Problem What if the private key is compromised before the certificate expires?

Solution Revoke the certificate

- CAs periodically publish **Certificate Revocation List (CRL)** with certificates that have been revoked.
  - What should the period be?
  - To reduce the amount of data transferred, CAs can publish a full CRL with a larger period and delta CRLs with a shorter period
- The Online Certificate Status Protocol (OCSL) (RFC 2560) allows browsers to verify the validity of a certificate in real-time
  - If the CA runs an on-line revocation server

Roadmap

Further Reading

- Chapter 9, Tanenbaum e van Steen, *Distributed Systems, 3rd Ed.*
  - Section 9.2: *Secure Channels*
  - Subsection 9.5[.1]: *Key Management*