Message Authentication

Perhaps the most confusing area of network security is that of message authentication and the related topic of digital signatures. Message authentication is a procedure to verify that received messages come from the alleged source and have not been altered. Message authentication may also verify sequencing and timeliness.

Authentication Requirements:

In the context of communications across a network, the following attacks can be identified:

1. **Disclosure**: Release of message contents to any person or process not possessing the appropriate cryptographic key.
2. **Traffic analysis**: Discovery of the pattern of traffic between parties. In a connection-oriented application, the frequency and duration of connections could be determined. In either a connection-oriented or connectionless environment, the number and length of messages between parties could be determined.
3. **Masquerade**: Insertion of messages into the network from a fraudulent source. This includes the creation of messages by an opponent that are purported to come from an authorized entity. Also included are fraudulent acknowledgments of message receipt or non receipt by someone other than the message recipient.
4. **Content modification**: Changes to the contents of a message, including insertion, deletion, transposition, and modification.
5. **Sequence modification**: Any modification to a sequence of messages between parties, including insertion, deletion, and reordering.
6. **Timing modification**: Delay or replay of messages. In a connection-oriented application, an entire session or sequence of messages could be a replay of some previous valid session, or individual messages in the sequence could be delayed or replayed. In a connectionless application, an individual message (e.g., datagram) could be delayed or replayed.
7. **Source repudiation**: Denial of transmission of message by source.
8. **Destination repudiation**: Denial of receipt of message by destination.

Authentication Functions

Any message authentication or digital signature mechanism has two levels of functionality. At the lower level, there must be some sort of function that produces an authenticator: a value to be used to authenticate a message. This lower-level function is then used as a primitive in a higher-level authentication protocol that enables a receiver to verify the authenticity of a message.

Types of functions that may be used to produce an authenticator may be grouped into three classes, as follows:

- **Message encryption:** The ciphertext of the entire message serves as its authenticator
- **Message Authentication Code (MAC): A** function of the message and a secret key that produces a fixed-length value that serves as the authenticator
- **Hash function**: A function that maps a message of any length into a fixed-length hash value, which serves as the authenticator.

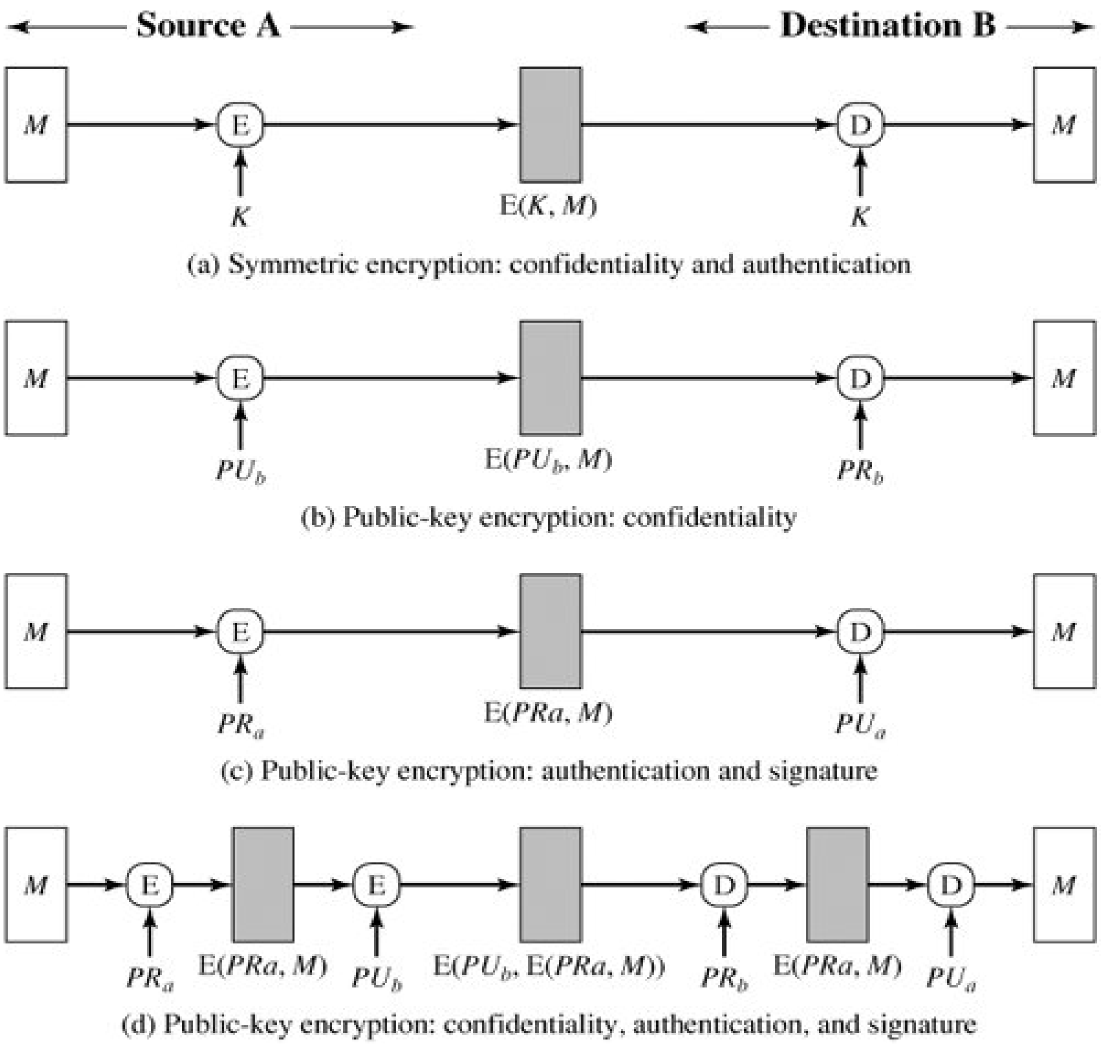
Message Encryption

Message encryption by itself can provide a measure of authentication. The analysis differs for symmetric and public-key encryption schemes.

Symmetric Encryption

Consider the straightforward use of symmetric encryption (Figure13a). A message M transmitted from source A to destination B is encrypted using a secret key K shared by A and B. If no other party knows the key, then confidentiality is provided: No other party can recover the plaintext of the message.

In addition, we may say that B is assured that the message was generated by A. Why? The message must have come from A because A is the only other party that possesses K and therefore the only other party with the information necessary to construct ciphertext that can be decrypted with K. Furthermore, if M is recovered, B knows that none of the bits of M have been altered, because an opponent that does not know K would not know how to alter bits in the ciphertext to produce desired changes in the plaintext.



Source A
Destination B
M
E
K
E(K, M)
D
K
M
(a) Symmetric encryption: confidentiality and authentication
M
E
PU_b
$E(PU_b, M)$
D
PR_b
M
(b) Public-key encryption: confidentiality
M
E
PR_a
E(PRa, M)
D
PU_a
M
(c) Public-key encryption: authentication and signature
M
E
PR_a
E(PRa, M)
E
PU_b
$E(PU_b, E(PRa, M))$
D
PR_b
E(PRa, M)
D
PU_a
M
(d) Public-key encryption: confidentiality, authentication, and signature

Figure 13. Basic Uses of Message Encryption

So we may say that symmetric encryption provides authentication as well as confidentiality.

Public-Key Encryption

The straightforward use of public-key encryption (Figure 13b) provides confidentiality but not authentication. The source (A) uses the public key PU_b of the destination (B) to encrypt M. Because only B has the corresponding private key PR_b, only B can decrypt the message. This scheme provides no authentication because any opponent could also use B's public key to encrypt a message, claiming to be A.

To provide authentication, A uses its private key to encrypt the message, and B uses A's public key to decrypt (Figure 13c). This provides authentication using the same type of reasoning as in the symmetric encryption case: The message must have come from A because A is the only party that possesses PR_a and therefore the only party with the information necessary to construct ciphertext that can be decrypted with PU_a. Again, the same reasoning as before applies: There must be some internal structure to the plaintext so that the receiver can distinguish between well-formed plaintext and random bits.

Assuming there is such structure, then the scheme of Figure 13c does provide authentication. It also provides what is known as digital signature.[1] Only A could have constructed the ciphertext because only A possesses PR_a. Not even B, the recipient, could have constructed the ciphertext. Therefore, if B is in possession of the ciphertext, B has the means to prove that the message must have come from A. In effect, A has "signed" the message by using its private key to encrypt. Note that this scheme does not provide confidentiality. Anyone in possession of A's public key can decrypt the ciphertext.

To provide both confidentiality and authentication, A can encrypt M first using its private key, which provides the digital signature, and then using B's public key, which provides confidentiality (Figure 13d). The disadvantage of this approach is that the public-key algorithm, which is complex, must be exercised four times rather than two in each communication.

Message Authentication Code

An alternative authentication technique involves the use of a secret key to generate a small fixed-size block of data, known as a cryptographic checksum or MAC that is appended to the message. This technique assumes that two communicating parties, say A and B, share a common secret key K. When A has a message to send to B, it calculates the MAC as a function of the message and the key:MAC = C(K, M), where

M	= input message
C	= MAC function
K	= shared secret key
MAC	= message authentication code

The message plus MAC are transmitted to the intended recipient. The recipient performs the same calculation on the received message, using the same secret key, to generate a new MAC. The received MAC is compared to the calculated MAC (Figure 14). If we assume that only the receiver and the sender know the identity of the secret key, and if the received MAC matches the calculated MAC, then

1. The receiver is assured that the message has not been altered. If an attacker alters the message but does not alter the MAC, then the receiver's calculation of the MAC will differ from the received MAC. Because the attacker is assumed not to know the secret key, the attacker cannot alter the MAC to correspond to the alterations in the message.
2. The receiver is assured that the message is from the alleged sender. Because no one else knows the secret key, no one else could prepare a message with a proper MAC.
3. If the message includes a sequence number, then the receiver can be assured of the proper sequence because an attacker cannot successfully alter the sequence number.

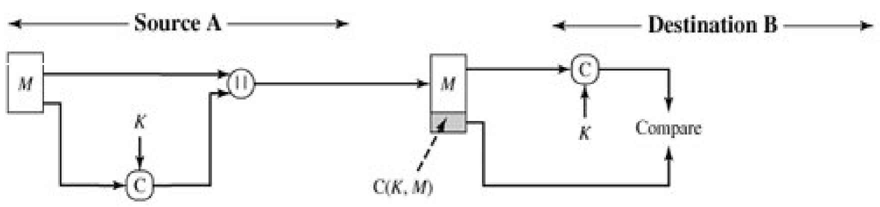


Figure 14. Basic Uses of Message Authentication Code (MAC)

Hash Function

A variation on the message authentication code is the one-way hash function. As with the message authentication code, a hash function accepts a variable-size message M as input and produces a fixed-size output, referred to as a **hash code** H(M). Unlike a MAC, a hash code does not use a key but is a function only of the input message. The hash code is also referred to as a **message digest** or hash value. The hash code is a function of all the bits of the message and provides an error-detection capability: A change to any bit or bits in the message results in a change to the hash code.

Figure 15 illustrates a variety of ways in which a hash code can be used to provide message authentication, as follows:

a. The message plus concatenated hash code is encrypted using symmetric encryption. The same line of reasoning applies: Because only A and B share the secret key, the message must have come from A and has not been altered. The hash code provides the structure or redundancy required to achieve authentication. Because encryption is applied to the entire message plus hash code, confidentiality is also provided.
b. Only the hash code is encrypted, using symmetric encryption. This reduces the processing burden for those applications that do not require confidentiality.

   Note that the combination of hashing and encryption results in an overall function that is, in fact, a MAC (Figure 14). That is, E(K, H(M)) is a function of a variable-length message M and a secret key K, and it produces a fixed-size output that is secure against an opponent who does not know the secret key.

c. Only the hash code is encrypted, using public-key encryption and using the sender's private key. As with (b), this provides authentication. It also provides a digital signature, because only the sender could have produced the encrypted hash code. In fact, this is the essence of the digital signature technique.
d. If confidentiality as well as a digital signature is desired, then the message plus the private-key-encrypted hash code can be encrypted using a symmetric secret key. This is a common technique.
e. It is possible to use a hash function but no encryption for message authentication. The technique assumes that the two communicating parties share a common secret value S. A computes the hash value over the concatenation of M and S and appends the resulting hash value to M. Because B possesses S, it can recompute the hash value to verify. Because the secret value itself is not sent, an opponent cannot modify an intercepted message and cannot generate a false message.
f. Confidentiality can be added to the approach of (e) by encrypting the entire message plus the hash code.

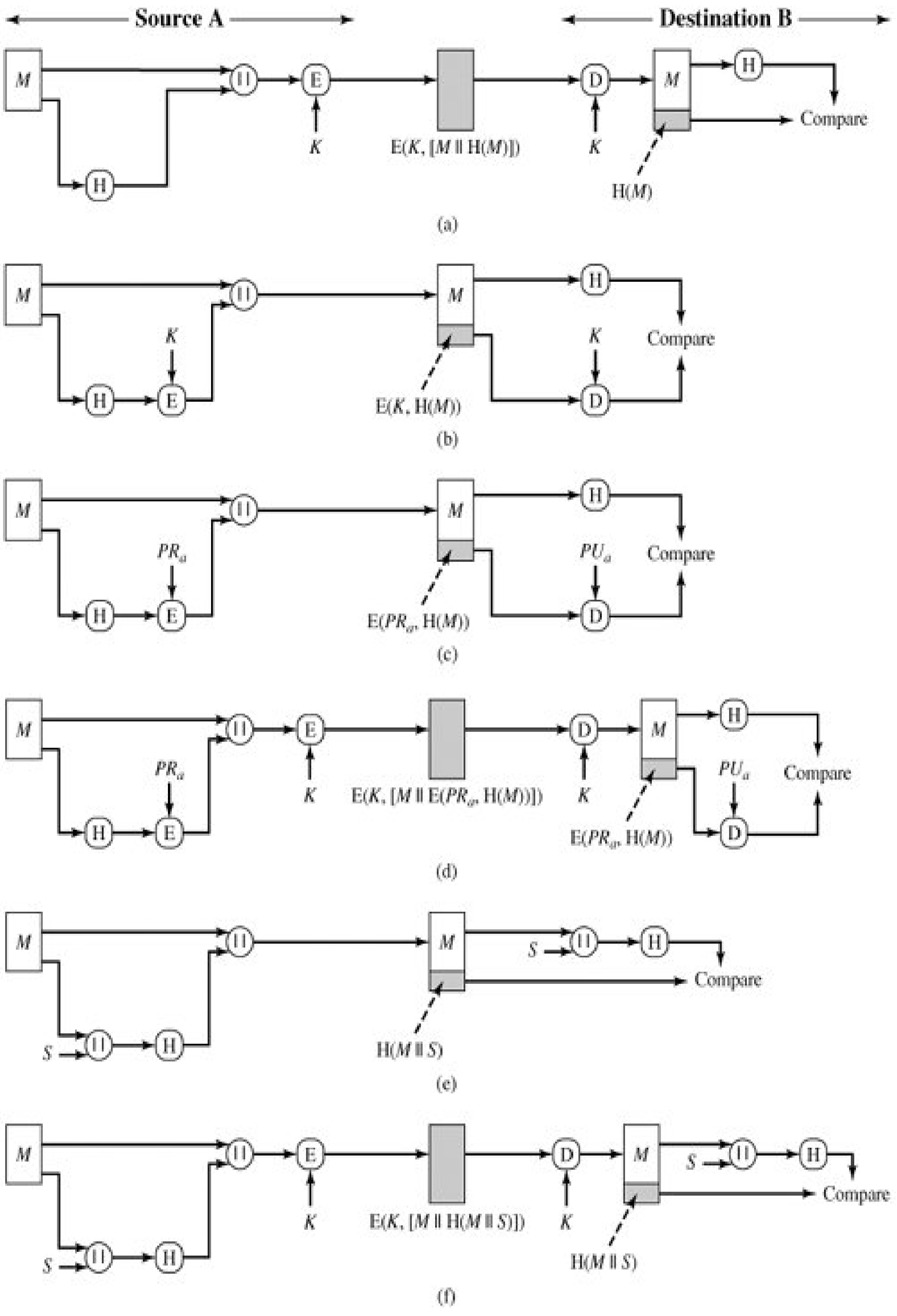


Figure 15. Basic Uses of Hash Function

A hash value h is generated by a function H of the form

$h = H(M)$

where M is a variable-length message and H(M) is the fixed-length hash value. The hash value is appended to the message at the source at a time when the message is assumed or known to be correct. The receiver authenticates that message by recomputing the hash value. Because the hash function itself is not considered to be secret, some means is required to protect the hash value (Figure 15).

Requirements for a Hash Function

The purpose of a hash function is to produce a "fingerprint" of a file, message, or other block of data. To be useful for message authentication, a hash function H must have the following properties:

1. H can be applied to a block of data of any size.
2. H produces a fixed-length output.
3. H(x) is relatively easy to compute for any given x, making both hardware and software implementations practical.
4. For any given value h, it is computationally infeasible to find x such that $H(x) = h$. This is sometimes referred to in the literature as the one-way property.
5. For any given block x, it is computationally infeasible to find $y \neq x$ such that $H(y) = H(x)$. This is sometimes referred to as **weak collision resistance**.
6. It is computationally infeasible to find any pair (x, y) such that $H(x) = H(y)$. This is sometimes referred to as **strong collision resistance**.

Simple Hash Functions

All hash functions operate using the following general principles. The input (message, file, etc.) is viewed as a sequence of n-bit blocks. The input is processed one block at a time in an iterative fashion to produce an n-bit hash function.

One of the simplest hash functions is the bit-by-bit exclusive-OR (XOR) of every block. This can be expressed as follows:

$$C_i = b_{i1} \oplus b_{i1} \oplus \ldots \oplus b_{im}$$

where

C_i	= ith bit of the hash code, $1 \leq i \leq n$
m	= number of n-bit blocks in the input
b_{ij}	= ith bit in jth block
$\oplus$	= XOR operation

This operation produces a simple parity for each bit position and is known as a longitudinal redundancy check. It is reasonably effective for random data as a data integrity check. Each n-bit hash value is equally likely. Thus, the probability that a data error will result in an unchanged hash value is 2^{n} . With more predictably formatted data, the function is less effective. For example, in most normal text files, the high-order bit of each octet is always zero. So if a 128-bit hash value is used, instead of an effectiveness of 2^{128}, the hash function on this type of data has an effectiveness of 2^{112}. A simple way to improve matters is to perform a one-bit circular shift, or rotation, on the hash value after each block is processed. The procedure can be summarized as follows:

1. Initially set the n-bit hash value to zero.

2. Process each successive n-bit block of data as follows:

a. Rotate the current hash value to the left by one bit.

b. XOR the block into the hash value. This has the effect of "randomizing" the input more completely and overcoming any regularities that appear in the input.