Key Management; Other Public-Key Cryptosystems

In a confidential communication, the authenticity needs to be carefully established for the two partners before sending any confidential information one needs to be sure to whom it sends that information: **authentication protocols**.

<u>Authentication protocols and setting up secret keys</u>

*<u>**A** . Direct authentication</u>*

1.Based on a shared secret master key

2.Based on a public-key system

3.Diffie-Hellman

*<u>**B** . Mediated authentication</u>*

1.Based on key distribution centers

2.kerberos.

In this chapter we examined the problem of the distribution of secret keys. One of the major roles of public-key encryption has been to address the problem of key distribution. There are actually two distinct aspects to the use of public-key cryptography in this regard:

1. The distribution of public keys
2. The use of public-key encryption to distribute secret keys

We examine each of these areas in turn.

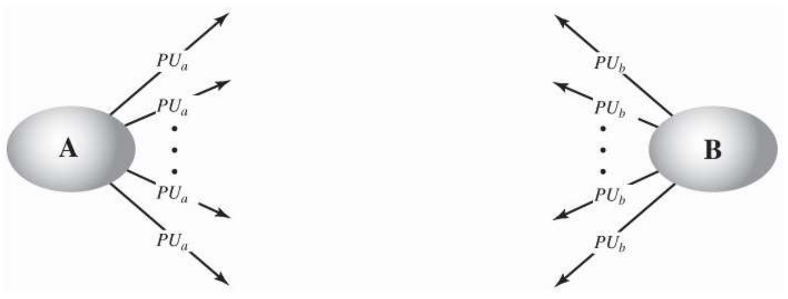
1 Distribution of Public Keys

Several techniques have been proposed for the distribution of public keys. Virtually all these proposals can be grouped into the following general schemes:

- Public announcement
- Publicly available directory
- Public-key authority
- Public-key certificates

Public Announcement of Public Keys

On the face of it, the point of public-key encryption is that the public key is public. Thus, if there is some broadly accepted public-key algorithm, such as RSA, any participant can send his or her public key to any other participant or broadcast the key to the community at large



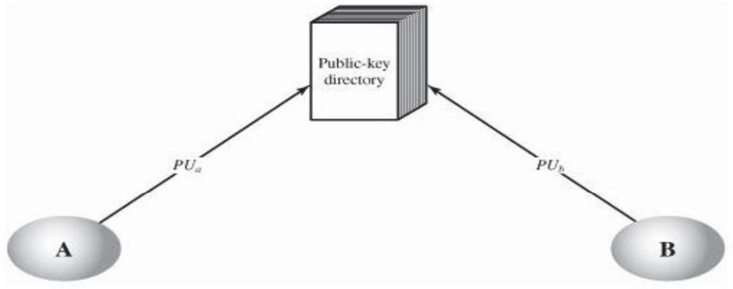
Uncontrolled Public-Key Distribution

Although this approach is convenient, it has a major weakness. Anyone can forge such a public announcement. That is, some user could pretend to be user A and send a public key to another participant or broadcast such a public key. Until such time as user A discovers the forgery and alerts other participants, the forger is able to read all encrypted messages intended for A and can use the forged keys for authentication.

Publicly Available Directory

A greater degree of security can be achieved by maintaining a publicly available dynamic directory of public keys. Maintenance and distribution of the public directory would have to be the responsibility of some trusted entity or organization as in the following Figure . Such a scheme would include the following elements:

1. The authority maintains a directory with a {name, public key} entry for each participant.
2. Each participant registers a public key with the directory authority. Registration would have to be in person or by some form of secure authenticated communication.
3. A participant may replace the existing key with a new one at any time, either because of the desire to replace a public key that has already been used for a large amount of data, or because the corresponding private key has been compromised in some way.
4. Participants could also access the directory electronically. For this purpose, secure, authenticated communication from the authority to the participant is mandatory.



Public-Key Publication

This scheme is clearly more secure than individual public announcements but still has vulnerabilities. If an adversary succeeds in obtaining or computing the private key of the directory authority, the adversary could authoritatively pass out counterfeit public keys and subsequently impersonate any participant and eavesdrop on messages sent to any participant. Another way to achieve the same end is for the adversary to tamper with the records kept by the authority.

Public-Key Authority

Stronger security for public-key distribution can be achieved by providing tighter control over the distribution of public keys from the directory. A typical scenario is illustrated as in Figure below. As before, the scenario assumes that a central authority maintains a dynamic directory of public keys of all participants. In addition, each participant reliably knows a public key for the authority, with only the authority knowing the corresponding private key. The following steps (matched by number to Figure below) occur:

1. A sends a time stamped message to the public-key authority containing a request for the current public key of B.

2. The authority responds with a message that is encrypted using the authority's private key, PR_{auth} Thus, A is able to decrypt the message using the authority's public key. Therefore, A is assured that the message originated with the authority. The message includes the following:
   - B's public key, PU_b which A can use to encrypt messages destined for B
   - The original request, to enable A to match this response with the corresponding earlier request and to verify that the original request was not altered before reception by the authority
   - The original timestamp, so A can determine that this is not an old message from the authority containing a key other than B's current public key

3. A stores B's public key and also uses it to encrypt a message to B containing an identifier of A (ID_A) and a nonce (N_1), which is used to identify this transaction uniquely.

4, B retrieves A's public key from the authority in the same manner as A retrieved B's public key.

5. At this point, public keys have been securely delivered to A and B, and they may begin their protected exchange. However, two additional steps are desirable:

6. B sends a message to A encrypted with PU_a and containing A's nonce (N_1) as well as a new nonce generated by B (N_2) Because only B could have decrypted message, the presence of N_1 in message assures A that the correspondent is B.

7. A returns N_2, encrypted using B's public key, to assure B that its correspondent is A.

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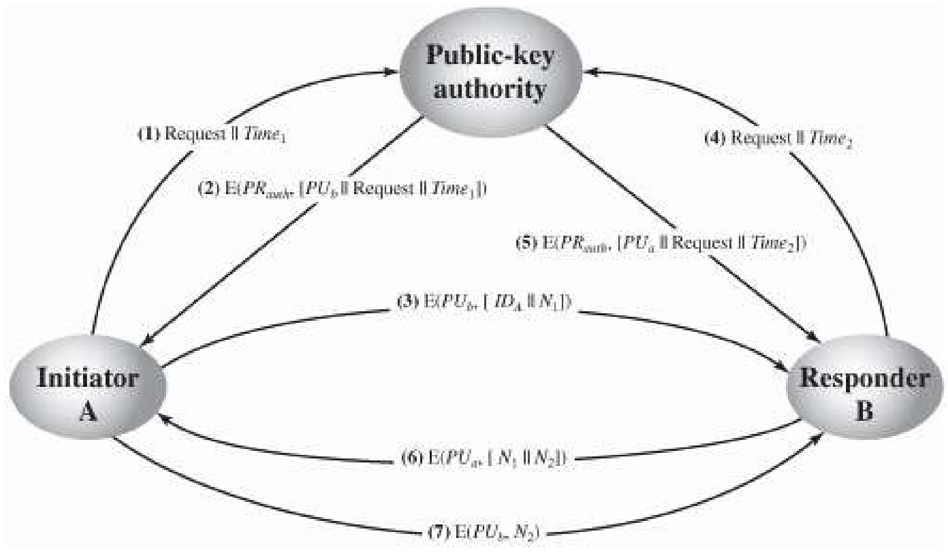

Public-key authority
Initiator A
Responder B
(1) Request || $Time_1$
(2) E(PR_{auth}, [PU_b || Request || $Time_1$])
(3) E(PU_b, [ID_A || N_1])
(4) Request || $Time_2$
(5) E(PR_{auth}, [PU_a || Request || $Time_2$])
(6) E(PU_a, [N_1 || N_2])
(7) E(PU_b, N_2)

Public-Key Distribution Scenario

Thus, a total of seven messages are required. However, the initial four messages need be used only infrequently because both A and B can save the other's public key for future use, a technique known as caching. Periodically, a user should request fresh copies of the public keys of its correspondents to ensure currency.

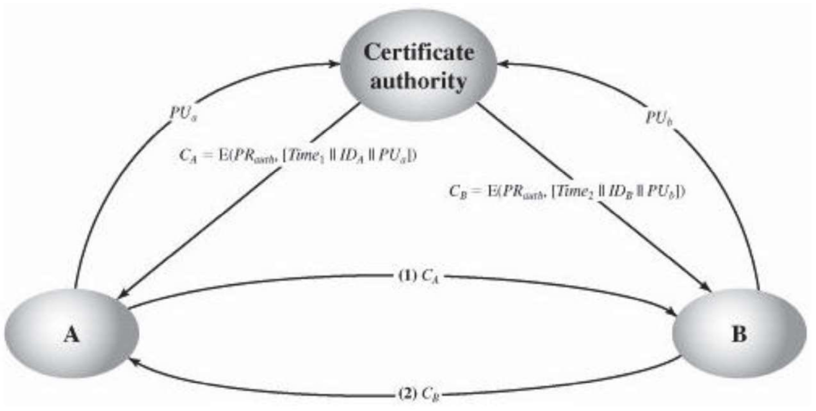
Public-Key Certificates

The scenario of above Figure is attractive, yet it has some drawbacks. The public-key authority could be somewhat of a bottleneck in the system, for a user must appeal to the authority for a public key for every other user that it wishes to contact. As before, the directory of names and public keys maintained by the authority is vulnerable to tampering.

In essence, a certificate consists of a public key plus an identifier of the key owner, with the whole block signed by a trusted third party. Typically, the third party is a certificate authority, such as a government agency or a financial institution, that is trusted by the user community. A user can present his or her public key to the authority in a secure manner, and obtain a certificate. The user can then publish the certificate. Anyone needed this user's public key can obtain the certificate and verify that it is valid by way of the attached trusted signature. A participant can also convey its key information to another by transmitting its certificate. Other participants can verify that the certificate was created by the authority. We can place the following requirements on this scheme:

1. Any participant can read a certificate to determine the name and public key of the certificate's owner.
2. Any participant can verify that the certificate originated from the certificate authority and is not counterfeit.
3. Only the certificate authority can create and update certificates.
4. Any participant can verify the currency of the certificate.

A certificate scheme is illustrated in the following Figure. Each participant applies to the certificate authority, supplying a public key and requesting a certificate.


Certificate authority
PU_a
PU_b
$C_A = E(PR_{auth}, [Time_1 \| ID_A \| PU_a])$
$C_B = E(PR_{auth}, [Time_2 \| ID_B \| PU_b])$
A
B
(1) C_A
(2) C_B

Exchange of Public-Key Certificates

Application must be in person or by some form of secure authenticated communication. For participant A, the authority provides a certificate of the form
$C_A = E(PR_{auth}, [T||ID_A||PU_a])$
where PR_{auth} is the private key used by the authority and T is a timestamp. A may then pass this certificate on to any other participant, who reads and verifies the certificate as follows:
$D(PU_{auth}, C_A) = D(PU_{auth}, E(PR_{auth}, [T||ID_A||PU_a])) = (T||ID_A||PU_a)$
The recipient uses the authority's public key, PU_{auth} to decrypt the certificate. Because the certificate is readable only using the authority's public key, this verifies that the certificate came from the certificate authority. The elements ID_A and PU_a provide the recipient with the name and public key of the certificate's holder. The timestamp T validates the currency of the certificate. The timestamp counters the following scenario. A's private key is learned by an adversary. A generates a new private/public key pair and applies to the certificate authority for a new certificate. Meanwhile, the adversary replays the old certificate to B. If B then encrypts messages using the compromised old public key, the adversary can read those messages.

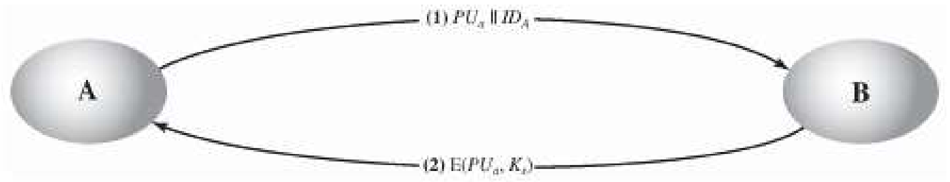
2 Distribution of Secret Keys Using Public-Key Cryptography

Once public keys have been distributed or have become accessible, secure communication that thwarts eavesdropping, tampering, or both is possible. However, few users will wish to make exclusive use of public-key encryption for communication because of the relatively slow data rates that can be achieved. Accordingly, public-key encryption provides for the distribution of secret keys to be used for conventional encryption.

a. Simple Secret Key Distribution

An extremely simple scheme was put forward by Merkle, as illustrated in the following Figure . If A wishes to communicate with B, the following procedure is employed:

1. A generates a public/private key pair {PU_a, PR_a} and transmits a message to B consisting of PU_a and an identifier of A, ID_A.
2. B generates a secret key, K_s, and transmits it to A, encrypted with A's public key.
3. A computes $D(PR_a, E(PU_a, K_s))$ to recover the secret key. Because only A can decrypt the message, only A and B will know the identity of K_s.
4. A discards PU_a and PR_a and B discards PU_a.



Simple Use of Public-Key Encryption to Establish a Session Key

A and B can now securely communicate using conventional encryption and the session key K_s. At the completion of the exchange, both A and B discard K_s. Despite its simplicity, this is an attractive protocol. No keys exist before the start of the communication and none exist after the completion of communication. Thus, the risk of compromise of the keys is minimal. At the same time, the communication is secure from eavesdropping.

The protocol depicted in the above Figure is insecure against an adversary who can intercept messages and then either relay the intercepted message or substitute another message.

b. Secret Key Distribution with Confidentiality and Authentication

Figure below, based on an approach suggested, provides protection against both active and passive attacks. We begin at a point when it is assumed that A and B have exchanged public keys by one of the schemes described earlier in this section. Then the following steps occur:

1. A uses B's public key to encrypt a message to B containing an identifier of A (ID_A) and a nonce (N_1), which is used to identify this transaction uniquely.

2. B sends a message to A encrypted with PU_a and containing A's nonce (N_1) as well as a new nonce generated by B (N_2) Because only B could have decrypted message (1), the presence of N_1 in message (2) assures A that the correspondent is B.
3. A returns N_2 encrypted using B's public key, to assure B that its correspondent is A.
4. A selects a secret key K_s and sends $M = E(PU_b, E(PR_a, K_s))$ to B. Encryption of this message with B's public key ensures that only B can read it; encryption with A's private key ensures that only A could have sent it.
5. B computes $D(PU_a, D(PR_b, M))$ to recover the secret key.

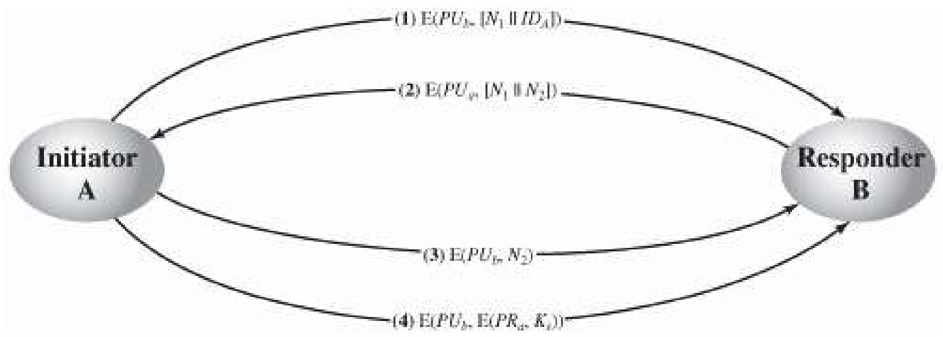

(1) $E(PU_b, [N_1 \| ID_A])$
(2) $E(PU_a, [N_1 \| N_2])$
Initiator A
Responder B
(3) $E(PU_b, N_2)$
(4) $E(PU_b, E(PR_a, K_s))$

Figure Public-Key Distribution of Secret Keys

Notice that the first three steps of this scheme are the same as the last three steps of the above Figure. The result is that this scheme ensures both confidentiality and authentication in the exchange of a secret key.

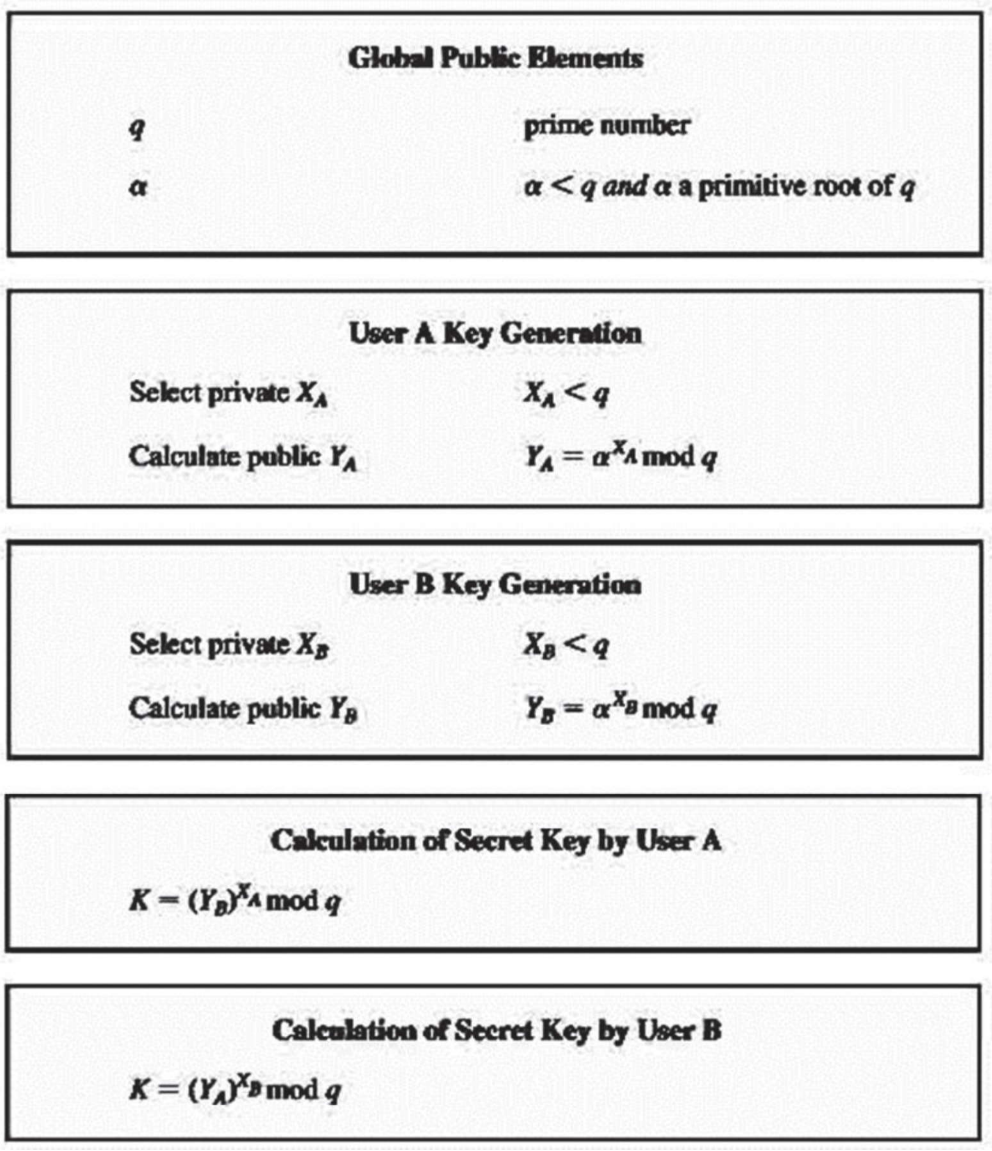
c. Diffie-Hellman Key Exchange

The first published public-key algorithm appeared in the seminal paper by Diffie and Hellman that defined public-key cryptography and is generally referred to as Diffie-Hellman key exchange. A number of commercial products employ this key exchange technique.

The Diffie-Hellman algorithm depends for its effectiveness on the difficulty of computing discrete logarithms. Briefly, we can define the discrete logarithm in the

following way. First, we define a primitive root of a prime number p as one whose powers modulo p generate all the integers from 1 to p 1. That is, if a is a primitive root of the prime number p, then the numbers
a mod p, a^2 mod p,..., a^{p-1} mod p
are distinct and consist of the integers from 1 through p 1 in some permutation.
For any integer b and a primitive root a of prime number p, we can find a unique exponent i such that
$b \equiv a^i \pmod{p}$ where $0 \leq i \leq (p - 1)$
The exponent *i* is referred to as the discrete logarithm of *b* for the base *a*, mod *p*.

The Algorithm
The Diffie-Hellman key exchange algorithm. For this scheme, there are two publicly known numbers: a prime number q and an integer that is a primitive root of q.



Global Public Elements

q	prime number
α	$\alpha < q$ *and* α a primitive root of q

User A Key Generation

Select private X_A	$X_A < q$
Calculate public Y_A	$Y_A = \alpha^{X_A} \bmod q$

User B Key Generation

Select private X_B	$X_B < q$
Calculate public Y_B	$Y_B = \alpha^{X_B} \bmod q$

Calculation of Secret Key by User A

$K = (Y_B)^{X_A} \bmod q$

Calculation of Secret Key by User B

$K = (Y_A)^{X_B} \bmod q$

The result is that the two sides have exchanged a secret value as shown in Figure below. The security of the Diffie-Hellman key exchange lies in the fact that, while it is relatively easy to calculate exponentials modulo a prime, it is very difficult to calculate discrete logarithms. For large primes, the latter task is considered infeasible.

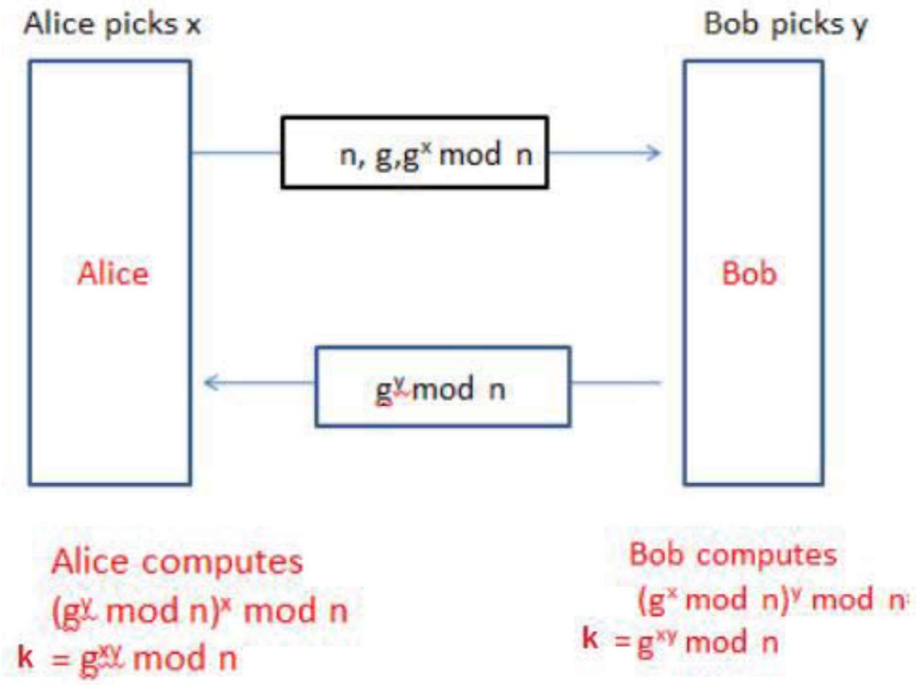


Figure The Diffie-Hellman Key Exchange Algorithm

Here is an example. Key exchange is based on the use of the prime number q = 353 and a primitive root of 353, in this case α = 3. A and B select secret keys X_A = 97 and X_B = 233, respectively. Each computes its public key:

A computes $Y_A = 3^{97} \bmod 353 = 40$.

B computes $Y_B = 3^{233} \bmod 353 = 248$.

After they exchange public keys, each can compute the common secret key:

A computes $K = (Y_B)^{X_A} \bmod 353 = 248^{97} \bmod 353 = 160$.

B computes $K = (Y_A)^{X_B} \bmod 353 = 40^{233} \bmod 353 = 160$.

Authentication using Kerberos

1. User **Alice** logs on to Authentication Server (AS) and requests service.

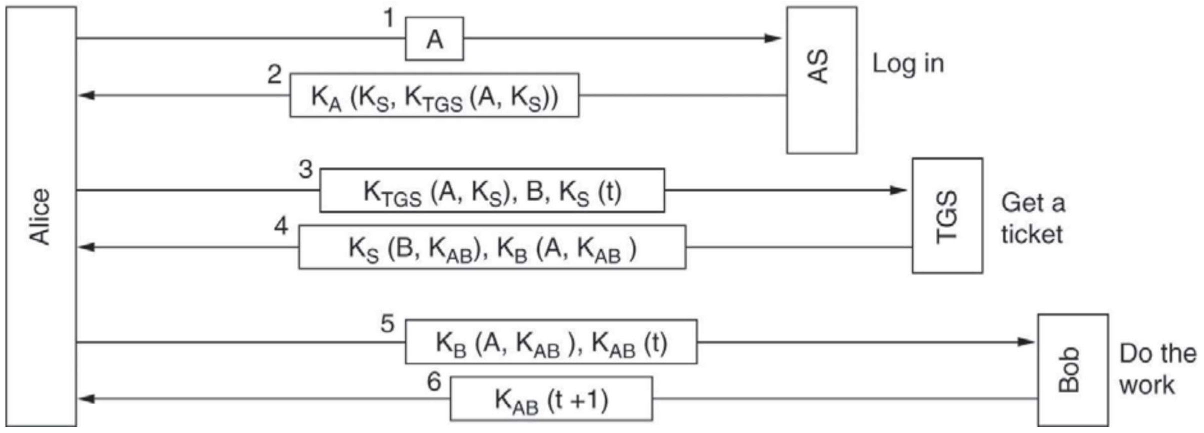
2. AS verifies user's access right in database, creates ticket-granting ticket and session key. Results are encrypted using key derived from user's password.

3. User Alice uses password to decrypt incoming message, then sends ticket and authenticator that contains user's name, network address, and time to Ticket Granting Server (TGS).

4. TGS decrypts ticket and authenticator, verifies request, then creates ticket for requested server (Bob).

5. User Alice sends ticket and authenticator to server.

6. Server verifies that ticket and authenticator match, then grants access to service.


Alice
1
A
AS
Log in
2
$K_A(K_S, K_{TGS}(A, K_S))$
3
$K_{TGS}(A, K_S), B, K_S(t)$
TGS
Get a ticket
4
$K_S(B, K_{AB}), K_B(A, K_{AB})$
5
$K_B(A, K_{AB}), K_{AB}(t)$
Bob
Do the work
6
$K_{AB}(t+1)$