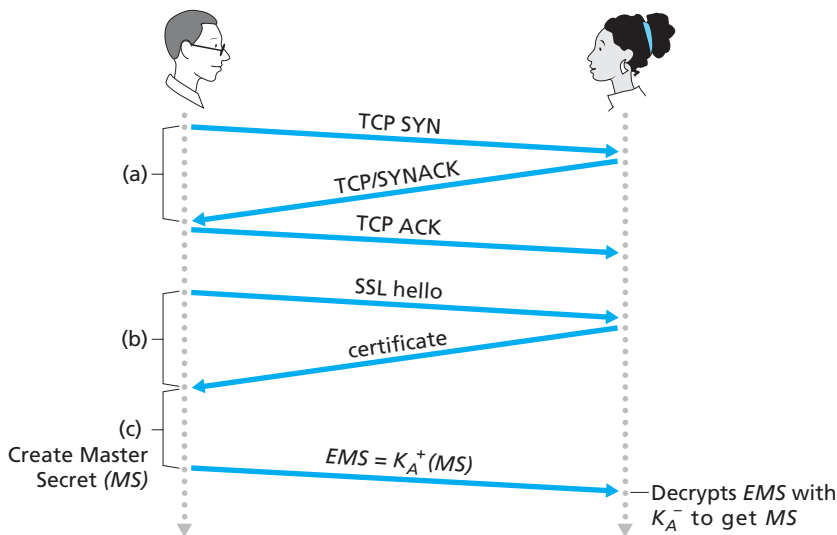


### 8.6.1 The Big Picture

We begin by describing a simplified version of SSL, one that will allow us to get a big-picture understanding of the *why* and *how* of SSL. We will refer to this simplified version of SSL as “almost-SSL.” After describing almost-SSL, in the next subsection we’ll then describe the real SSL, filling in the details. Almost-SSL (and SSL) has three phases: *handshake*, *key derivation*, and *data transfer*. We now describe these three phases for a communication session between a client (Bob) and a server (Alice), with Alice having a private/public key pair and a certificate that binds her identity to her public key.

#### Handshake

During the handshake phase, Bob needs to (a) establish a TCP connection with Alice, (b) verify that Alice is *really* Alice, and (c) send Alice a master secret key, which will be used by both Alice and Bob to generate all the symmetric keys they need for the SSL session. These three steps are shown in Figure 8.25. Note that once the TCP connection is established, Bob sends Alice a hello message. Alice then responds with her certificate, which contains her public key. As discussed in Section 8.3, because the certificate has been certified by a CA, Bob knows for sure that the



**Figure 8.25** ♦ The almost-SSL handshake, beginning with a TCP connection

public key in the certificate belongs to Alice. Bob then generates a Master Secret (MS) (which will only be used for this SSL session), encrypts the MS with Alice's public key to create the Encrypted Master Secret (EMS), and sends the EMS to Alice. Alice decrypts the EMS with her private key to get the MS. After this phase, both Bob and Alice (and no one else) know the master secret for this SSL session.

### Key Derivation

In principle, the MS, now shared by Bob and Alice, could be used as the symmetric session key for all subsequent encryption and data integrity checking. It is, however, generally considered safer for Alice and Bob to each use different cryptographic keys, and also to use different keys for encryption and integrity checking. Thus, both Alice and Bob use the MS to generate four keys:

- $E_B$  = session encryption key for data sent from Bob to Alice
- $M_B$  = session MAC key for data sent from Bob to Alice
- $E_A$  = session encryption key for data sent from Alice to Bob
- $M_A$  = session MAC key for data sent from Alice to Bob

Alice and Bob each generate the four keys from the MS. This could be done by simply slicing the MS into four keys. (But in *real* SSL it is a little more complicated, as we'll see.) At the end of the key derivation phase, both Alice and Bob have all four keys. The two encryption keys will be used to encrypt data; the two MAC keys will be used to verify the integrity of the data.

### Data Transfer

Now that Alice and Bob share the same four session keys ( $E_B$ ,  $M_B$ ,  $E_A$ , and  $M_A$ ), they can start to send secured data to each other over the TCP connection. Since TCP is a byte-stream protocol, a natural approach would be for SSL to encrypt application data on the fly and then pass the encrypted data on the fly to TCP. But if we were to do this, where would we put the MAC for the integrity check? We certainly do not want to wait until the end of the TCP session to verify the integrity of all of Bob's data that was sent over the entire session! To address this issue, SSL breaks the data stream into *records*, appends a MAC to each record for integrity checking, and then encrypts the record+MAC. To create the MAC, Bob inputs the record data along with the key  $M_B$  into a hash function, as discussed in Section 8.3. To encrypt the package record+MAC, Bob uses his session encryption key  $E_B$ . This encrypted package is then passed to TCP for transport over the Internet.

Although this approach goes a long way, it still isn't bullet-proof when it comes to providing data integrity for the entire message stream. In particular, suppose Trudy is a woman-in-the-middle and has the ability to insert, delete, and replace segments

in the stream of TCP segments sent between Alice and Bob. Trudy, for example, could capture two segments sent by Bob, reverse the order of the segments, adjust the TCP sequence numbers (which are not encrypted), and then send the two reverse-ordered segments to Alice. Assuming that each TCP segment encapsulates exactly one record, let's now take a look at how Alice would process these segments.

1. TCP running in Alice would think everything is fine and pass the two records to the SSL sublayer.
2. SSL in Alice would decrypt the two records.
3. SSL in Alice would use the MAC in each record to verify the data integrity of the two records.
4. SSL would then pass the decrypted byte streams of the two records to the application layer; but the complete byte stream received by Alice would not be in the correct order due to reversal of the records!

You are encouraged to walk through similar scenarios for when Trudy removes segments or when Trudy replays segments.

The solution to this problem, as you probably guessed, is to use sequence numbers. SSL does this as follows. Bob maintains a sequence number counter, which begins at zero and is incremented for each SSL record he sends. Bob doesn't actually include a sequence number in the record itself, but when he calculates the MAC, he includes the sequence number in the MAC calculation. Thus, the MAC is now a hash of the data plus the MAC key  $M_B$  *plus the current sequence number*. Alice tracks Bob's sequence numbers, allowing her to verify the data integrity of a record by including the appropriate sequence number in the MAC calculation. This use of SSL sequence numbers prevents Trudy from carrying out a woman-in-the-middle attack, such as reordering or replaying segments. (Why?)

### SSL Record

The SSL record (as well as the almost-SSL record) is shown in Figure 8.26. The record consists of a type field, version field, length field, data field, and MAC field. Note that the first three fields are not encrypted. The type field indicates whether the record is a handshake message or a message that contains application data. It is also



**Figure 8.26** ♦ Record format for SSL