Cryptography (CS-501)

Key Management

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15-1 SYMMETRIC-KEY DISTRIBUTION

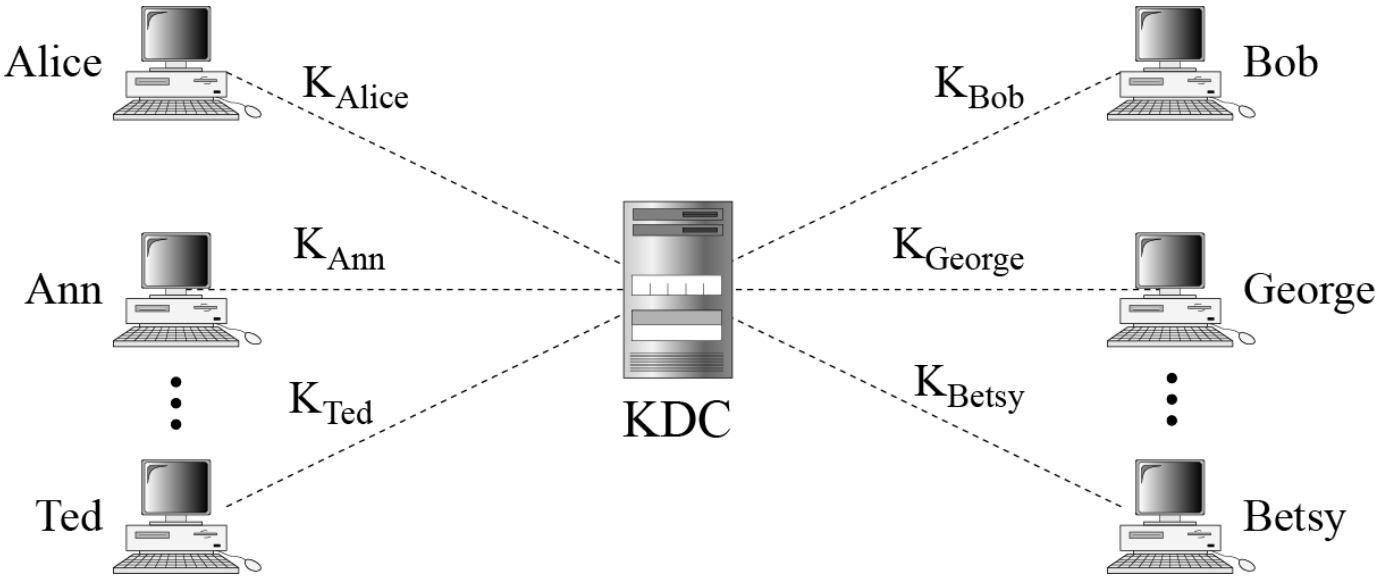
Symmetric-key cryptography is more efficient than asymmetric-key cryptography for enciphering large messages. Symmetric-key cryptography, however, needs a shared secret key between two parties. The distribution of keys is another problem.

Topics discussed in this section:

15.1.1 Key-Distribution Center: KDC
15.1.2 Session Keys

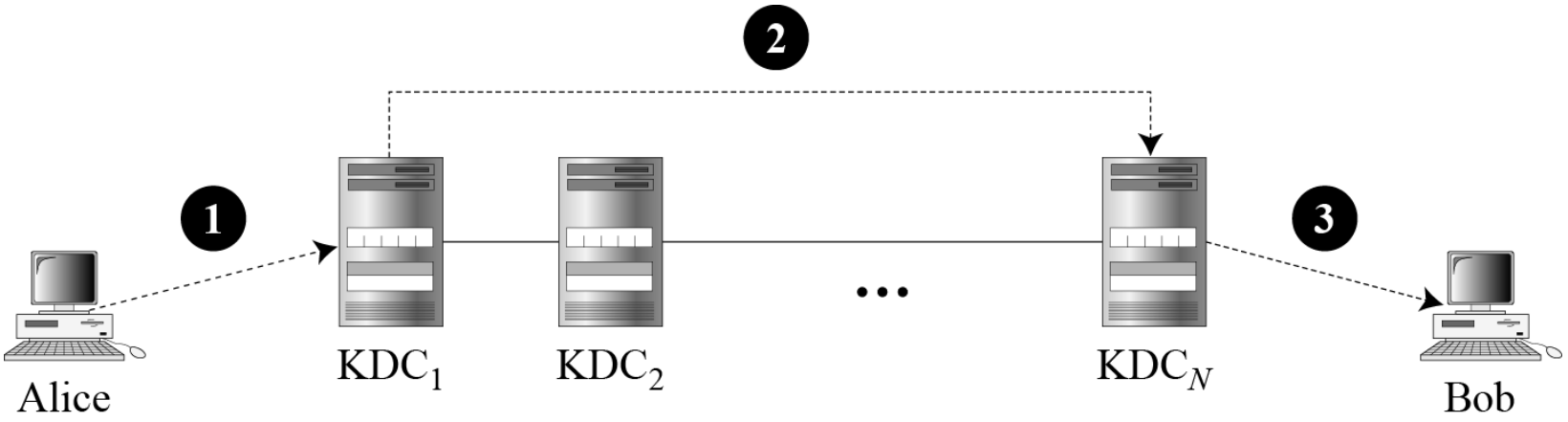
15.1.1 Key-Distribution Center: KDC

Figure 15.1 *Key-distribution center (KDC)*



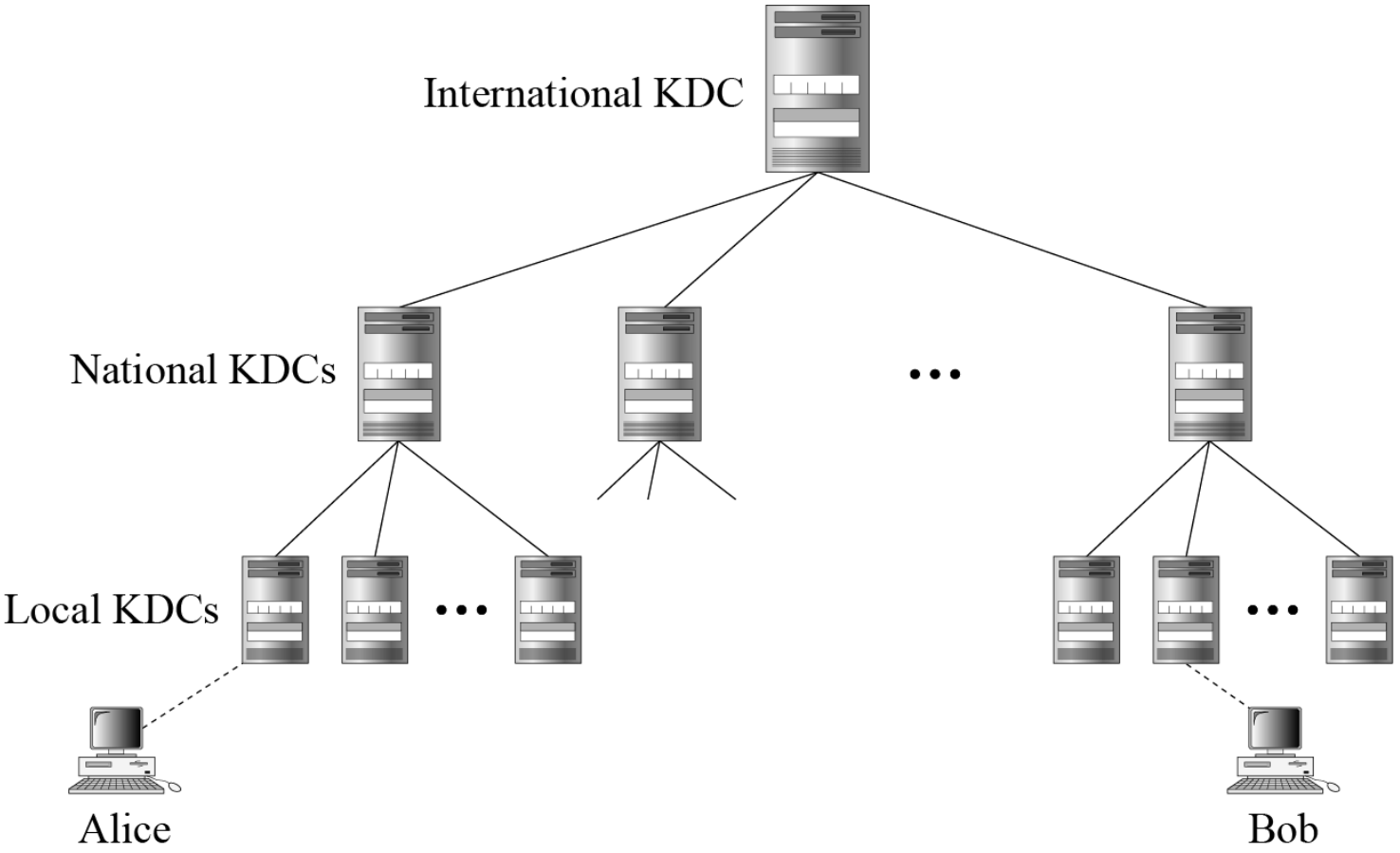
Flat Multiple KDCs.

Figure 15.2 *Flat multiple KDCs*



Hierarchical Multiple KDCs

Figure 15.3 ***Hierarchical multiple KDCs***



15.1.2 Session Keys

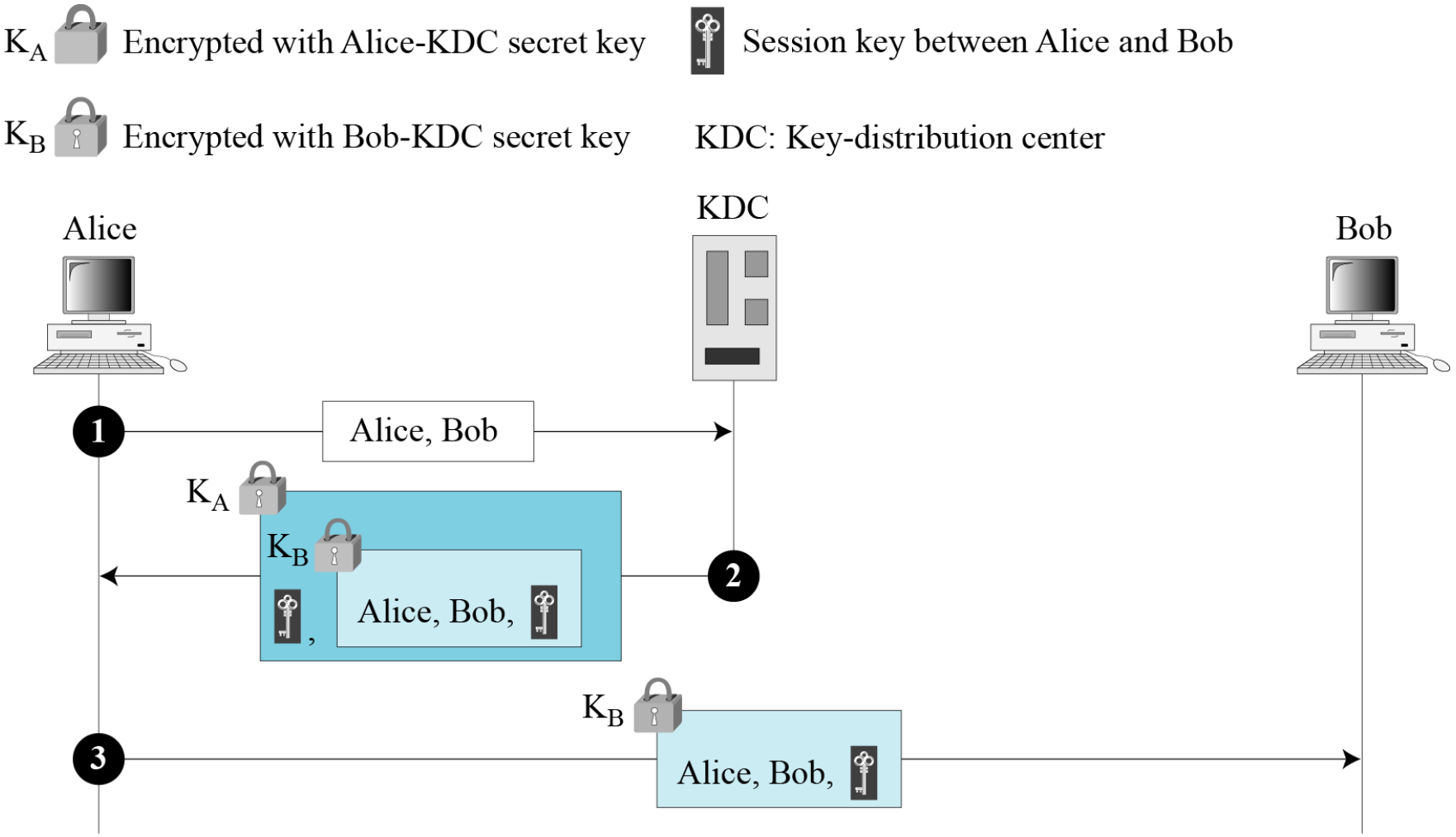
A KDC creates a secret key for each member. This secret key can be used only between the member and the KDC, not between two members.

Note

A session symmetric key between two parties is used only once.

A Simple Protocol Using a KDC

Figure 15.4 *First approach using KDC*



Needham-Schroeder Protocol

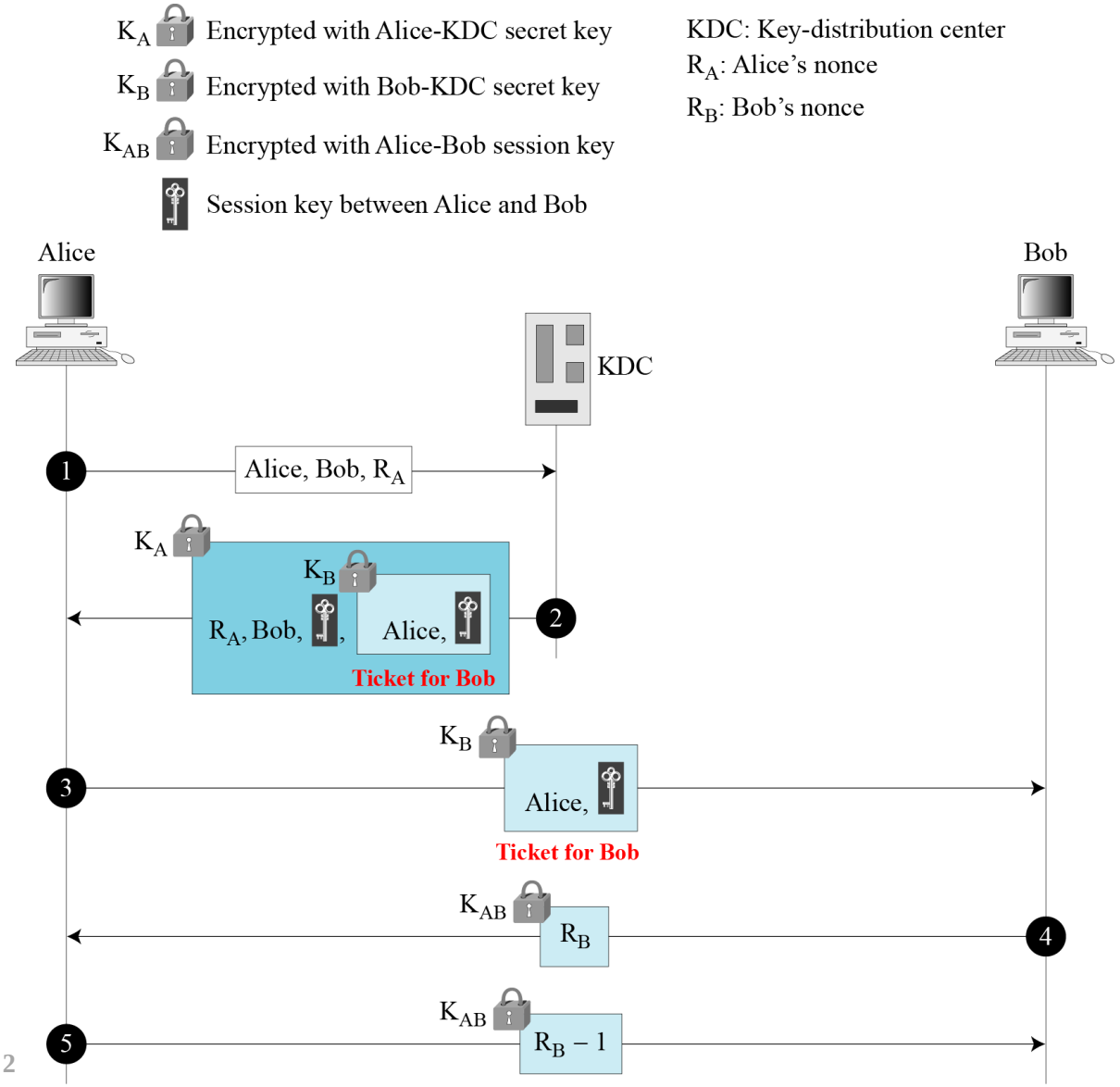


Figure 15.5

Needham-Schroeder protocol

Otway-Rees Protocol

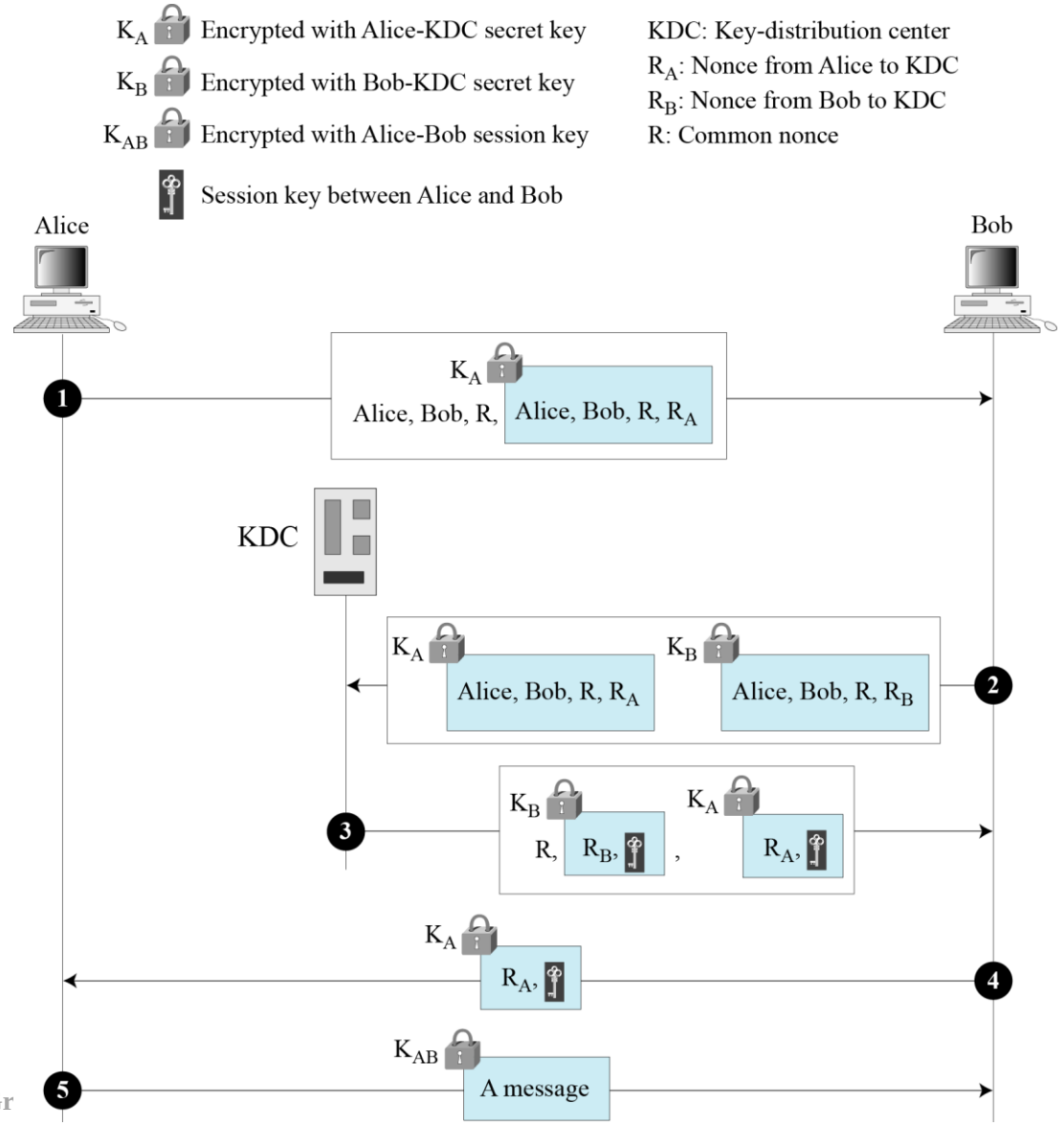


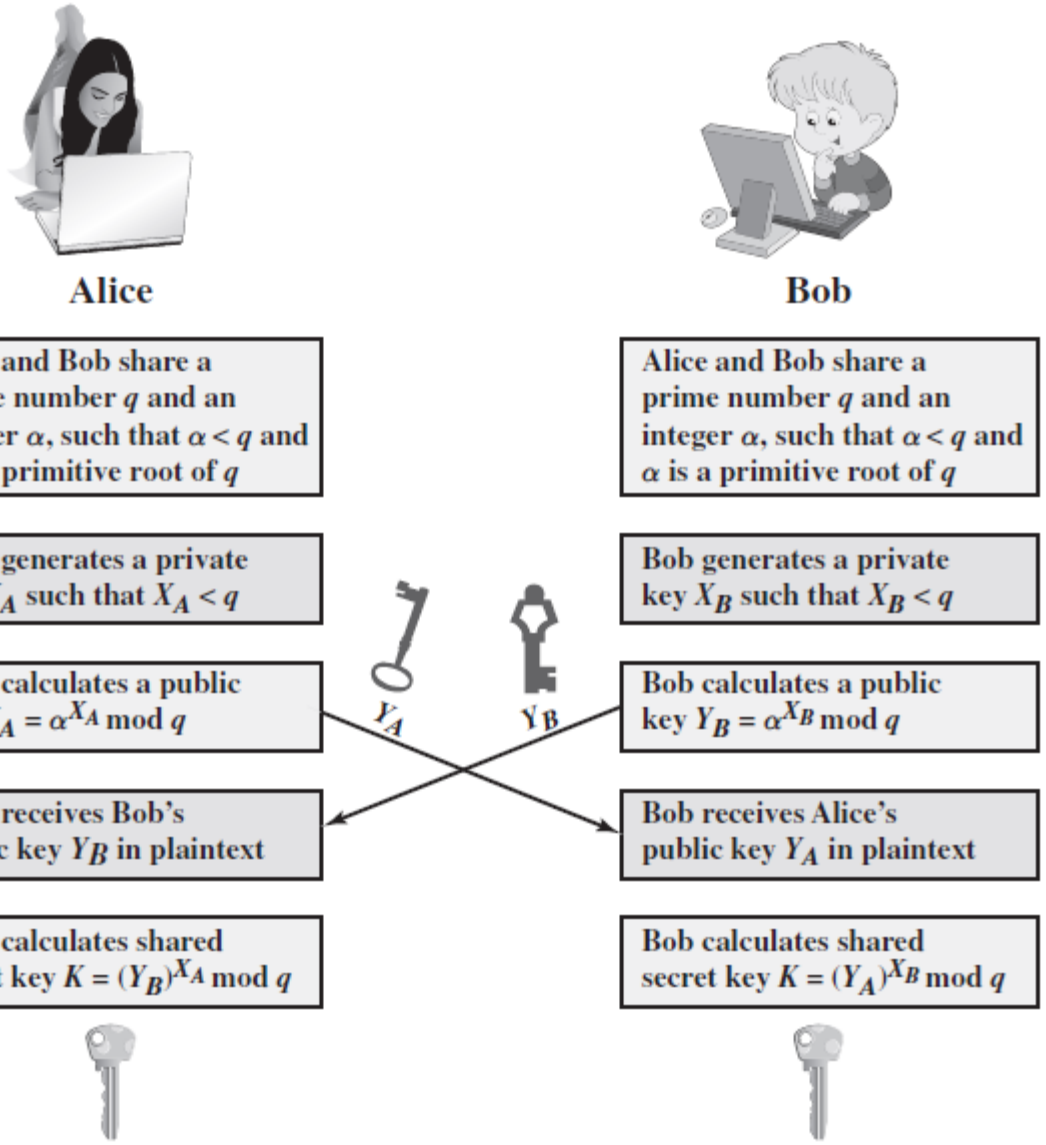
Figure 15.6

Otway-Rees protocol

10-5 Diffie Hellman Key Exchange Algorithm

The purpose of the algorithm is to enable two users to securely exchange a key that can then be used for subsequent asymmetric encryption of messages.

10.5 Procedure



10.5 Procedure

Key exchange is based on the use of the prime number $q = 353$ and a primitive root of 353, in this case $\alpha = 3$. A and B select private 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 $K = (Y_A)^{X_B} \bmod 353 = 40^{233} \bmod 353 = 160$.

We assume an attacker would have available the following information:

$$q = 353; \alpha = 3; Y_A = 40; Y_B = 248$$

15-2 KERBEROS

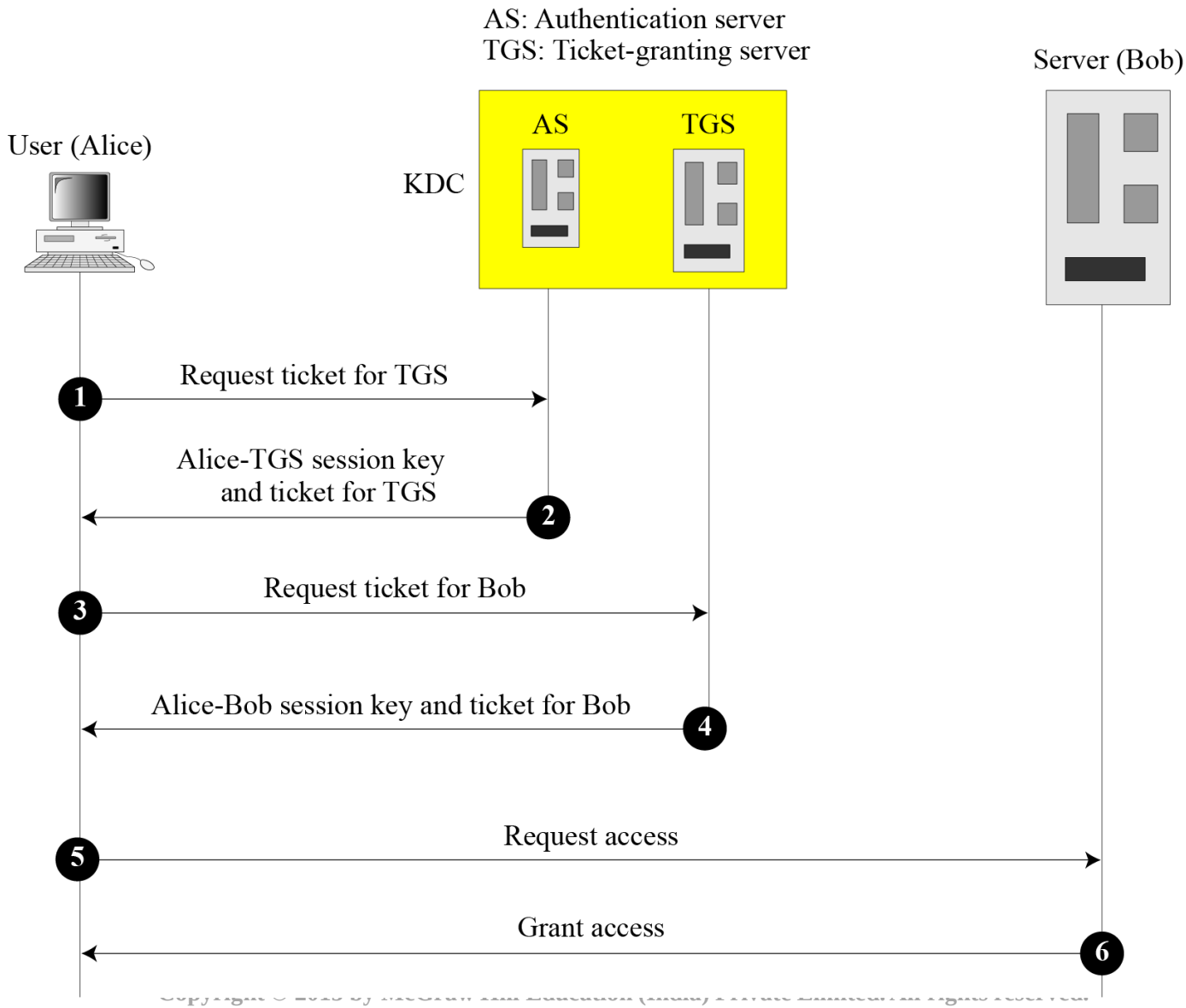
Kerberos is an authentication protocol, and at the same time a KDC, that has become very popular. Several systems, including Windows 2000, use Kerberos. Originally designed at MIT, it has gone through several versions.

Topics discussed in this section:

15.2.1 Servers
15.2.2 Operation
15.2.3 Using Different Servers
15.2.4 Kerberos Version 5

15.2.1 Servers

Figure 15.7 *Kerberos servers*



15.2.1 Continued

Authentication Server (AS)

The authentication server (AS) is the KDC in the Kerberos protocol.

Ticket-Granting Server (TGS)

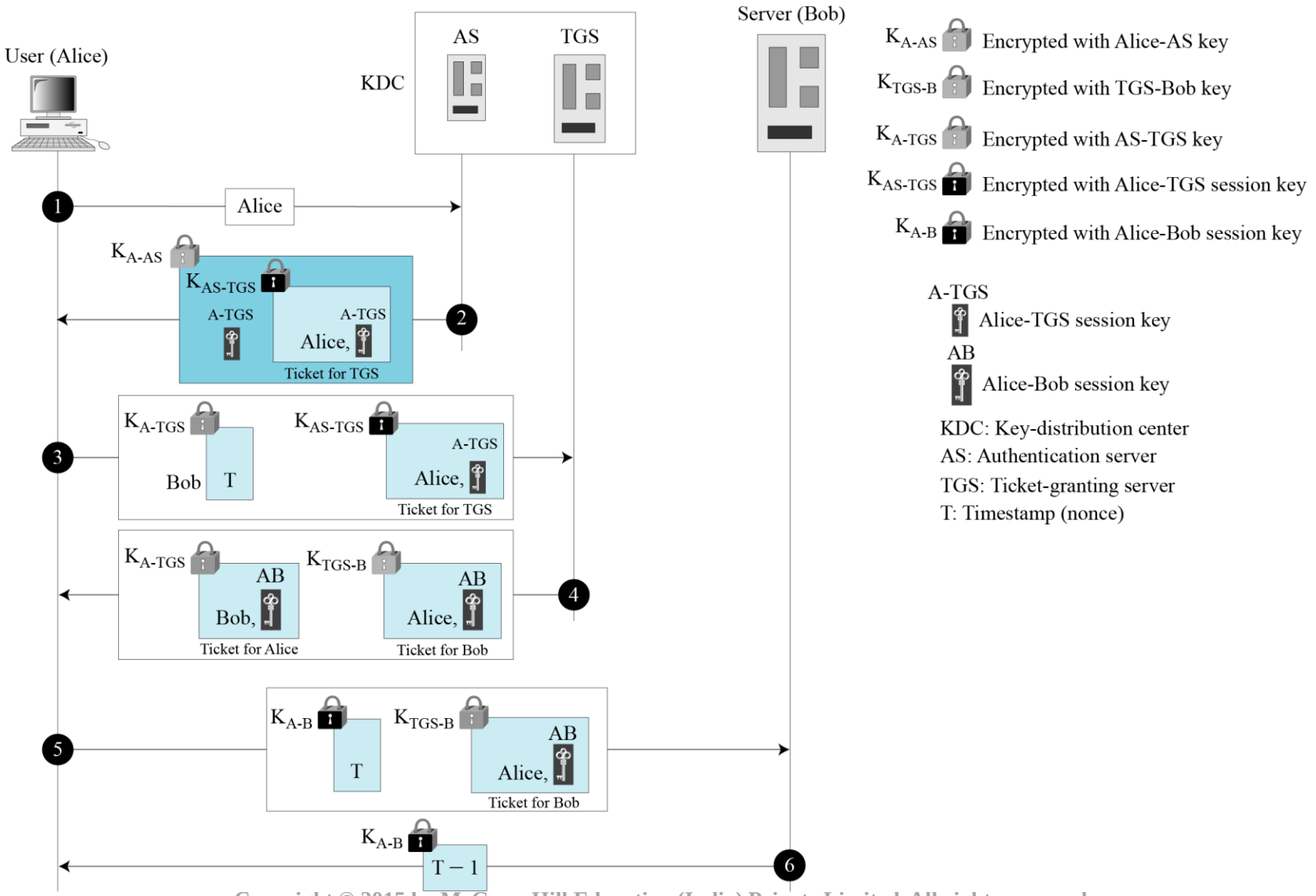
The ticket-granting server (TGS) issues a ticket for the real server (Bob).

Real Server

The real server (Bob) provides services for the user (Alice).

15.2.2 Operation

Figure 15.8 *Kerberos example*



15.2.3 Using Different Servers

Note that if Alice needs to receive services from different servers, she need repeat only the last four steps.

15.2.4 Kerberos Version 5

The minor differences between version 4 and version 5 are briefly listed below:

1) *Version 5 has a longer ticket lifetime.*
2) *Version 5 allows tickets to be renewed.*
3) *Version 5 can accept any symmetric-key algorithm.*
4) *Version 5 uses a different protocol for describing data types.*
5) *Version 5 has more overhead than version 4.*

15-3 SYMMETRIC-KEY AGREEMENT

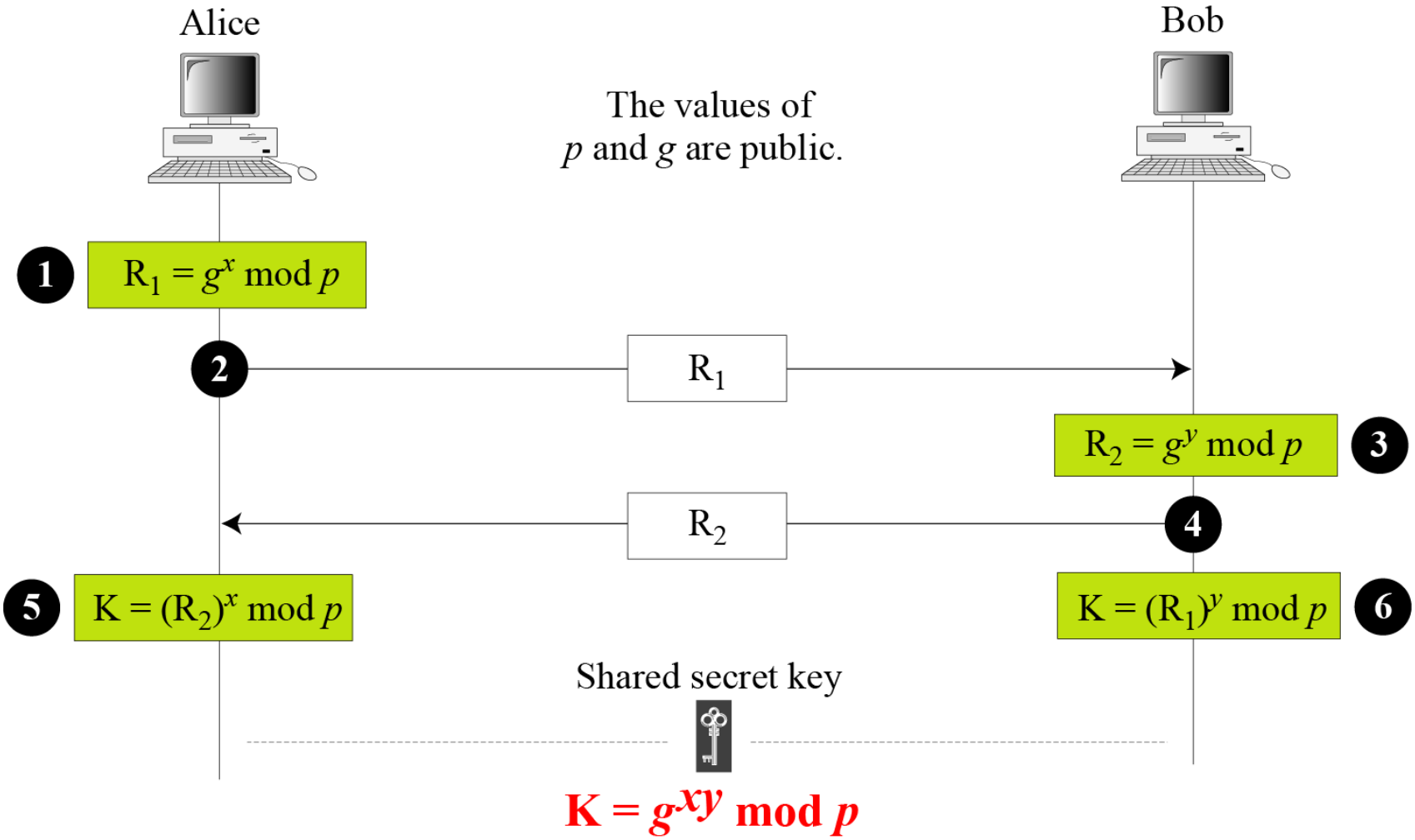
Alice and Bob can create a session key between themselves without using a KDC. This method of session-key creation is referred to as the symmetric-key agreement.

Topics discussed in this section:

15.3.1 Diffie-Hellman Key Agreement

15.3.1 Diffie-Hellman Key Agreement

Figure 15.9 *Diffie-Hellman method*



15.3.1 Continued

Note

The symmetric (shared) key in the Diffie-Hellman method is $K = g^{xy} \bmod p$.

15.3.1 Continued

Example 15.1

Let us give a trivial example to make the procedure clear. Our example uses small numbers, but note that in a real situation, the numbers are very large. Assume that $g = 7$ and $p = 23$. The steps are as follows:

1. **Alice chooses $x = 3$ and calculates $R_1 = 73 \bmod 23 = 21$.**
2. **Bob chooses $y = 6$ and calculates $R_2 = 76 \bmod 23 = 4$.**
3. **Alice sends the number 21 to Bob.**
4. **Bob sends the number 4 to Alice.**
5. **Alice calculates the symmetric key $K = 43 \bmod 23 = 18$.**
6. **Bob calculates the symmetric key $K = 216 \bmod 23 = 18$.**
7. **The value of K is the same for both Alice and Bob; $g^{xy} \bmod p = 718 \bmod 35 = 18$.**

15.3.1 Continued

Example 15.2

Let us give a more realistic example. We used a program to create a random integer of 512 bits (the ideal is 1024 bits). The integer *p* is a 159-digit number. We also choose *g*, *x*, and *y* as shown below:

p	764624298563493572182493765955030507476338096726949748923573772860925235666660755423637423309661180033338106194730130950414738700999178043654878580798758 1
g	2
x	557
y	273

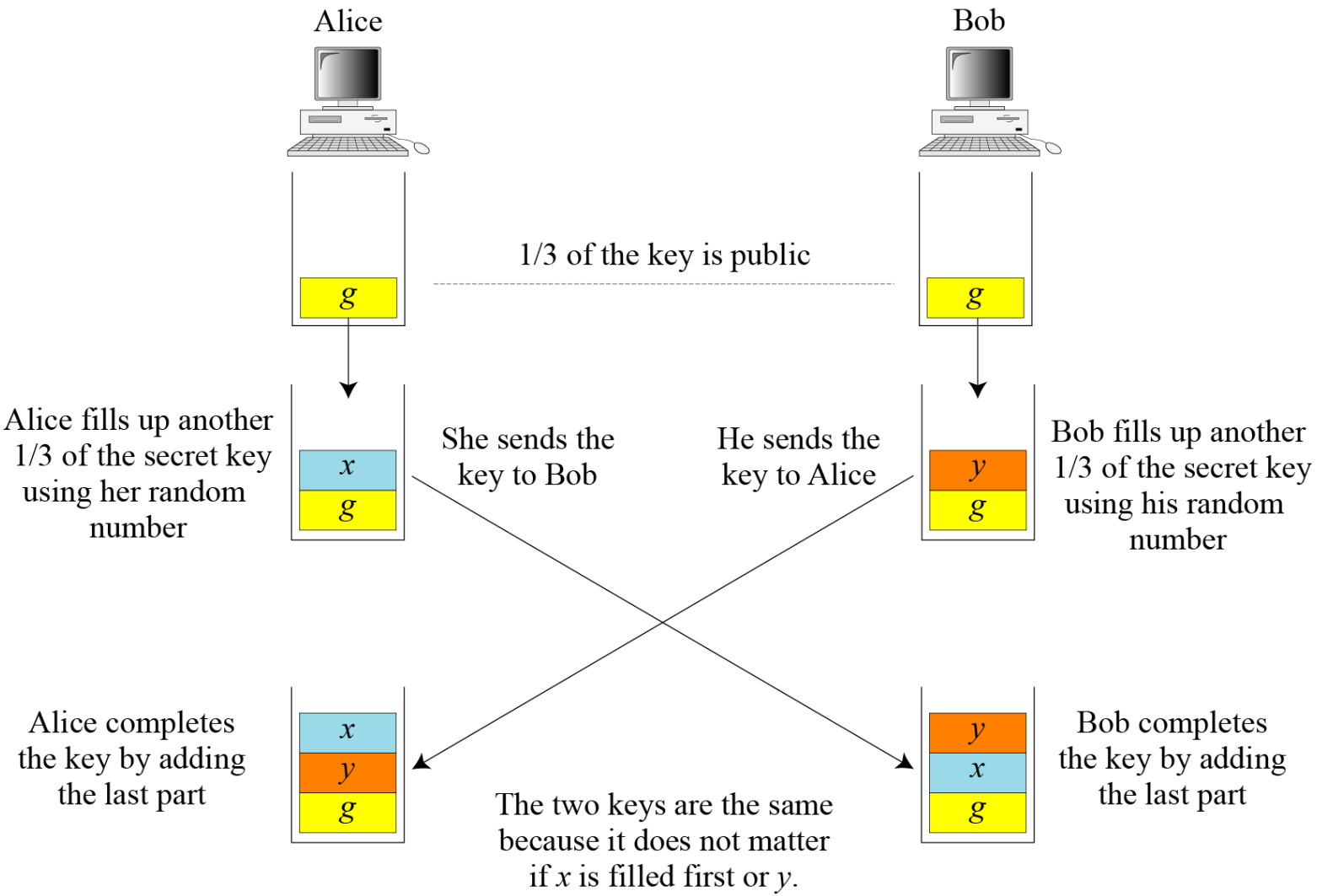
15.3.1 Continued

Example 15.2 *Continued*

The following shows the values of R_1, R_2, and K.

R_1	844920284205665505216172947491035094143433698520012660862863631067673619959280828586700802131859290945140217500319973312945836083821943065966020157955354
R_2	435262838709200379470747114895581627636389116262115557975123379218566310011435718208390040181876486841753831165342691630263421106721508589625520128859414 3
K	155638000664522290596225827523270765273218046944423678520320400146406500887936651204257426776608327911017153038674561252213151610976584200120408643361774 0

Figure 15.10 *Diffie-Hellman idea*



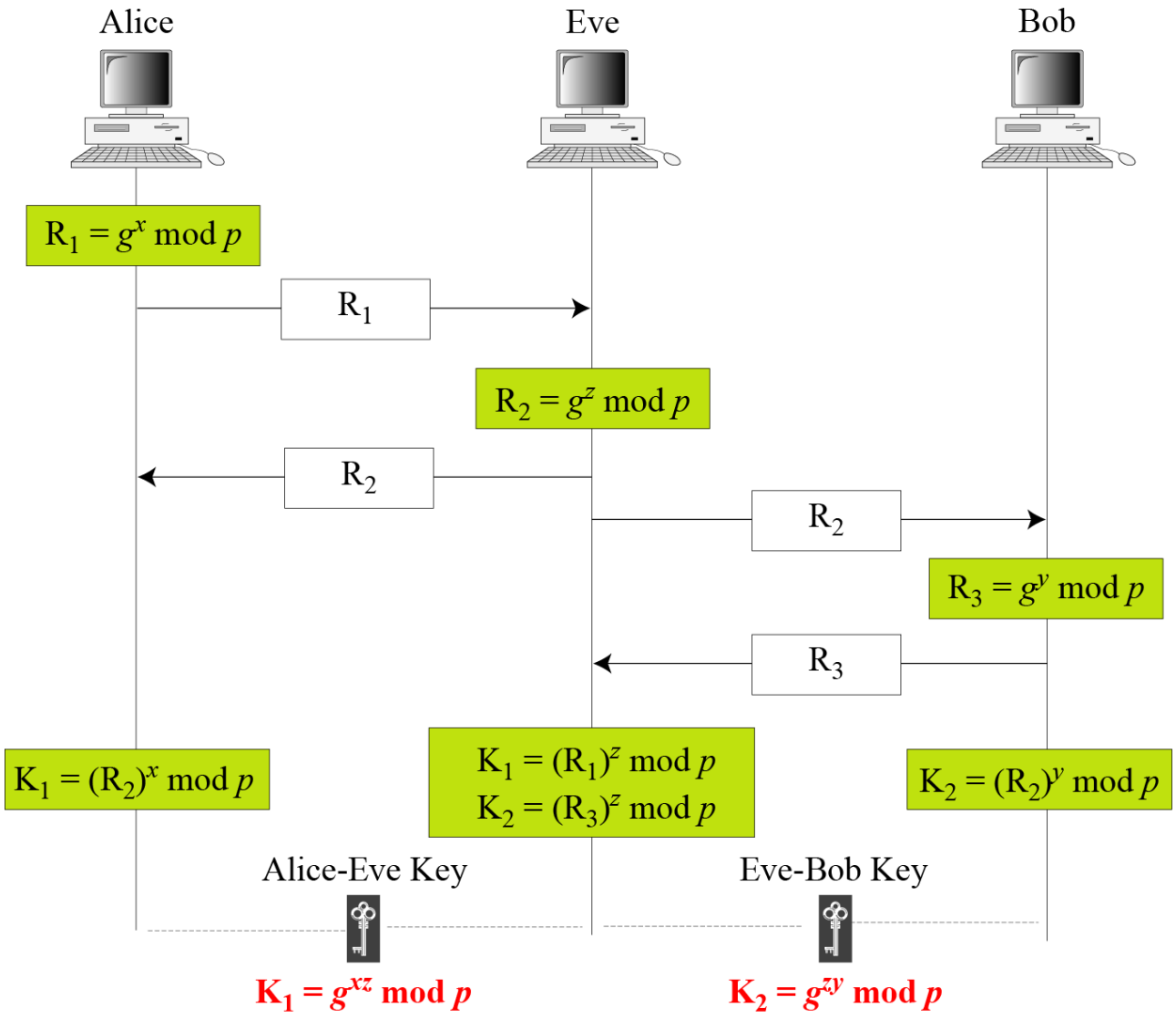
15.3.1 Continued

Security of Diffie-Hellman

Discrete Logarithm Attack

Man-in-the-Middle Attack

Figure 15.11 *Man-in-the-middle attack*



15-4 PUBLIC-KEY DISTRIBUTION

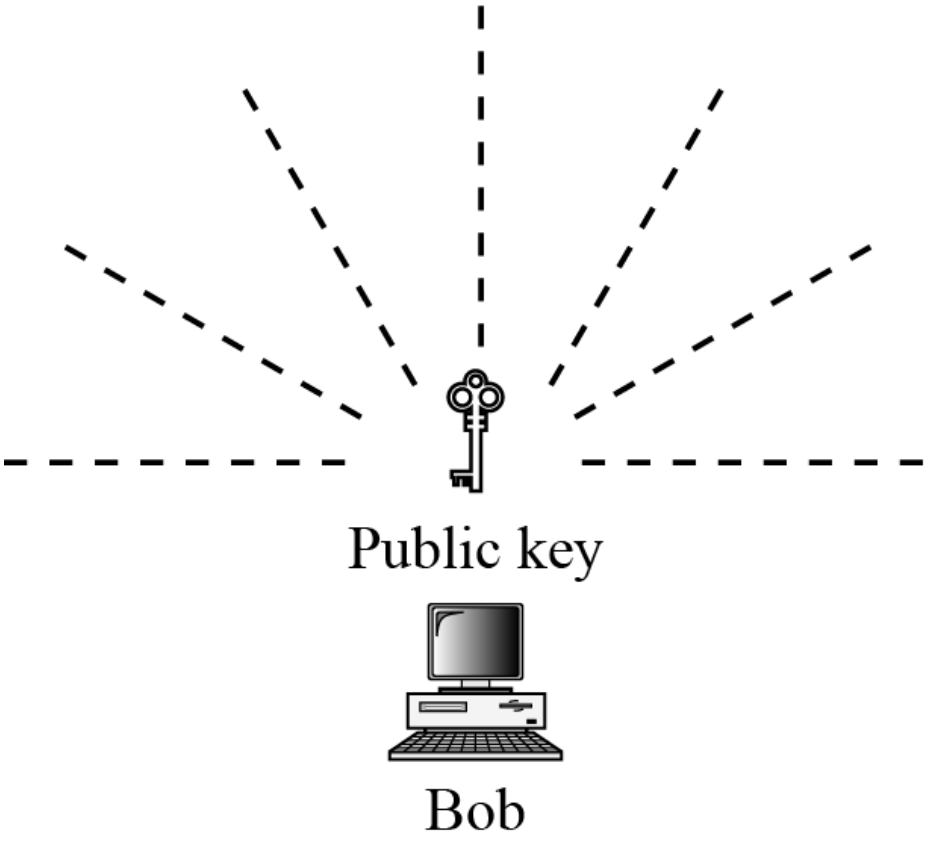
In asymmetric-key cryptography, people do not need to know a symmetric shared key; everyone shields a private key and advertises a public key.

Topics discussed in this section:

15.4.1 Public Announcement
15.4.2 Trusted Center
15.4.3 Controlled Trusted Center
15.4.4 Certification Authority
15.4.5 X.509
15.4.6 Public-Key Infrastructures (PKI)

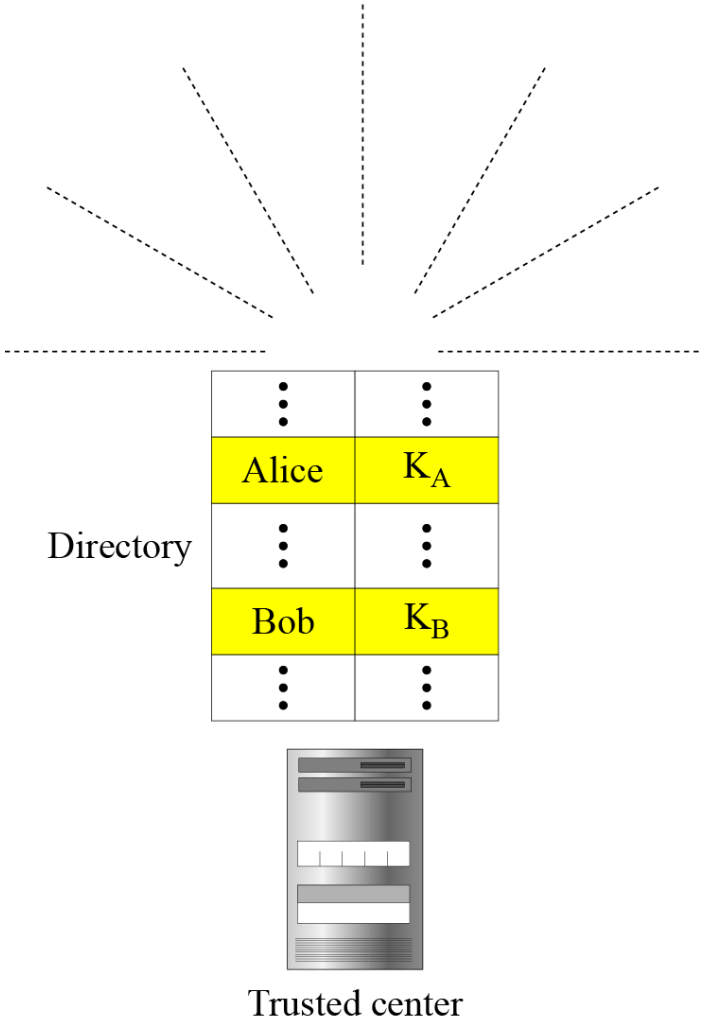
15.4.1 Public Announcement

Figure 15.13 *Announcing a public key*



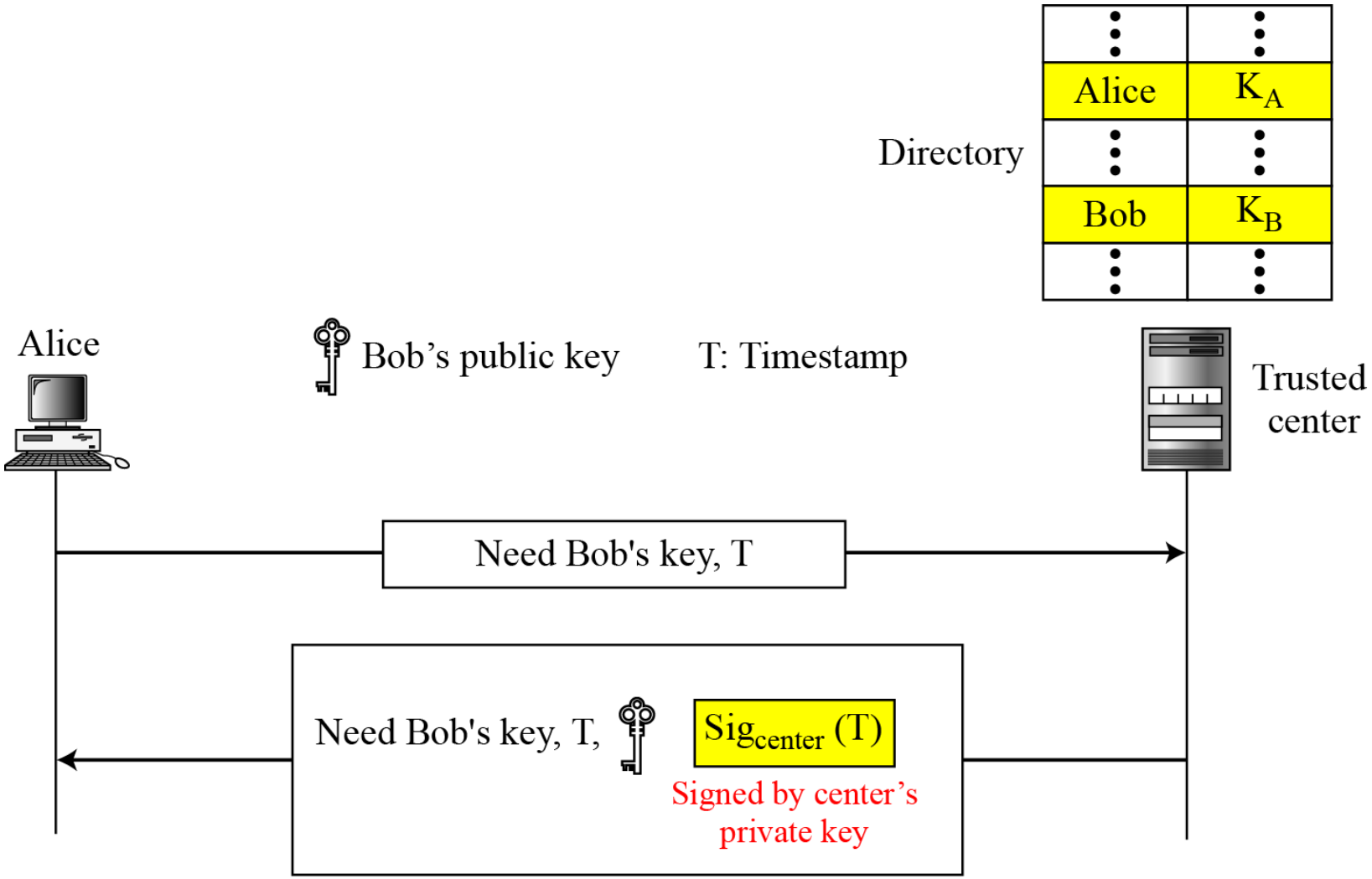
15.4.2 Trusted Center

Figure 15.14 *Trusted center*



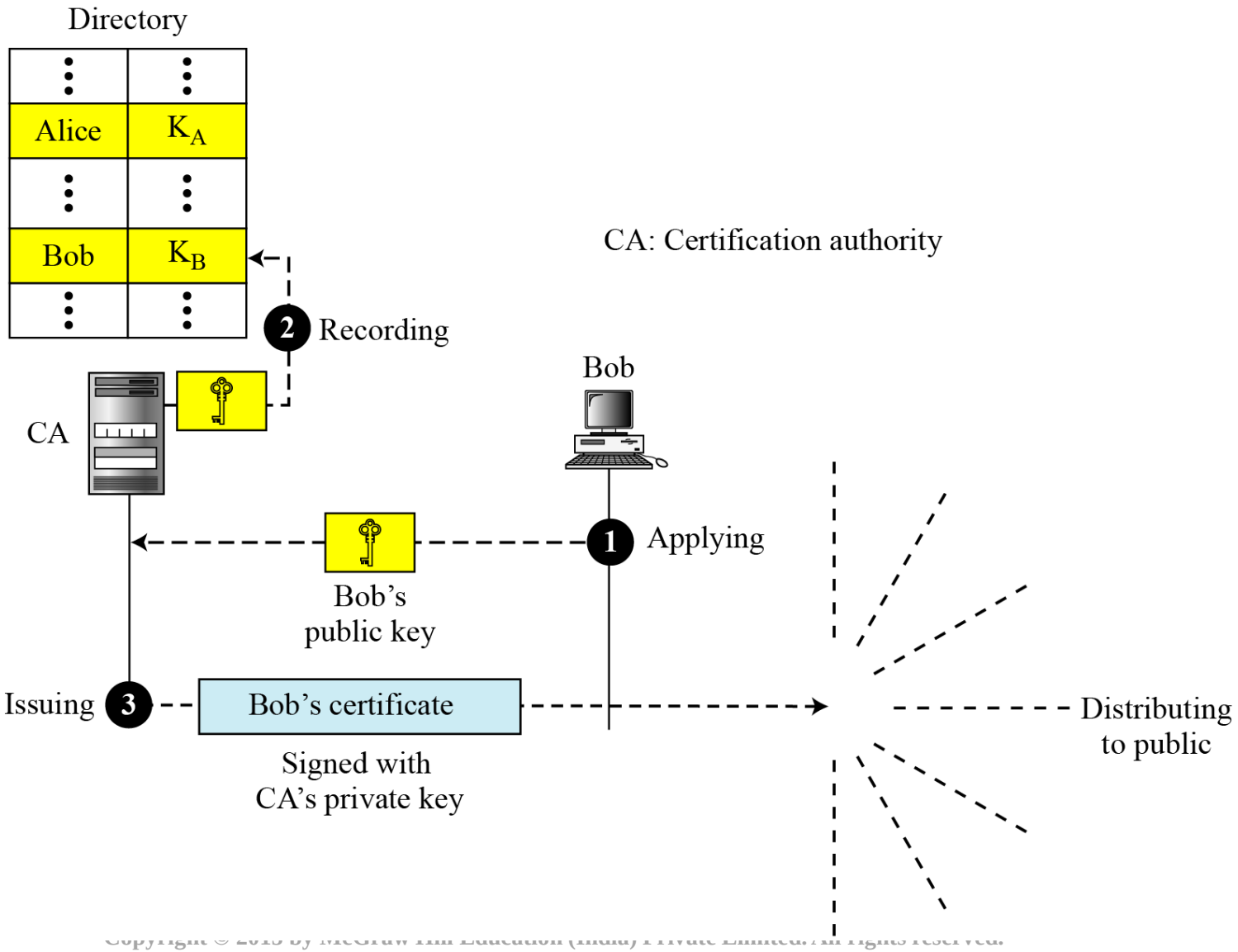
15.4.3 Controlled Trusted Center

Figure 15.15 *Controlled trusted center*



15.4.4 Certification Authority

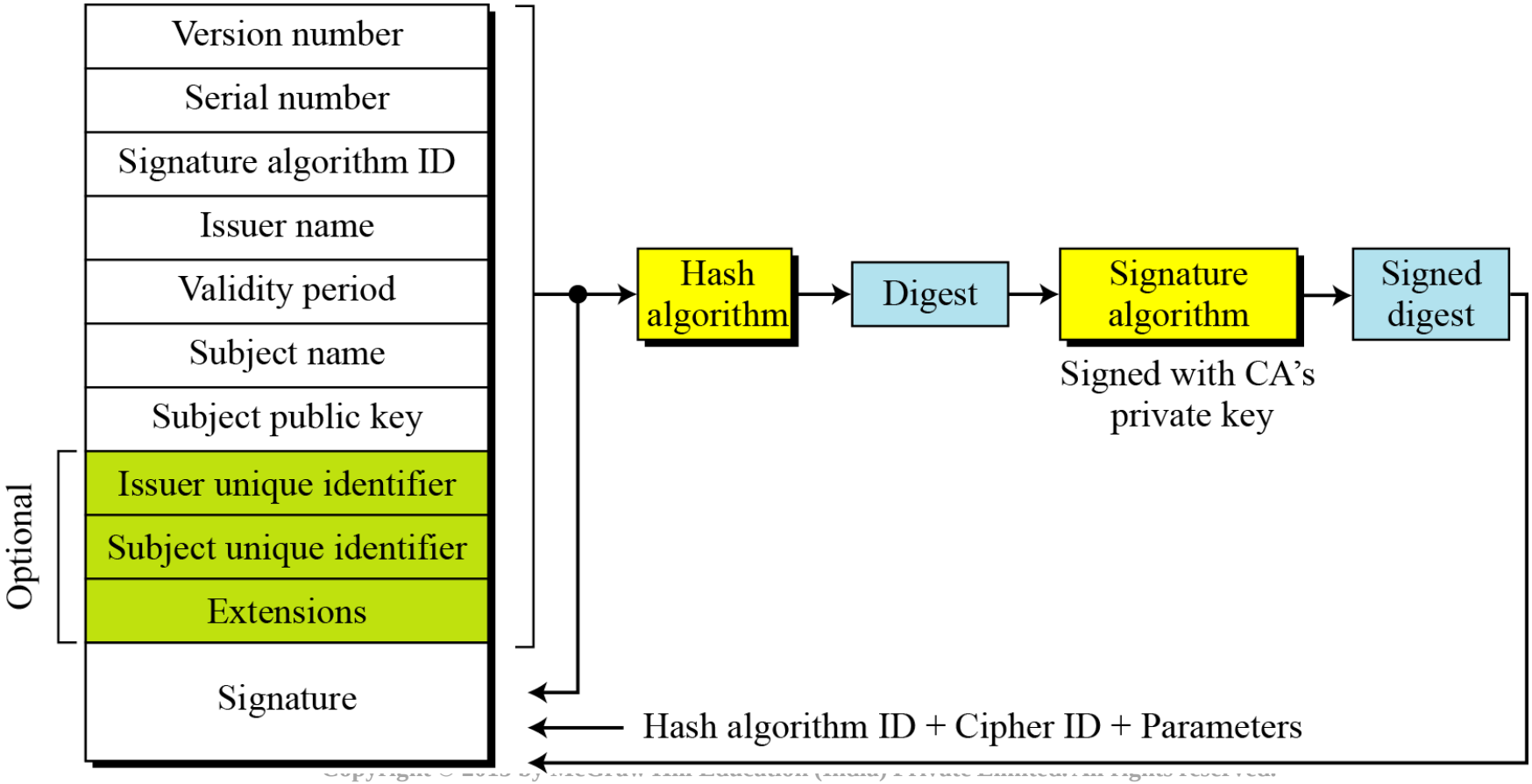
Figure 15.16 *Certification authority*



15.4.5 X.509

Certificate

Figure 15.17 shows the format of a certificate.



15.4.5 Continued

Certificate Renewal

Each certificate has a period of validity. If there is no problem with the certificate, the CA issues a new certificate before the old one expires.

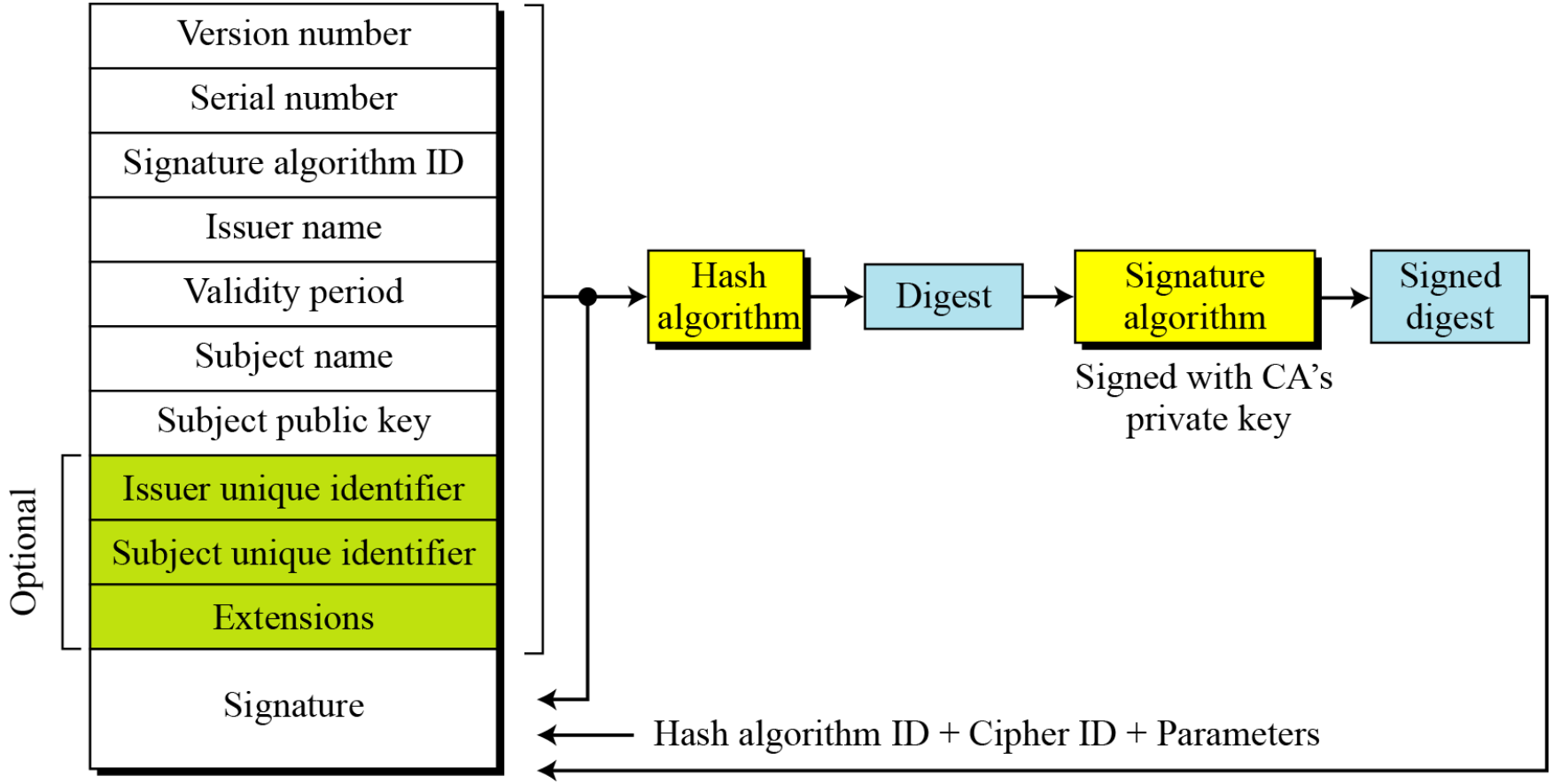
Certificate Renewal

In some cases a certificate must be revoked before its expiration.

Delta Revocation

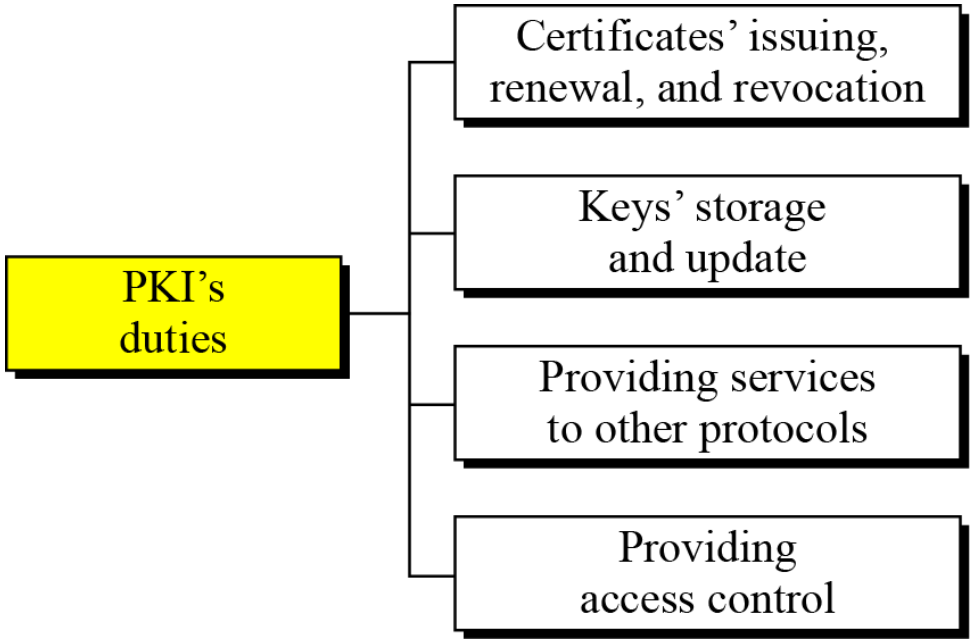
To make revocation more efficient, the delta certificate revocation list (delta CRL) has been introduced.

Figure 15.17 *Certificate revocation format*



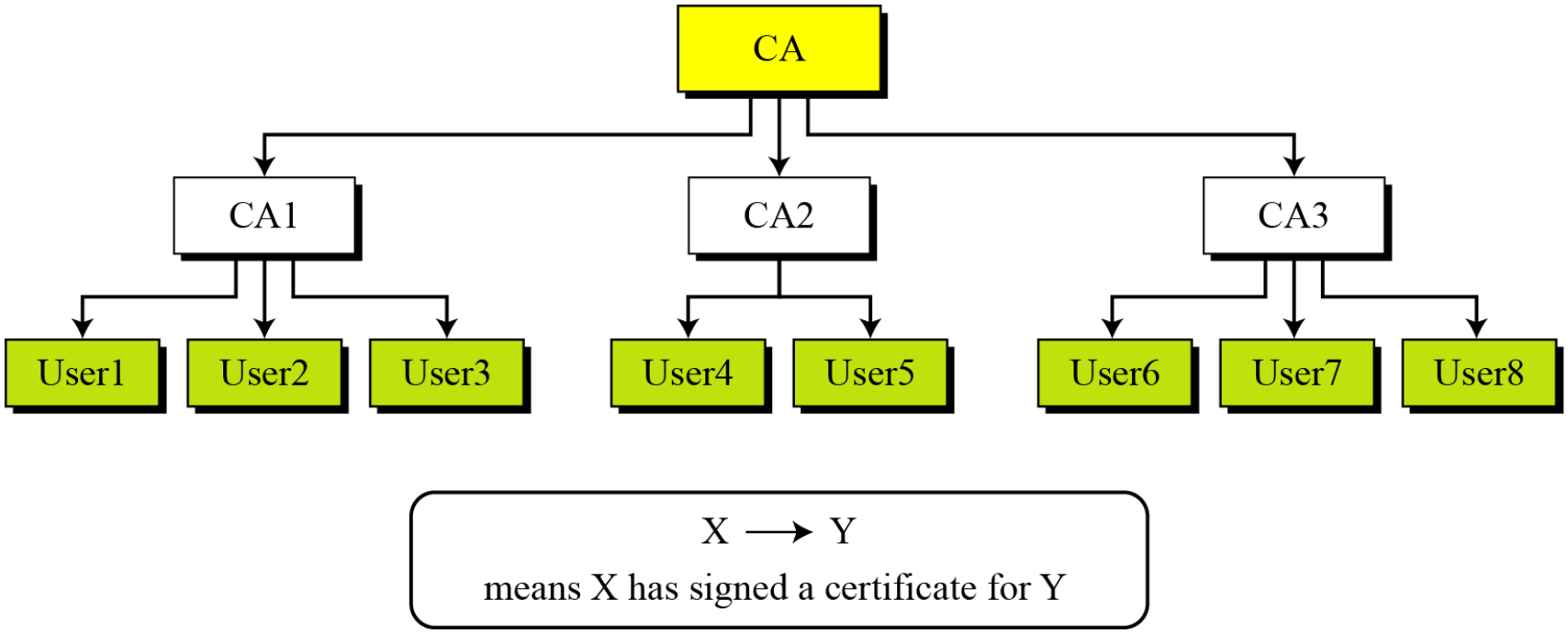
15.4.6 Public-Key Infrastructures (PKI)

Figure 15.19 ***Some duties of a PKI***



Trust Model

Figure 15.20 ***PKI hierarchical model***



15.4.6 Continued

Example 15.3

Show how User1, knowing only the public key of the CA (the root), can obtain a verified copy of User3's public key.

Solution

User3 sends a chain of certificates, CA<<CA1>> and CA1<<User3>>, to User1.

a. User1 validates CA<<CA1>> using the public key of CA.
b. User1 extracts the public key of CA1 from CA<<CA1>>.
c. User1 validates CA1<<User3>> using the public key of CA1.
d. User1 extracts the public key of User 3 from CA1<<User3>>.

15.4.6 Continued

Example 15.4

Some Web browsers, such as Netscape and Internet Explorer, include a set of certificates from independent roots without a single, high-level, authority to certify each root. One can find the list of these roots in the Internet Explorer at Tools/Internet Options/Contents/Certificate/Trusted roots (using pull-down menu). The user then can choose any of this root and view the certificate.