UNIT-IV

MESSAGE AUTHENTICATION

Message authentication is a mechanism or service used to verify the integrity of a message. Message authentication assures that data received are exactly as sent by (i.e., contain no modification, insertion, deletion, or replay) and that the purported identity of the sender is valid.

● Symmetric encryption provides authentication among those who share the secret key. Encryption of a message by a sender's private key also provides a form of authentication.

● The two most common cryptographic techniques for message authentication are a message authentication code (MAC) and a secure hash function.

● A MAC is an algorithm that requires the use of a secret key. A MAC takes a variable length message and a secret key as input and produces an authentication code. A recipient in possession of the secret key can generate an authentication code to verify the integrity of the message.

A hash function maps a variable-length message into a fixed length hash value, or message digest. For message authentication, a secure hash function must be combined in some fashion with a secret key.

A.1 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.

A.2 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.

- **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 can be encrypted with following two methods-

i) Symmetric Encryption- 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. 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. Further more,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. So we may say that symmetric encryption provides authentication as well as confidentiality.

ii) Public-Key Encryption- The straightforward use of public-key encryption provides confidentiality but not authentication. The source (A) uses the public key PUb of the destination (B) to encrypt M. Because only B has the corresponding private key PRb, 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. 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 PRa and therefore the only party with the information necessary to construct ciphertext that can be decrypted with PUa. 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.

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. **A MAC, also known as a cryptographic checksum, is generated by a function C of the form MAC = C(K, M).** 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:

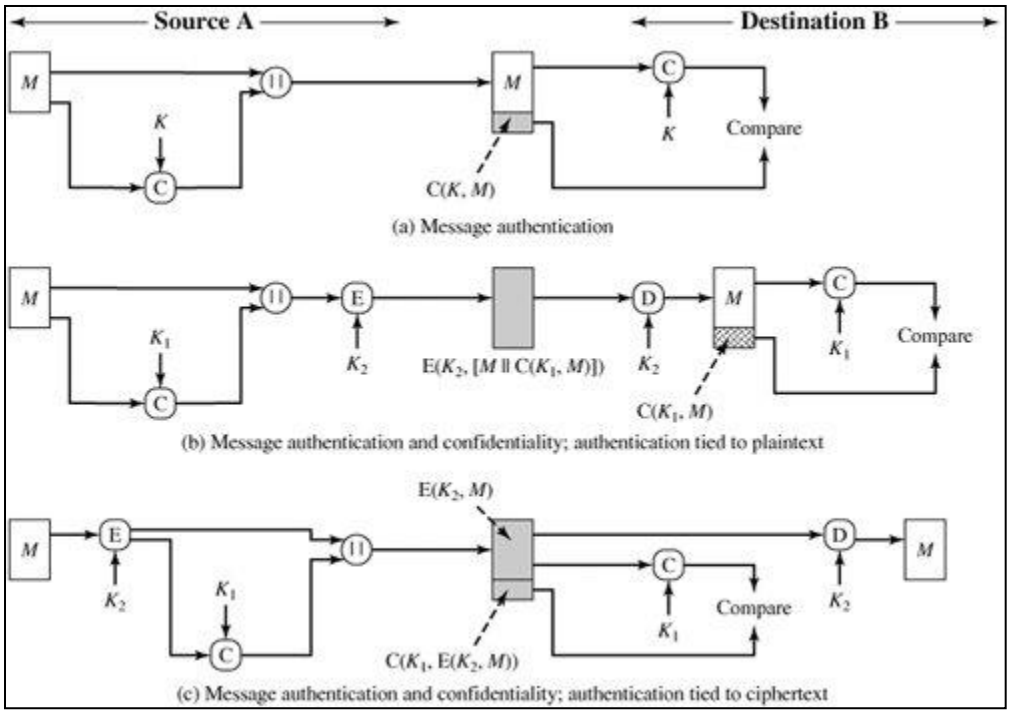
MAC = C(*K*,*M*), where
M = input message
C = MAC function
K = shared secret key
MAC = message authentication code

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. 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 (such as is used with HDLC, X.25, and TCP), then the receiver can be assured of the proper sequence because an attacker cannot successfully alter the sequence number.



Basic Uses of Message Authentication Code (MAC)

A MAC function is similar to encryption. One difference is that the MAC algorithm need not be reversible, as it must for decryption. In general, the MAC function is a many-to-one function. The domain of the function consists of messages of some arbitrary length, whereas the range consists of all possible MACs and all possible keys. If an n-bit MAC is used, then there are 2n possible MACs, whereas there are N possible messages with N >> 2n. Furthermore, with a k-bit key, there are 2k possible keys. The MAC provides authentication but not confidentiality, because the message as a whole is transmitted in the clear. Confidentiality can be provided by performing message encryption either after the MAC algorithm.

In both these cases, two separate keys are needed, each of which is shared by the sender and the receiver. In the first case, the MAC is calculated with the message as input and is then concatenated to the message. The entire block is then encrypted. In the second case, the message is encrypted first. Then the MAC is calculated using the resulting ciphertext and is concatenated to the ciphertext to form the transmitted block.

Situations in which a message authentication code is used:-

1. There are a number of applications in which the same message is broadcast to a number of destinations. Examples are notification to users that the network is now unavailable or an alarm signal in a military control center. It is cheaper and more reliable to have only one destination responsible for monitoring authenticity. Thus, the message must be broadcast in plaintext with an associated message authentication code. The responsible system has the secret key and performs authentication. If a violation occurs, the other destination systems are alerted by a general alarm.

2. Another possible scenario is an exchange in which one side has a heavy load and cannot afford the time to decrypt all incoming messages. Authentication is carried out on a selective basis, messages being chosen at random for checking.

3. Authentication of a computer program in plaintext is an attractive service. The computer program can be executed without having to decrypt it every time, which would be wasteful of processor resources. However, if a message authentication code were attached to the program, it could be checked whenever assurance was required of the integrity of the program.

4. For some applications, it may not be of concern to keep messages secret, but it is important to authenticate messages. An example is the Simple Network Management Protocol Version 3 (SNMPv3),

which separates the functions of confidentiality and authentication. For this application, it is usually important for a managed system to authenticate incoming SNMP messages, particularly if the message contains a command to change parameters at the managed system. On the other hand, it may not be necessary to conceal the SNMP traffic.

5. Separation of authentication and confidentiality functions affords architectural flexibility. For example, it may be desired to perform authentication at the application level but to provide confidentiality at a lower level, such as the transport layer.

6. A user may wish to prolong the period of protection beyond the time of reception and yet allow processing of message contents. With message encryption, the protection is lost when the message is decrypted, so the message is protected against fraudulent modifications only in transit but not within the target system. Finally, note that the MAC does not provide a digital signature because both sender and receiver share the same key.

To apply MAC, the MAC function should satisfy the following requirements:

1. If an opponent observes M and C(K, M), it should be computationally infeasible for the opponent to construct a message M' such that C(K, M') = C(K, M).

2. C(K, M) should be uniformly distributed in the sense that for randomly chosen messages, M and M', the probability that C(K, M) = C(K, M') is 2_n, where n is the number of bits in the MAC.

3. Let M' be equal to some known transformation on M. That is, M' = f(M). For example, f may involve inverting one or more specific bits. In that case, Pr[C(K, M) = C(K, M')] = 2^n.

HASH FUNCTION

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. 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.

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 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:

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

where

C_i = *i*th bit of the hash code, $1 \leq i \leq n$

m = number of *n*-bit blocks in the input

b_{ij} = *i*th bit in *j*th 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}.

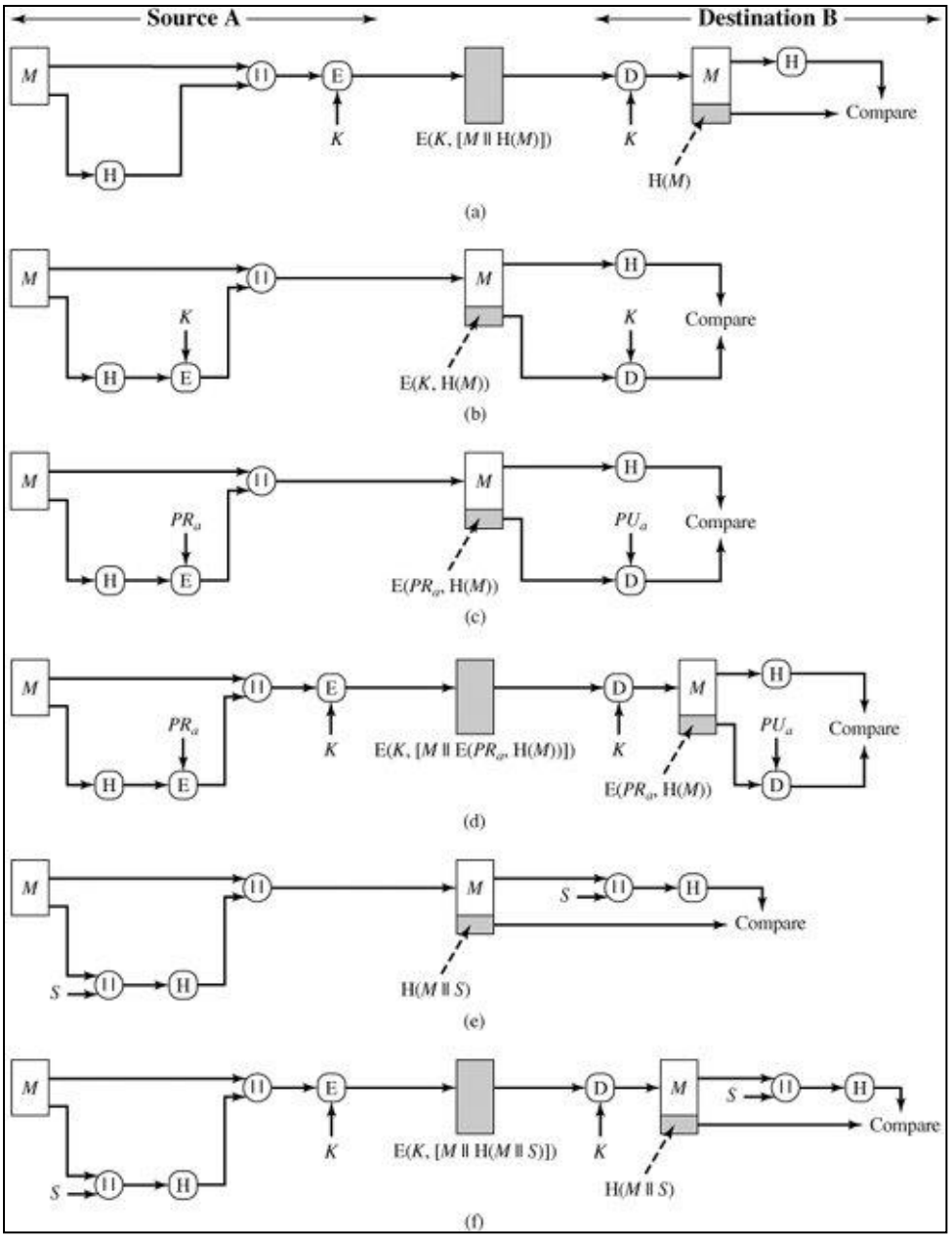
A simple way to improve matters is to perform a one-bit circular shift, or rotation, on the hash value after each block is processed. The procedure can be summarized as follows:

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.



Basic Uses of Hash Function

There are varieties 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. This is identical in structure to the internal error control strategy. 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.

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.

HASH ALGORITHMS

Two hash algorithms are discussed in detail:-

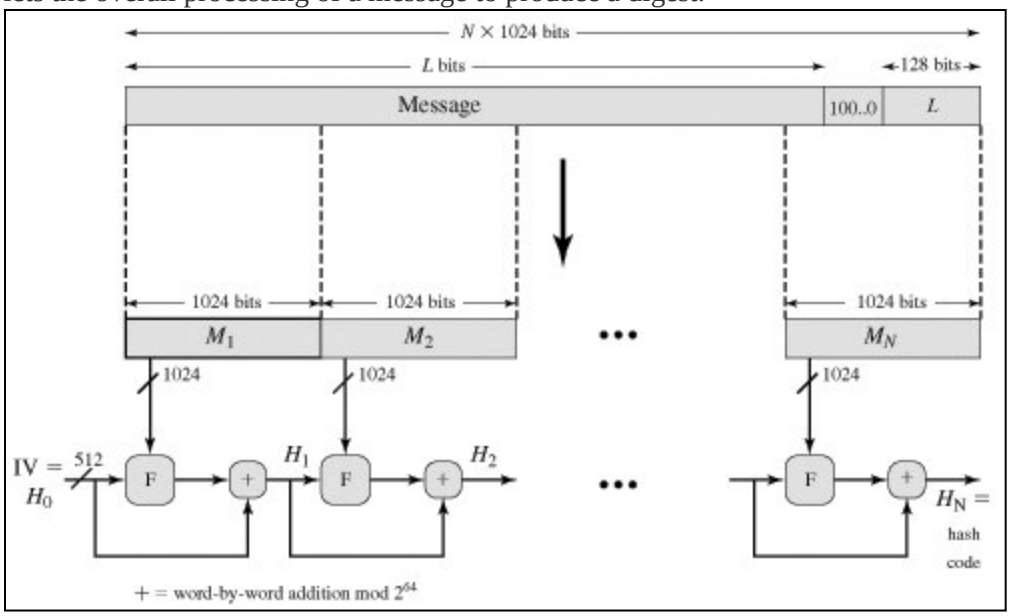
a) Secure Hash Algorithm
b) Message Digest MD5

a) Secure Hash Algorithm

The Secure Hash Algorithm (SHA) was developed by the National Institute of Standards and Technology (NIST) and published as a federal information processing standard (FIPS 180) in 1993; a revised version was issued as FIPS 180-1 in 1995 and is generally referred to as SHA-1. The actual standards document is entitled Secure Hash Standard. SHA is based on the hash function MD4 and its design closely models MD4.

SHA-1 produces a hash value of 160 bits. In 2002, NIST produced a revised version of the standard, FIPS 180-2, that defined three new versions of SHA, with hash value lengths of 256, 384, and 512 bits, known as SHA-256, SHA-384, and SHA-512.

SHA-512 Logic- The algorithm takes as input a message with a maximum length of less than 2^{128} bits and produces as output a 512-bit message digest. The input is processed in 1024-bit blocks. Figure below depicts the overall processing of a message to produce a digest.



Message Digest Generation Using SHA-512

The processing consists of the following steps:

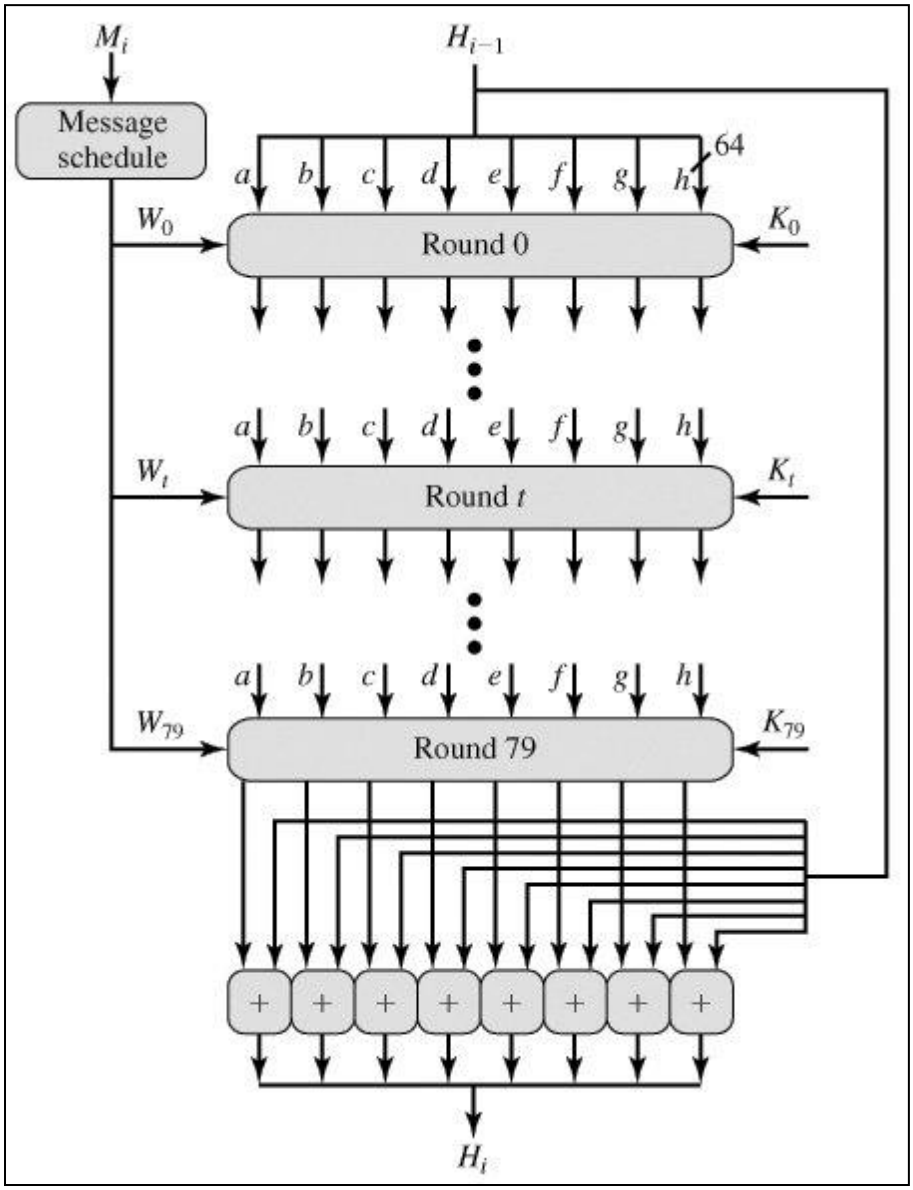
- **Step 1: Append padding bits.** The message is padded so that its length is congruent to 896 modulo 1024 [length ≡ 896 (mod 1024)]. Padding is always added, even if the message is already of the desired length. Thus, the number of padding bits is in the range of 1 to 1024. The padding consists of a single 1-bit followed by the necessary number of 0-bits.
- **Step 2: Append length.** A block of 128 bits is appended to the message. This block is treated as an unsigned 128-bit integer (most significant byte first) and contains the length of the original message (before the padding).

The outcome of the first two steps yields a message that is an integer multiple of 1024 bits in length.

• **Step 3: Initialize hash buffer.** A 512-bit buffer is used to hold intermediate and final results of the hash function. The buffer can be represented as eight 64-bit registers (a, b, c, d, e, f, g, h).
These registers are initialized to the following 64-bit integers (hexadecimal values):
a = 6A09E667F3BCC908

b = BB67AE8584CAA73B
c = 3C6EF372FE94F82B
c = A54FF53A5F1D36F1
e = 510E527FADE682D1
f = 9B05688C2B3E6C1F
g = 1F83D9ABFB41BD6B
h = 5BE0CDI9137E2179

These values are stored in big-endianformat, which is the most significant byte of a word in the low-address (leftmost) byte position. These words were obtained by taking the first sixty-four bits of the fractional parts of the square roots of the first eight prime numbers.
• **Step 4: Process message in 1024-bit (128-word) blocks.** The heart of the algorithm is a module that consists of 80 rounds;



SHA-512 Processing of a Single 1024-Bit Block

Each round takes as input the 512-bit buffer value abcdefgh, and updates the contents of the buffer. At input to the first round, the buffer has the value of the intermediate hash value, H_{i-1}.
Each round t makes use of a 64-bit value W_t derived from the current 1024-bit block being processed (M_i) These values are derived using a message schedule described subsequently. Each round also makes use of an additive constant K_t where $0 \leq t \leq 79$ indicates one of the 80 rounds. These words represent the first sixty-four bits of the fractional parts of the cube roots of the first eighty prime numbers. The constants provide a "randomized" set of 64-bit patterns, which should eliminate any regularities in the input data.

The output of the eightieth round is added to the input to the first round (H_{i-1})to produce H_i. The addition is done independently for each of the eight words in the buffer with each of the corresponding words in H_{i-1} using addition modulo 2^{64}.

- **Step 5: Output.** After all N 1024-bit blocks have been processed, the output from the Nth stage is the 512-bit message digest.

We can summarize the behavior of SHA-512 as follows:
H_0 = IV
H_i = SUM64(H_{i-1}, abcdefgh$_i$)
$MD = H_N$
where
IV = initial value of the abcdefgh buffer, defined in step 3
abcdefgh$_i$ = the output of the last round of processing of the ith message block
N = the number of blocks in the message (including padding and length fields)
SUM64 = Addition modulo 2^{64} performed separately on each word of the pair of inputs
MD = final message digest value

SHA-512 Round Function

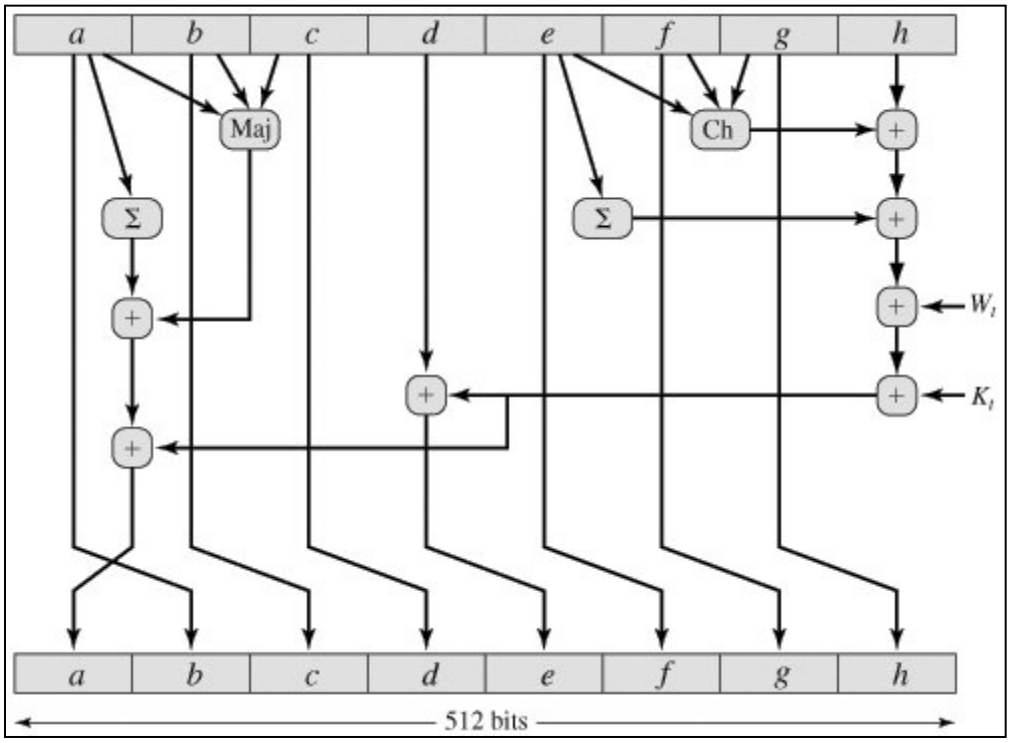
Let us look in more detail at the logic in each of the 80 steps of the processing of one 512-bit block. Each round is defined by the following set of equations:

$$T_1 = h + \text{Ch}(e, f, g) + \left(\sum_1^{512} e\right) + W_t + K_t$$
$$T_2 = \left(\sum_0^{512} a\right) + \text{Maj}(a, b, c)$$
$$a = T_1 + T_2$$
$$b = a$$
$$c = b$$
$$d = c$$
$$e = d + T_1$$
$$f = e$$
$$g = f$$
$$h = g$$

where
t =step number; $0 \leq t \leq 79$
Ch(e, f, g)
= (e AND f) $\oplus$(NOT e AND g) *the conditional function*: *If* e then f else g
Maj(a, b, c)
= (a AND b) $\oplus$(a AND c) $\oplus$ (b AND c) *the function is true only of the majority (two or three) of the arguments are true.*

$$\left(\sum_0^{512} a\right) = \text{ROTR}^{28}(a) \oplus \text{ROTR}^{34}(a) \oplus \text{ROTR}^{39}(a)$$
$$\left(\sum_1^{512} e\right) = \text{ROTR}^{14}(e) \oplus \text{ROTR}^{18}(e) \oplus \text{ROTR}^{41}(e)$$

$\text{ROTR}^n(x)$ = circular right shift (rotation) of the 64-bit argument x by n bits
W_t = a 64-bit word derived from the current 512-bit input block
K_t = a 64-bit additive constant
+ = addition modulo 2^{64}



Elementary SHA-512 Operation (single round)

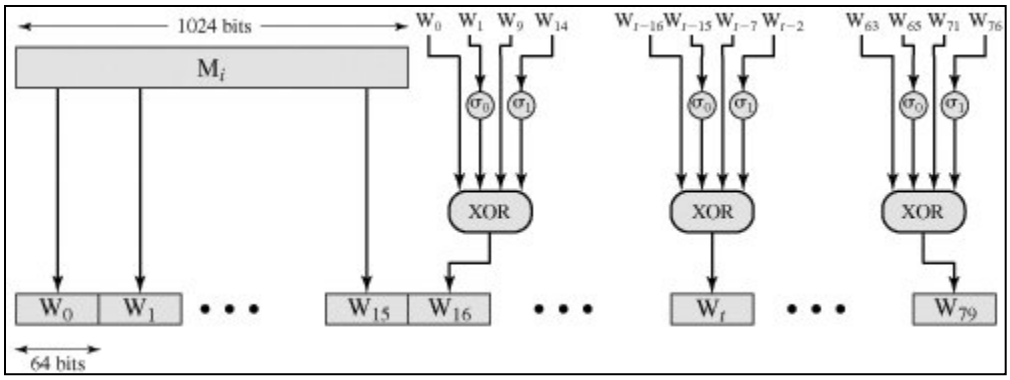
It remains to indicate how the 64-bit word values W_t are derived from the 1024-bit message. The first 16 values of W_t are taken directly from the 16 words of the current block. The remaining values are defined as follows:

$$W_t = \sigma_1^{512}(W_{t-2}) + W_{t-7} + \sigma_0^{512}(W_{t-15}) + W_{t-16}$$

Where

$$\sigma_0^{512}(x) = \text{ROTR}^1(x) \oplus \text{ROTR}^8(x) \oplus \text{SHR}^7(x)$$
$$\sigma_1^{512}(x) = \text{ROTR}^{19}(x) \oplus \text{ROTR}^{61}(x) \oplus \text{SHR}^6(x)$$

$\text{ROTR}^n(x)$ = circular right shift (rotation) of the 64-bit argument x by n bits
$\text{SHR}^n(x)$ = left shift of the 64-bit argument x by n bits with padding *by zeros on the right*



Single Block

Thus, in the first 16 steps of processing, the value of W_t is equal to the corresponding word in the message block. For the remaining 64 steps, the value of W_t consists of the circular left shift by one bit of the XOR of four of the preceding values of W_t, with two of those values subjected to shift and rotate operations. This introduces a great deal of redundancy and interdependence into the message blocks that are compressed, which complicates the task of finding a different message block that maps to the same compression function output.

b) Message Digest MD5 Algorithm

MD5 message digest algorithm is the 5th version of the Message Digest Algorithm developed by Ron Rivest to produce 128 bit message digest. MD5 is quite fast than other versions of message digest which takes the plain text of 512 bit blocks which is further divided into 16 blocks, each of 32 bit and produces the 128 bit message digest which is a set of four blocks, each of 32 bits. MD5 produces the message digest through five steps i.e. padding, append length, divide input into 512 bit blocks, initialize chaining variables a process blocks and 4 rounds, uses different constant it in each iteration.

Use of MD 5

MD5 Algorithm was developed with the main motive of security as it takes an input of any size and produces an output if a 128-bit hash value. To be considered cryptographically secure MD5 should meet two requirements:

1. It is impossible to generate two inputs that cannot produce the same hash function.
2. It is impossible to generate a message having the same hash value.

Initially, MD5 was developed to store one way hash of a password and some file servers also provide pre-computed MD5 checksum of a file so that the user can compare the checksum of the downloaded file to it. Most Unix based Operating Systems include MD5 checksum utilities in their distribution packages.

Working of MD5 Algorithm

Step1: Append Padding Bits

- Padding means adding extra bits to the original message. So in MD5 original message is padded such that its length in bits is congruent to 448 modulo 512. Padding is done such that the total bits are 64 less being a multiple of 512 bits length.
- Padding is done even if the length of the original message is already congruent to 448 modulo 512. In padding bits, the only first bit is 1 and the rest of the bits are 0.

Step 2: Append Length

After padding, 64 bits are inserted at the end which is used to record the length of the original input. Modulo 2^64. At this point, the resulting message has a length multiple of 512 bits.

Step 3: Initialize MD buffer

A four-word buffer (A, B, C, D) is used to compute the values for the message digest. Here A, B, C, D are 32- bit registers and are initialized in the following way

Word A	01	23	45	67
Word B	89	Ab	Cd	Ef
Word C	Fe	Dc	Ba	98
Word D	76	54	32	10

Step 4: Processing message in 16-word block

MD5 uses the auxiliary functions which take the input as three 32-bit number and produces a 32-bit output. These functions use logical operators like OR, XOR, NOR.

F(X, Y, Z)	XY v not (X)Z
G(X, Y, Z)	XZ v Y not (Z)
H(X, Y, Z)	X xor Y xor Z
I(X, Y, Z)	Y xor (X v not (Z))

The content of four buffers are mixed with the input using this auxiliary buffer and 16 rounds are performed using 16 basic operations.

Output-

After all, rounds have performed the buffer A, B, C, D contains the MD5 output starting with lower bit A and ending with higher bit D.

Advantages and Disadvantages of MD5 Algorithm:

- MD5 Algorithms are useful because it is easier to compare and store these smaller hashes than to store a large text of variable length. The MD5 algorithm is a widely used algorithm for one way hashes that are used to verify without necessarily giving the original value.MD5 Algorithm is used by Unix systems to store the passwords of the user in a 128-bit encrypted format. MD5 algorithms are widely used to check the integrity of the files.

- Moreover, it is very easy to generate a message digest of the original message using this algorithm.MD5 algorithm can perform the message digest of a message having any number of bits, it is not limited to message in the multiples of 8, unlike MD5sum which is limited to octets.
- But from many years MD5 has prone to hash collision weakness, i.e it is possible to create the same hash function for two different inputs. MD5 provides no security over these collision attacks. Instead of MD5, SHA (Secure Hash Algorithm, which produces 160-bit message digest and designed by NSA to be a part of digital signature algorithm) is now acceptable in the cryptographic field for generating the hash function as it is not easy to produce SHA-I collision and till now no collision has been produced yet.
- Moreover, the MD5 algorithm is quite slow then the optimized SHA algorithm.SHA is much secure than MD5 algorithm and moreover, it can be implemented in existing technology with exceeding rates, unlike MD5. Nowadays new hashing algorithms are coming up in the market keeping in mind higher security of data like SHA256 (which generates 256 bits signature of a text).

DIGITAL SIGNATURES AND AUTHENTICATION PROTOCOLS

The most important development from the work on public-key cryptography is the digital signature. The digital signature provides a set of security capabilities that would be difficult to implement in any other way.

Key Points

● A digital signature is an authentication mechanism that enables the creator of a message to attach a code that acts as a signature. The signature is formed by taking the hash of the message and encrypting the message with the creator's private key. The signature guarantees the source and integrity of the message.

● Mutual authentication protocols enable communicating parties to satisfy themselves mutually about each other's identity and to exchange session keys.

● In one-way authentication, the recipient wants some assurance that a message is from the alleged sender.

● The digital signature standard (DSS) is an NIST standard that uses the secure hash algorithm (SHA).

A.1 Digital Signatures Requirements

Message authentication protects two parties who exchange messages from any third party. However, it does not protect the two parties against each other. Several forms of dispute between the two are possible. For example, suppose that John sends an authenticated message to Mary Consider the following disputes that could arise:

1. Mary may forge a different message and claim that it came from John. Mary would simply have to create a message and append an authentication code using the key that John and Mary share.

2. John can deny sending the message. Because it is possible for Mary to forge a message, there is no way to prove that John did in fact send the message.

Both scenarios are of legitimate concern.

In situations where there is not complete trust between sender and receiver, something more than authentication is needed. The most attractive solution to this problem is the digital signature. The digital signature is analogous to the handwritten signature. It must have the following properties:

- It must verify the author and the date and time of the signature.
- It must to authenticate the contents at the time of the signature.
- It must be verifiable by third parties, to resolve disputes.

Thus, the digital signature function includes the authentication function. On the basis of these properties, we can formulate the following requirements for a digital signature:

- The signature must be a bit pattern that depends on the message being signed.
- The signature must use some information unique to the sender, to prevent both forgery and Denial.
- It must be relatively easy to produce the digital signature.
- It must be computationally infeasible to forge a digital signature, either by constructing a new message for an existing digital signature or by constructing a fraudulent digital signature for a given message.
- It must be practical to retain a copy of the digital signature in storage.

A secure hash function, embedded to satisfies these requirements.

A.1.1 Direct Digital Signature

The direct digital signature involves only the communicating parties (source, destination). It is assumed that the destination knows the public key of the source. A digital signature may be formed by encrypting the entire message with the sender's private key or by encrypting a hash code of the message with the sender's private key. Confidentiality can be provided by further encrypting the entire message plus signature with either the receiver's public key (public-key encryption) or a shared secret key (symmetric encryption); In case of dispute, some third party must view the message and its signature. If the signature is calculated on an encrypted message, then the third party also needs access to the decryption key to read the original message. However, if the signature is the inner operation, then the recipient can store the plaintext message and its signature for later use in dispute resolution.

All direct schemes described so far share a **common weakness**. The validity of the scheme depends on the security of the sender's private key. If a sender later wishes to deny sending a particular message, the sender can claim that the private key was lost or stolen and that someone else forged his or her signature. Administrative controls relating to the security of private keys can be employed to thwart or at least weaken this ploy, but the threat is still there, at least to some degree. One example is to require every signed message to include a timestamp (date and time) and to require prompt reporting of compromised keys to a central authority. **Another threat** is that some private key might actually be stolen from X at time T. The opponent can then send a message signed with X's signature and stamped with a time before or equal to T.

A.1.2 Arbitrated Digital Signature

The problems associated with direct digital signatures can be addressed by using an arbiter. As with direct signature schemes, there is a variety of arbitrated signature schemes. In general terms, they all operate as follows. Every signed message from a sender X to a receiver Y goes first to an arbiter A, who subjects the message and its signature to a number of tests to check its origin and content. The message is then dated and sent to Y with an indication that it has been verified to the satisfaction of the arbiter. The presence of A solves the problem faced by direct signature schemes: that X might disown the message. The arbiter plays a sensitive and crucial role in this sort of scheme, and all parties must have a great deal of trust that the arbitration mechanism is working properly.

In the first, symmetric encryption is used. It is assumed that the sender X and the arbiter A share a secret key K_{xa} and that A and Y share secret key K_{ay}. X constructs a message M and computes its hash value H(M). Then X transmits the message plus a signature to A. The signature consists of an identifier ID_X of X plus the hash value, all encrypted using K_{xa}. A decrypts the signature and checks the hash value to validate the message. Then A transmits a message to Y, encrypted with K_{ay}. The message includes ID_X, the original message from X, the signature, and a timestamp. Y can decrypt this to recover the message and the signature. The timestamp informs Y that this message is timely and not a replay. Y can store M and the signature. In case of dispute, Y, who claims to have received M from X, sends the following message to A:

$$E(K_{ay}, [ID_X||M||E(K_{xa}, [ID_X||H(M)])])$$

(1) X A: M||E(K_{xa}, [IDX||H(M)])
(2) A Y: E(K_{ay}, [IDX||M||E(K_{xa}, [IDX||H(M)])||T])
(a) Conventional Encryption, Arbiter Sees Message
(1) X A: IDX||E(K_{xy}, M)||E(K_{xa}, [IDX||H(E(K_{xy}, M))])
(2) A Y: E(K_{ay},[IDX||E(K_{xy}, M)])||E(K_{xa}, [IDX||H(E(K_{xy}, M))||T])
(b) Conventional Encryption, Arbiter Does Not See Message
(1) X A: IDX||E(PR_x, [IDX||E(PU_y, E(PR_x, M))])
(2) A Y: E(PR_a, [IDX||E(PU_y, E(PR_x, M))||T])
(c) Public-Key Encryption, Arbiter Does Not See Message
Notation:
X = sender Y = recipient A = Arbiter M = message T = timestamp

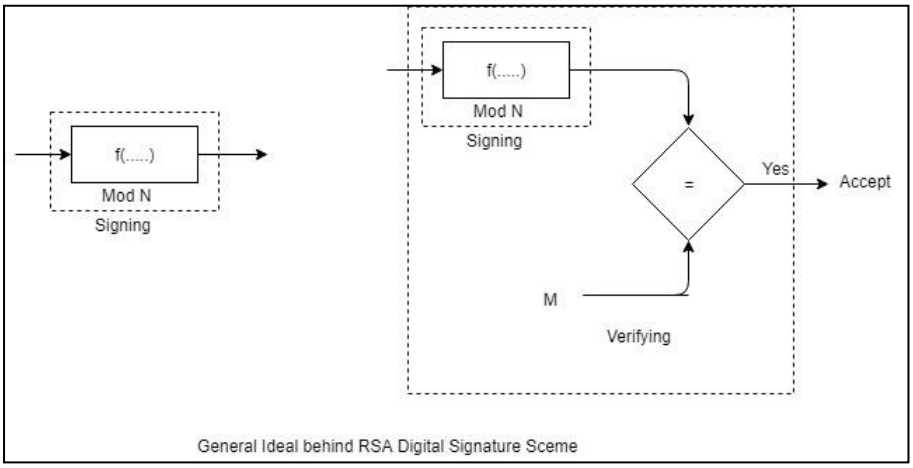
The arbiter uses K_{ay} to recover ID_X, M, and the signature, and then uses K_{xa} to decrypt the signature and verify the hash code. In this scheme, Y cannot directly check X's signature; the signature is there solely to settle disputes. Y considers the message from X authentic because it comes through A. In this scenario, both sides must have a high degree of trust in A:

- X must trust A not to reveal K_{xa} and not to generate false signatures of the form $E(K_{xa}, [ID_X||H(M)])$.
- Y must trust A to send $E(K_{ay}, [ID_X||M||E(K_{xa}, [ID_X||H(M)])||T])$ only if the hash value is correct and the signature was generated by X.
- Both sides must trust A to resolve disputes fairly. If the arbiter does live up to this trust, then X is assured that no one can forge his signature and Y is assured that X cannot disavow his signature.

A. 2 RSA Based digital signature

RSA digital signature scheme

- RSA idea is also used for signing and verifying a message it is called RSA digital signature scheme.
- Digital signature scheme changes the role of the private and public keys
- Private and public keys of only the sender are used not the receiver
- Sender uses her own private key to sign the document and the receiver uses the sender's public key to verify it.



General Ideal behind RSA Digital Signature Sceme

- The signing and verifying sets use the same function, but with different parameters. The verifier compares the message and the output of the function for congruence. If the result is two true the message is accepted.

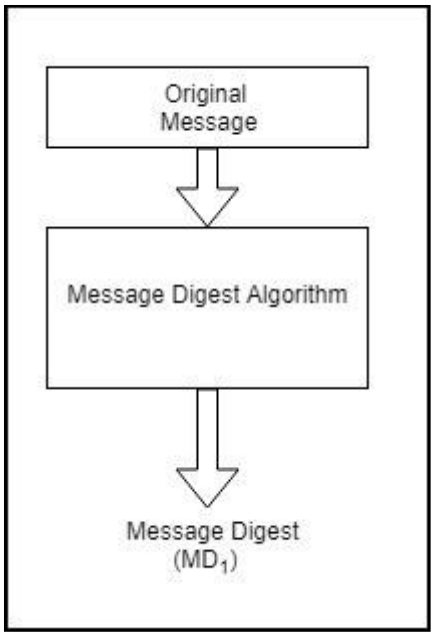
Key generation in RSA

Key generation in RSA digital signature scheme is exactly the same as key generation in RSA cryptosystem.

Working of RSA digital signature scheme:

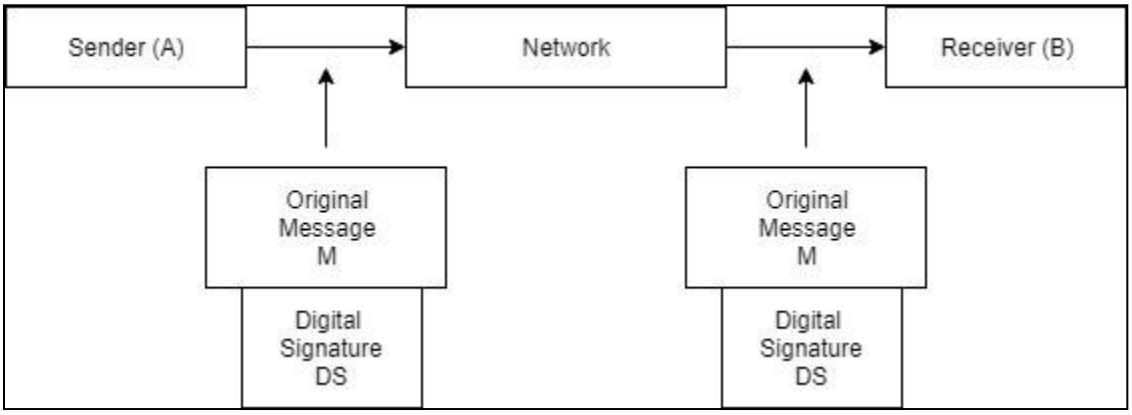
Sender A wants to send a message M to the receiver B along with the digital signature S calculated over the message M

Step1: The sender A uses the message digest algorithm to calculate the message digest MD1 over the original message M

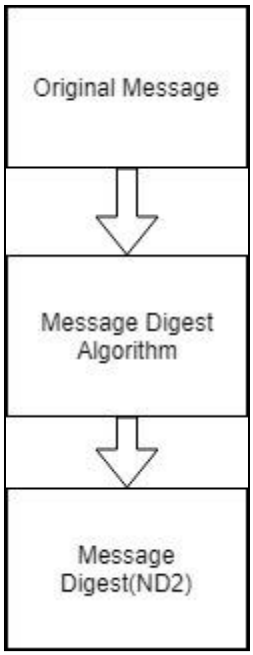


Step 2: The sender A now encrypts the message digest with her private key. The output of this process is called the digital signature.

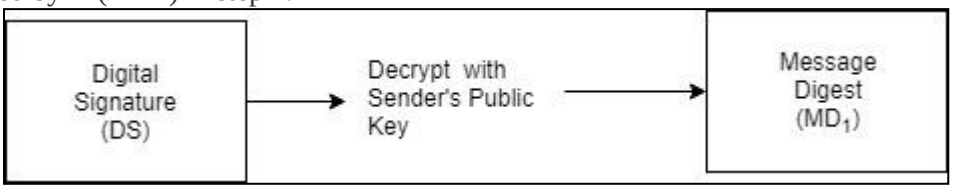
Step 3: Now the sender A sends the original message M along with digital signature DS to receiver B



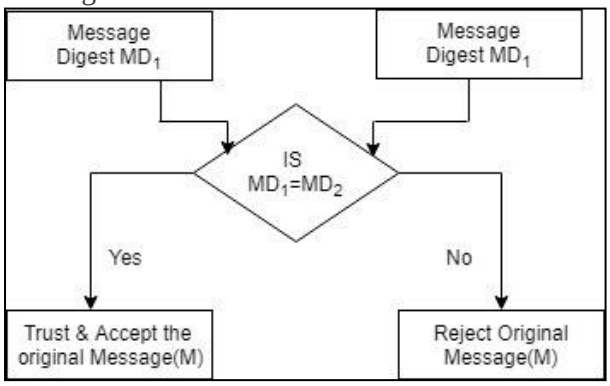
Step 4: After the receiver B receives the original message M and the sender A's digital signature, B uses the same message digest algorithm which was used by A and calculate its own message digest MD2 as shown below.



Step 5: The receiver B now uses the sender's A's public key to decrypt the digital signature. Note that A had used his private key to decrypt the message digest MD1 to form the digital signature. Therefore only A's public key can be used to decrypt it. The output of this process is the original message digest which was calculated by A (MD1) in step 1.



Step 6: B now compare the following two message digests.
MD2, which it had calculated in step 4
MD1, which is retrieved from A's digital signature in step 5
If MD1 = MD2 the following facts are established:
a. B accepts the original message (M) as the correct, unaltered message from A
b. B is also assured that the message came from A and not from someone else attached, posing as A



Thus, the principle of digital signature is quite strong, secure and reliable.

A.3 Authentication Protocols

A.3.1 Mutual Authentication

An important application area is that of mutual authentication protocols. Such protocols enable communicating parties to satisfy themselves mutually about each other's identity and to exchange session keys. Central to the problem of authenticated key exchange are two issues: confidentiality and timeliness. To prevent masquerade and to prevent compromise of session keys, essential identification and session key information must be communicated in encrypted form. This requires the prior existence of secret or public keys that can be used for this purpose. The second issue, timeliness, is important because of the threat of message replays. Such replays, at worst, could allow an opponent to compromise a session key or successfully impersonate another party. At minimum, a successful replay can disrupt operations by presenting parties with messages that appear genuine but are not.

Examples of replay attacks:

- **Simple replay:** The opponent simply copies a message and replays it later.
- **Repetition that can be logged:** An opponent can replay a timestamped message within the valid time window.
- **Repetition that cannot be detected:** This situation could arise because the original message could have been suppressed and thus did not arrive at its destination; only the replay message arrives.
- **Backward replay without modification:** This is a replay back to the message sender. This attack is possible if symmetric encryption is used and the sender cannot easily recognize the difference between messages sent and messages received on the basis of content.

To prevent from replay one of the following two general approaches is used:

- **Timestamps:** Party A accepts a message as fresh only if the message contains a timestamp that, in A's judgment, is close enough to A's knowledge of current time. This approach requires that clocks among the various participants be synchronized.
- **Challenge/response:** Party A, expecting a fresh message from B, first sends B a nonce (challenge) and requires that the subsequent message (response) received from B contain the correct nonce value.

But **problems with the timestamp approach** should not be used for connectionoriented applications because of the inherent difficulties with this technique. First, some sort of protocol is needed to maintain synchronization among the various processor clocks. This protocol must be both fault tolerant, to cope with network errors, and secure, to cope with hostile attacks. Second, the opportunity for a successful attack will arise if there is a temporary loss of synchronization resulting from a fault in the clock mechanism of one of the parties. Finally, because of the variable and unpredictable nature of network delays, distributed clocks cannot be expected to maintain precise synchronization.

On the other hand**, the challenge-response approach is unsuitable** for a connectionless type of application because it requires the overhead of a handshake before any connectionless transmission, effectively negating the chief characteristic of a connectionless transaction. For such applications, reliance on some sort of secure time server and a consistent attempt by each party to keep its clocks in synchronization may be the best approach.

a) Symmetric Encryption Approaches

A two-level hierarchy of symmetric encryption keys can be used to provide confidentiality for communication in a distributed environment. In general, this strategy involves the use of a trusted key distribution center (KDC). Each party in the network shares a secret key, known as a master key, with the KDC. The KDC is responsible for generating keys to be used for a short time over a connection between two parties, known as session keys, and for distributing those keys using the master keys to protect the distribution. This approach is quite common.

The protocol can be summarized as follows:

1. A KDC: $ID_A||ID_B||N_1$

2. KDC A: $E(K_a, [K_s||ID_B||N_1||E(K_b, [K_s||ID_A])])$

3. A B: $E(K_b, [K_s||ID_A])$

4. A A: E(K_s, N_2)
5. A B: E(K_s, f(N_2))
Secret keys Ka and Kb are shared between A and the KDC and B and the KDC, respectively. The purpose of the protocol is to distribute securely a session key Ks to A and B. A securely acquires a new session key in step 2. The message in step 3 can be decrypted, and hence understood, only by B. Step 4 reflects B's knowledge of Ks, and step 5 assures B of A's knowledge of Ks and assures B that this is a fresh message because of the use of the nonce N2. the purpose of steps 4 and 5 is to prevent a certain type of replay attack. In particular, if an opponent is able to capture the message in step 3 and replay it, this might in some fashion disrupt operations at B. Despite the handshake of steps 4 and 5, the protocol is still vulnerable to a form of replay attack. Suppose that an opponent, X, has been able to compromise an old session key. Admittedly, this is a much more unlikely occurrence than that an opponent has simply observed and recorded step 3. Nevertheless, it is a potential security risk. X can impersonate A and trick B into using the old key by simply replaying step 3. Unless B remembers indefinitely all previous session keys used with A, B will be unable to determine that this is a replay. If X can intercept the handshake message, step 4, then it can impersonate A's response, step 5. From this point on, X can send bogus messages to B that appear to B to come from A using an authenticated session key. To overcome this problem we includes the addition of a timestamp to steps 2 and 3.
Step 4 and 5 were originally were not included in the protocol but it was included by DENN and this Denning protocol seems to provide an increased degree of security. To prevent the communication from suppress-replay attacks it is to enforce that parties regularly check their clocks against the KDC's clock.

b) Public-Key Encryption Approaches

Public-key encryption for the purpose of session key distribution is used here. This protocol assumes that each of the two parties is in possession of the current public key of the other.
1. A AS: $ID_A||ID_B$
2. AS A: E(PR_{as}, [$ID_A||PU_a||T$])||E(PR_{as}, [$ID_B||PU_b||T$])
3. A B: E(PR_{as}, [$ID_A||PU_a||T$])||E(PR_{as}, [$ID_B||PU_b||T$])
$||E(PU_b$, E(PR_a, [$K_s||T$]))
In this case, the central system is referred to as an authentication server (AS), because it is not actually responsible for secret key distribution. Rather, the AS provides public-key certificates. The session key is chosen and encrypted by A; hence, there is no risk of exposure by the AS. The timestamps protect against replays of compromised keys.
This protocol is compact but, as before, requires synchronization of clocks. Another approach, proposed by Woo and Lam makes use of nonces. The protocol consists of the following steps:
1. A KDC: $ID_A||ID_B$
2. KDC A: E(PR_{auth}, [$ID_B||PU_b$])
3. A B: E(PU_b, [$N_a||ID_A$])
4. B KDC: $ID_A||ID_B||$E(PU_{auth}, N_a)
5. KDC B: E(PR_{auth}, [$ID_A||PU_a$])||E(PU_b, E(PR_{auth}, [$N_a||K_s||ID_B$]))
6. B A: E(PU_a, E(PR_{auth}, [($N_a||K_s||ID_B$)||N_b]))
7. A B: E(K_s, N_b)
In step 1, A informs the KDC of its intention to establish a secure connection with B. The KDC returns to A a copy of B's public-key certificate (step 2). Using B's public key, A informs B of its desire to communicate and sends a nonce Na (step 3). In step 4, B asks the KDC for A's public-key certificate and requests a session key; B includes A's nonce so that the KDC can stamp the session key with that nonce. The nonce is protected using the KDC's public key. In step 5, the KDC returns to B a copy of A's public-key certificate, plus the information {Na, Ks, IDB}. This information basically says that Ks is a secret key generated by the KDC on behalf of B and tied to Na; the binding of Ks and Na will assure A that Ks is fresh. This triple is encrypted, using the KDC's private key, to allow B to verify that the triple is in fact from the KDC. It is also encrypted using B's public key, so that no other entity may use the triple in an attempt to establish a fraudulent connection with A. In step 6, the triple {Na, Ks, IDB}, still encrypted with the KDC's private key, is relayed to A, together with a nonce Nb generated by B. All the foregoing

are encrypted using A's public key. A retrieves the session key Ks and uses it to encrypt Nb and return it to B. This last message assures B of A's knowledge of the session key.

A.3.2 One-Way Authentication

One application for which encryption is growing in popularity is electronic mail (e-mail). The very nature of electronic mail, and its chief benefit, is that it is not necessary for the sender and receiver to be online at the same time. Instead, the e-mail message is forwarded to the receiver's electronic mailbox, where it is buffered until the receiver is available to read it.

The "envelope" or header of the e-mail message must be in the clear, so that the message can be handled by the store-and-forward e-mail protocol, such as the Simple Mail Transfer Protocol (SMTP) or X.400. However, it is often desirable that the mail-handling protocol not require access to the plaintext form of the message, because that would require trusting the mail-handling mechanism. Accordingly, the e-mail message should be encrypted such that the mail-handling system is not in possession of the decryption key. A second requirement is that of authentication. Typically, the recipient wants some assurance that the message is from the alleged sender.

a) Symmetric Encryption Approach

Using symmetric encryption, the decentralized key distribution is impractical but With some refinement, the KDC strategy is a candidate for encrypted electronic mail. Because we wish to avoid requiring that the recipient be on line at the same time as the sender some modification is required. For a message with content M, the sequence is as follows:

1. A KDC: $ID_A||ID_B||N_1$

2. KDC A: $E(K_a, [K_s||ID_B||N_1||E(K_b, [K_s||ID_A])])$

3. A B: $E(K_b, [K_s||ID_A])||E(K_s, M)$

This approach guarantees that only the intended recipient of a message will be able to read it. It also provides a level of authentication that the sender is A. As specified, the protocol does not protect against replays. Some measure of defense could be provided by including a timestamp with the message. However, because of the potential delays in the e-mail process, such timestamps may have limited usefulness.

b) Public-Key Encryption Approaches

Public Key encryption approach is suited to electronic mail, including the straightforward encryption of the entire message for confidentiality or authentication or both. require that either the sender know the recipient's public key (confidentiality) or the recipient know the sender's public key (authentication) or both (confidentiality plus authentication). In addition, the public-key algorithm must be applied once or twice to what may be a long message.

If **confidentiality** is the primary concern, then the following may be more efficient:

A B: $E(PU_b, K_s)||E(K_s, M)$

In this case, the message is encrypted with a one-time secret key. A also encrypts this one-time key with B's public key. Only B will be able to use the corresponding private key to recover the one-time key and then use that key to decrypt the message. This scheme is more efficient than simply encrypting the entire message with B's public key.

If **authentication** is the primary concern, then a digital signature may suffice

A B:$M||E(PR_a, H(M))$

This method guarantees that A cannot later deny having sent the message. However, this technique is open to another kind of fraud. Bob composes a message to his boss Alice that contains an idea that will save the company money. He appends his digital signature and sends it into the e-mail system. Eventually, the message will get delivered to Alice's mailbox. But suppose that Max has heard of Bob's idea and gains access to the mail queue before delivery. He finds Bob's message, strips off his signature, appends his, and requeues the message to be delivered to Alice. Max gets credit for Bob's idea. To counter such a scheme, both the message and signature can be encrypted with the recipient's public key:

A B: $E(PU_b, [M||E(PR_a, H(M))])$

The latter two schemes require that B know A's public key and be convinced that it is timely. An effective way to provide this assurance is the digital certificate. Now we have-

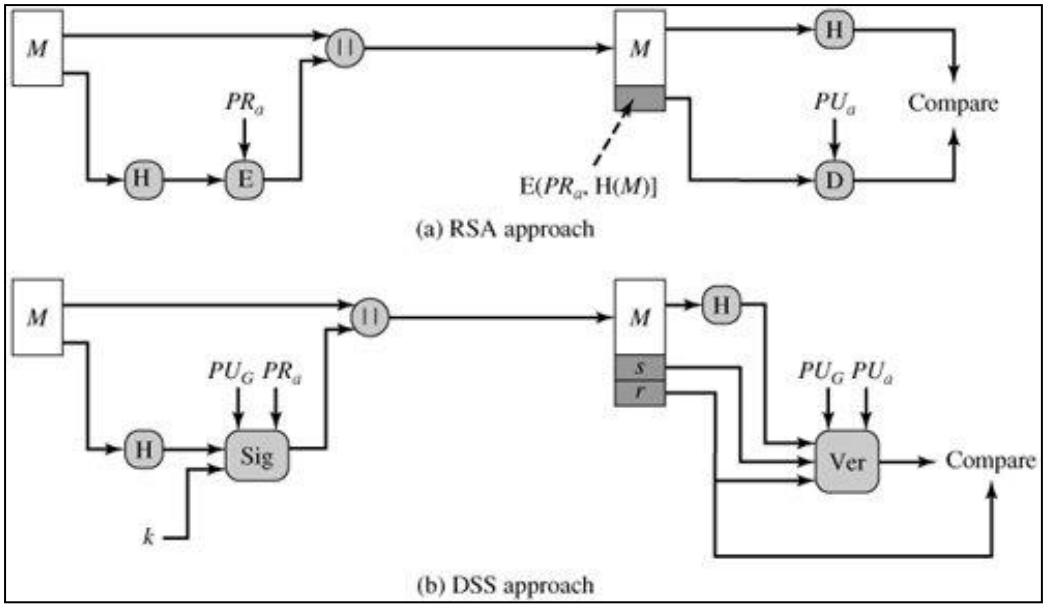
A B:M||E(PRa, H(M))||E(PRas, [T||IDA||PUa])
In addition to the message, A sends B the signature, encrypted with A's private key, and A's certificate, encrypted with the private key of the authentication server. The recipient of the message first uses the certificate to obtain the sender's public key and verify that it is authentic and then uses the public key to verify the message itself. If confidentiality is required, then the entire message can be encrypted with B's public key. Alternatively, the entire message can be encrypted with a one-time secret key; the secret key is also transmitted, encrypted with B's public key.

A.4 Digital Signature Standard

The National Institute of Standards and Technology (NIST) has published Federal Information Processing Standard FIPS 186, known as the Digital Signature Standard (DSS). The DSS makes use of the Secure Hash Algorithm (SHA).

A.4.1 The DSS Approach

The DSS uses an algorithm that is designed to provide only the digital signature function. Unlike RSA, it cannot be used for encryption or key exchange. Nevertheless, it is a public-key technique. In the RSA approach, the message to be signed is input to a hash function that produces a secure hash code of fixed length. This hash code is then encrypted using the sender's private key to form the signature. Both the message and the signature are then transmitted. The recipient takes the message and produces a hash code. The recipient also decrypts the signature using the sender's public key. If the calculated hash code matches the decrypted signature, the signature is accepted as valid. Because only the sender knows the private key, only the sender could have produced a valid signature. The DSS approach also makes use of a hash function. The hash code is provided as input to a signature function along with a random number k generated for this particular signature. The signature function also depends on the sender's private key (PRa)and a set of parameters known to a group of communicating principals. We can consider this set to constitute a global public key (PU_G). The result is a signature consisting of two components, labeled s and r.
At the receiving end, the hash code of the incoming message is generated. This plus the signature is input to a verification function. The verification function also depends on the global public key as well as the sender's public key (PUa), which is paired with the sender's private key. The output of the verification function is a value that is equal to the signature component r if the signature is valid. The signature function is such that only the sender, with knowledge of the private key, could have produced the valid signature.



Two Approaches to Digital Signatures

A.4.2 The Digital Signature Algorithm

The DSA is based on the difficulty of computing discrete logarithms.There are three parameters that are public and can be common to a group of users. A 160-bit prime number q is chosen. Next, a prime number p is selected with a length between 512 and 1024 bits such that q divides (p 1). Finally, g is chosen to be of the form h(p1)/q mod p where h is an integer between 1 and (p 1) with the restriction that g must be greater than 1.

With these numbers in hand, each user selects a private key and generates a public key. The private key x must be a number from 1 to (q 1) and should be chosen randomly or pseudorandomly. The public key is calculated from the private key as y = gx mod p.

Global Public-Key Components	
p	prime number where $2^{L-1} < p < 2^L$ for 512 L 1024 and L a multiple of 64; i.e., bit length of between 512 and 1024 bits in increments of 64 bits
q	prime divisor of $(p-1)$, where $2^{159} < q < 2^{160}$; i.e., bit length of 160 bits
g	$= h^{(p-1)/q} \bmod p$, where h is any integer with $1 < h < (p-1)$ such that $h^{(p-1)/q} \bmod p > 1$
User's Private Key	
x	random or pseudorandom integer with $0 < x < q$
User's Public Key	
y	$= g^x \bmod p$
User's Per-Message Secret Number	
k	= random or pseudorandom integer with $0 < k < q$
Signing	
r	$= (g^k \bmod p) \bmod q$
s	$= [k^{-1} (H(M) + xr)] \bmod q$
Signature = (r, s)	
Verifying	
w	$= (s')^{-1} \bmod q$
u1	$= [\mathbf{H(M'})w] \bmod q$
u2	$=(r')w \bmod q$
v	$= [(g^{u1} y^{u2}) \bmod p] \bmod q$
TEST: v = r'	
M	= message to be signed
H(M)	= hash of M using SHA-1
M',r',s'	= received versions of M, r, s

To create a signature, a user calculates two quantities, r and s, that are functions of the public key components (p, q, g), the user's private key (x), the hash code of the message, H(M), and an additional integer k that should be generated randomly or pseudorandomly and be unique for each signing.At the receiving end, verification is performed. The receiver generates a quantity v that is a function of the public key components, the sender's public key, and the hash code of the incoming message. If this quantity matches the r component of the signature, then the signature is validated.

NETWORK SECURITY PRACTICE

AUTHENTICATION APPLICATIONS

Authentication application includes following three topics:-

a) **Kerberos**
b) **X.509 Authentication Service**
c) **public key infrastructure (PKIX)**

Key Points

● Kerberos is an authentication service designed for use in a distributed environment.
● Kerberos makes use of a trusted third-part authentication service that enables clients and servers to establish authenticated communication.
● X.509 defines the format for public-key certificates. This format is widely used in a variety of applications.
● A public key infrastructure (PKI) is defined as the set of hardware, software, people, policies, and procedures needed to create, manage, store, distribute, and revoke digital certificates based on asymmetric cryptography.
● Typically, PKI implementations make use of X.509 certificates.

A) Kerberos

Kerberos is an authentication service developed as part of Project Athena at MIT. The problem that Kerberos addresses is this: Assume an open distributed environment in which users at workstations wish to access services on servers distributed throughout the network. We would like for servers to be able to restrict access to authorized users and to be able to authenticate requests for service. In this environment, a workstation cannot be trusted to identify its users correctly to network services.
In particular, the following **three threats** exist:
● A user may gain access to a particular workstation and pretend to be another user operating from that workstation.
● A user may alter the network address of a workstation so that the requests sent from the altered workstation appear to come from the impersonated workstation.
● A user may eavesdrop on exchanges and use a replay attack to gain entrance to a server or to disrupt operations.
In any of these cases, an unauthorized user may be able to gain access to services and data that he or she is not authorized to access. Rather than building in elaborate authentication protocols at each server, **Kerberos** provides a centralized authentication server whose function is to authenticate users to servers and servers to users.
Two versions of Kerberos are in common use. Version 4 implementations still exist. Version 5 corrects some of the security deficiencies of version 4 and has been issued as a proposed Internet Standard (RFC 1510).
If a set of users is provided with dedicated personal computers that have no network connections, then a user's resources and files can be protected by physically securing each personal computer. When these users instead are served by a centralized time-sharing system, the time-sharing operating system must provide the security. The operating system can enforce access control policies based on user identity and use the logon procedure to identify users.

Today, neither of these scenarios is typical. More common is a distributed architecture consisting of dedicated user workstations (clients) and distributed or centralized servers. In this environment, **three approaches** to security can be envisioned:
1. Rely on each individual client workstation to assure the identity of its user or users and rely on each server to enforce a security policy based on user identification (ID).
2. Require that client systems authenticate themselves to servers, but trust the client system concerning the identity of its user.
3. Require the user to prove his or her identity for each service invoked. Also require that servers prove their identity to clients.

The first published report on Kerberos [STEI88] listed the following **requirements**:
● **Secure:** A network eavesdropper should not be able to obtain the necessary information to impersonate a user. More generally, Kerberos should be strong enough that a potential opponent does not find it to be the weak link.
● **Reliable:** For all services that rely on Kerberos for access control, lack of availability of the Kerberos service means lack of availability of the supported services. Hence, Kerberos should be highly reliable and should employ a distributed server architecture, with one system able to back up another.
● **Transparent:** Ideally, the user should not be aware that authentication is taking place, beyond the requirement to enter a password.
● **Scalable:** The system should be capable of supporting large numbers of clients and servers. This suggests a modular, distributed architecture.

A.1 Kerberos Version 4

Version 4 of Kerberos makes use of DES, in a rather elaborate protocol, to provide the authentication service.

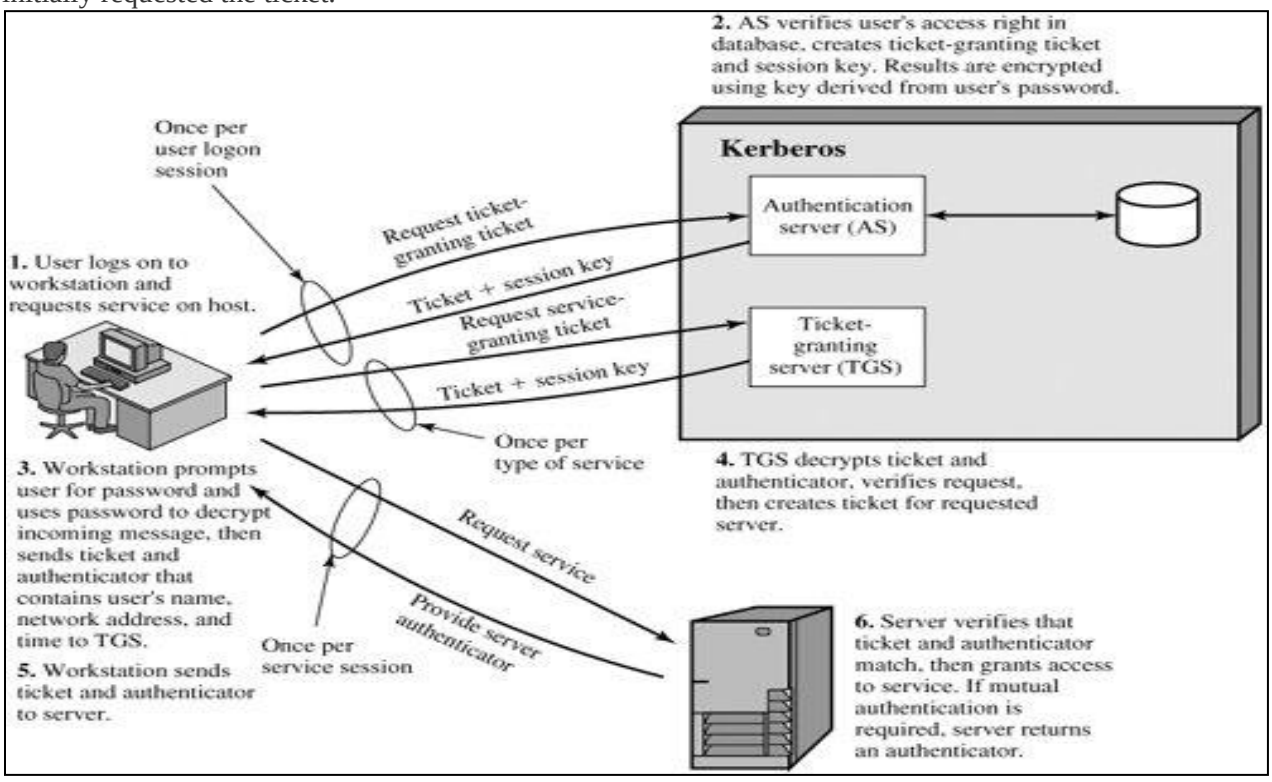
A.1.a) A Simple Authentication Dialogue

In an unprotected network environment, any client can apply to any server for service. The obvious security risk is that of impersonation.
An opponent can pretend to be another client and obtain unauthorized privileges on server machines. To counter this threat, servers must be able to confirm the identities of clients who request service. Each server can be required to undertake this task for each client/server interaction, but in an open environment, this places a substantial burden on each server. An alternative is to use an authentication server (AS) that knows the passwords of all users and stores these in a centralized database. In addition, the AS shares a unique secret key with each server. These keys have been distributed physically or in some other secure manner.
Consider the following hypothetical dialogue:
The portion to the left of the colon indicates the sender and receiver; the portion to the right indicates the contents of the message, the symbol || indicates concatenation.
(1) C AS: $ID_C||P_C||ID_V$
(2) AS C: $Ticket$
(3) C V: $ID_C||Ticket$
$Ticket = E(K_V, [ID_C||AD_C||ID_V])$
where
C = client
AS = authentication server
V =server
IDC = identifier of user on C
IDV = identifier of V
PC = password of user on C
ADC = network address of C
Kv = secret encryption key shared by AS and V
In this scenario, the user logs on to a workstation and requests access to server V. The client module C in the user's workstation requests the user's password and then sends a message to the AS that includes the user's ID, the server's ID, and the user's password. The AS checks its database to see if the user has

supplied the proper password for this user ID and whether this user is permitted access to server V. If both tests are passed, the AS accepts the user as authentic and must now convince the server that this user is authentic. To do so, the AS creates a ticket that contains the user's ID and network address and the server's ID. This ticket is encrypted using the secret key shared by the AS and this server. This ticket is then sent back to C. Because the ticket is encrypted, it cannot be altered by C or by an opponent.

With this ticket, C can now apply to V for service. C sends a message to V containing C's ID and the ticket. V decrypts the ticket and verifies that the user ID in the ticket is the same as the unencrypted user ID in the message. If these two match, the server considers the user authenticated and grants the requested service.

Each of the ingredients of message (3) is significant. The ticket is encrypted to prevent alteration or forgery. The server's ID (IDV) is included in the ticket so that the server can verify that it has decrypted the ticket properly. IDC is included in the ticket to indicate that this ticket has been issued on behalf of C. Finally, ADC serves to counter the following threat. An opponent could capture the ticket transmitted in message (2), then use the name IDC and transmit a message of form (3) from another workstation. The server would receive a valid ticket that matches the user ID and grant access to the user on that other workstation. To prevent this attack, the AS includes in the ticket the network address from which the original request came. Now the ticket is valid only if it is transmitted from the same workstation that initially requested the ticket.



Overview of Kerberos

A.1.b) A More Secure Authentication Dialogue

Although the foregoing scenario solves some of the problems of authentication in an open network environment, problems remain. Two in particular stand out. First, we would like to minimize the number of times that a user has to enter a password. Suppose each ticket can be used only once. If user C logs on to a workstation in the morning and wishes to check his or her mail at a mail server, C must supply a password to get a ticket for the mail server. If C wishes to check the mail several times during the day, each attempt requires reentering the password. We can improve matters by saying that tickets are reusable. For a single logon session, the workstation can store the mail server ticket after it is received and use it on behalf of the user for multiple accesses to the mail server.

However, under this scheme it remains the case that a user would need a new ticket for every different service. If a user wished to access a print server, a mail server, a file server, and so on, the first instance of each access would require a new ticket and hence require the user to enter the password.

The second problem is that the earlier scenario involved a plaintext transmission of the password [message (1)]. An eavesdropper could capture the password and use any service accessible to the victim.

To solve these additional problems, we introduce a scheme for avoiding plaintext passwords and a new server, known as the ticket-granting server (TGS). The new but still hypothetical scenario is as follows:

Once per user logon session:

(1) C AS: $ID_C||ID_{tgs}$

(2) AS C: $E(K_c, Ticket_{tgs})$

Once per type of service:

(3) C TGS: $ID_C||ID_V||Ticket_{tgs}$

(4) TGS C: $Ticket_V$

Once per service session:

(5) C V: $ID_C||Ticket_V$

$Ticket_{tgs} = E(K_{tgs}, [ID_C||AD_C||ID_{tgs}||TS_1||Lifetime_1])$

$Ticket_V = E(K_V, [ID_C||AD_C||ID_V||TS_2||Lifetime_2])$

The new service, TGS, issues tickets to users who have been authenticated to AS. Thus, the user first requests a ticket-granting ticket ($Ticket_{tgs}$) from the AS. The client module in the user workstation saves this ticket. Each time the user requires access to a new service, the client applies to the TGS, using the ticket to authenticate itself. The TGS then grants a ticket for the particular service. The client saves each service-granting ticket and uses it to authenticate its user to a server each time a particular service is requested.

1. The client requests a ticket-granting ticket on behalf of the user by sending its user's ID and password to the AS, together with the TGS ID, indicating a request to use the TGS service.
2. The AS responds with a ticket that is encrypted with a key that is derived from the user's password. When this response arrives at the client, the client prompts the user for his or her password, generates the key, and attempts to decrypt the incoming message. If the correct password is supplied, the ticket is successfully recovered.

Because only the correct user should know the password, only the correct user can recover the ticket. Thus, we have used the password to obtain credentials from Kerberos without having to transmit the password in plaintext. The ticket itself consists of the ID and network address of the user, and the ID of the TGS. Sometimes the opponent would be able to reuse the ticket to spoof the TGS. To counter this, the ticket includes a timestamp, indicating the date and time at which the ticket was issued, and a lifetime, indicating the length of time for which the ticket is valid. To prevent it, ticket is reencrypted with a key based on the user's password. This assures that the ticket can be recovered only by the correct user, providing the authentication.

A.3 Kerberos Version 5

Kerberos Version 5 is specified in RFC 1510 and provides a number of improvements over version 4. Version 5 is intended to address the limitations of version 4 in two areas:

- environmental shortcomings
- technical deficiencies.

Kerberos Version 4 was not developed for general purpose and led to the following

a) **environmental shortcomings:**

1. Encryption system dependence: Version 4 requires the use of DES. Export restriction on DES as well as doubts about the strength of DES were thus of concern. In version 5, ciphertext is tagged with an encryption type identifier so that any encryption technique may be used. Encryption keys are tagged with a type and a length, allowing the same key to be used in different algorithms and allowing the specification of different variations on a given algorithm.

2. Internet protocol dependence: Version 4 requires the use of Internet Protocol (IP) addresses. Other address types, such as the ISO network address, are not accommodated. Version 5 network addresses are tagged with type and length, allowing any network address type to be used.

3. Message byte ordering: In version 4, the sender of a message employs a byte ordering of its own choosing and tags the message to indicate least significant byte in lowest address or most significant byte in lowest address. This techniques works but does not follow established conventions. In version 5, all message structures are defined using Abstract Syntax Notation One (ASN.1) and Basic Encoding Rules (BER), which provide an unambiguous byte ordering.
4. Ticket lifetime: Lifetime values in version 4 are encoded in an 8-bit quantity in units of five minutes. Thus, the maximum lifetime that can be expressed is 28 x 5 = 1280 minutes, or a little over 21 hours. This may be inadequate for some applications (e.g., a long-running simulation that requires valid Kerberos credentials throughout execution). In version 5, tickets include an explicit start time and end time, allowing tickets with arbitrary lifetimes.
5. Authentication forwarding: Version 4 does not allow credentials issued to one client to be forwarded to some other host and used by some other client. This capability would enable a client to access a server and have that server access another server on behalf of the client. For example, a client issues a request to a print server that then accesses the client's file from a file server, using the client's credentials for access. Version 5 provides this capability.
6. Interrealm authentication: In version 4, interoperability among *N* realms requires on the order of *N*2 Kerberos-to-Kerberos relationships, as described earlier. Version 5 supports a method that requires fewer relationships, as described shortly.

b) **technical deficiencies-**

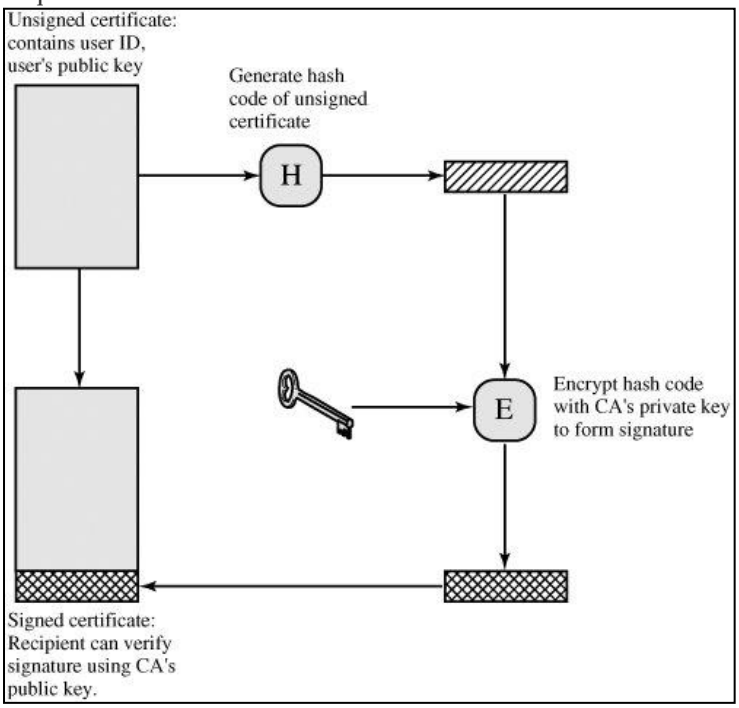
1.Double encryption: The tickets provided to clients are encrypted twice, once with the secret key of the target server and then again with a secret key known to the client. The second encryption is not necessary and is computationally wasteful.
2. PCBC encryption: Encryption in version 4 makes use of a nonstandard mode of DES known as propagating cipher block chaining (PCBC) It has been demonstrated that this mode is vulnerable to an attack involving the interchange of ciphertext blocks. PCBC was intended to provide an integrity check as part of the encryption operation. Version 5 provides explicit integrity mechanisms, allowing the standard CBC mode to be used for encryption.
3. Session keys: Each ticket includes a session key that is used by the client to encrypt the authenticator sent to the service associated with that ticket. In addition, the session key may subsequently be used by the client and the server to protect messages passed during that session. However, because the same ticket may be used repeatedly to gain service from a particular server, there is the risk that an opponent will replay messages from an old session to the client or the server. In version 5, it is possible for a client and server to negotiate a subsession key, which is to be used only for that one connection. A new access by the client would result in the use of a new subsession key.
4. Password attacks: Both versions are vulnerable to a password attack. The message from the AS to the client includes material encrypted with a key based on the client's password An opponent can capture this message and attempt to decrypt it by trying various passwords. If the result of a test decryption is of the proper form, then the opponent has discovered the client's password and may subsequently use it to gain authentication credentials from Kerberos. Version 5 does provide a mechanism known as preauthentication, which should make password attacks more difficult, but it does not prevent them.

A.3 Kerberos Realms and Multiple Kerberi

A full-service Kerberos environment consisting of a Kerberos server, a number of clients, and a number of application servers requires the following:
1. The Kerberos server must have the user ID and hashed passwords of all participating users in its database. All users are registered with the Kerberos server.
2. The Kerberos server must share a secret key with each server. All servers are registered with the Kerberos server.
Such an environment is referred to as a **Kerberos realm**.

B) X.509 Authentication Service

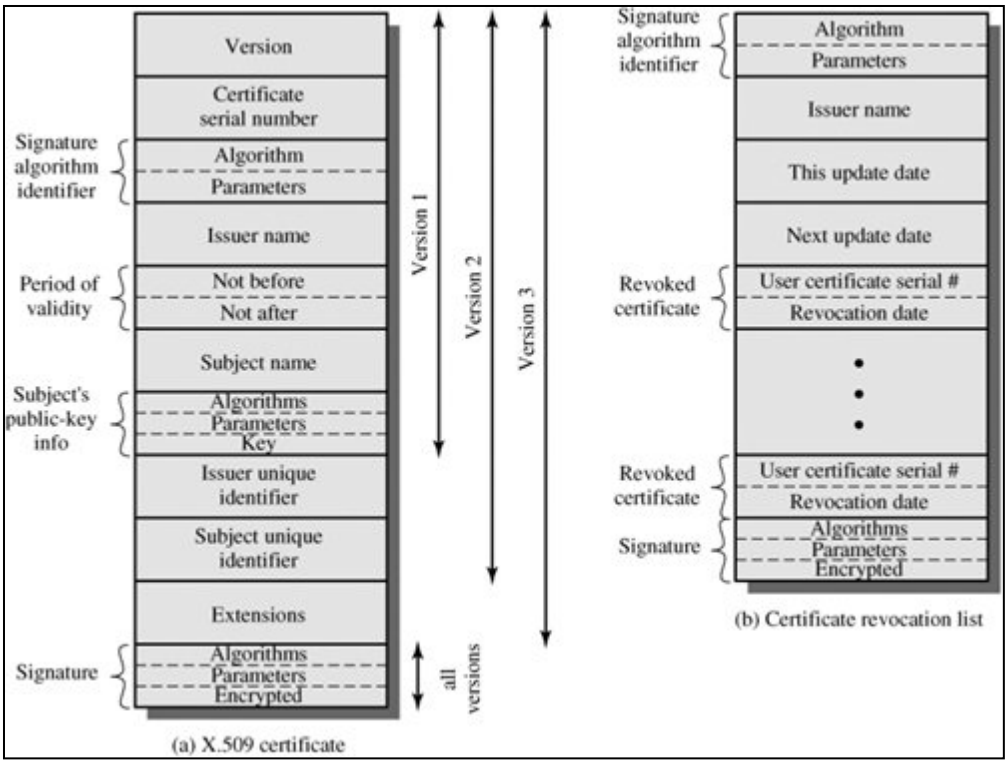
X.509 defines a framework for the provision of authentication services by the X.500 directory to its users. The directory may serve as a repository of public-key certificates. Each certificate contains the public key of a user and is signed with the private key of a trusted certification authority. In addition, X.509 defines alternative authentication protocols based on the use of public-key certificates. X.509 is an important standard because the certificate structure and authentication protocols defined in X.509 are used in a variety of contexts. X.509 is based on the use of public-key cryptography and digital signatures. The standard does not dictate the use of a specific algorithm but recommends RSA. The digital signature scheme is assumed to require the use of a hash function.



Public-Key Certificate Use

B.1 Certificates

The heart of the X.509 scheme is the public-key certificate associated with each user. These user certificates are assumed to be created by some trusted certification authority (CA) and placed in the directory by the CA or by the user. The directory server itself is not responsible for the creation of public keys or for the certification function; it merely provides an easily accessible location for users to obtain certificates.



X.509 Formats

The format of format of a certificate includes the following elements:

● **Version:** Differentiates among successive versions of the certificate format; the default is version 1. If the Issuer Unique Identifier or Subject Unique Identifier are present, the value must be version 2. If one or more extensions are present, the version must be version 3.

● **Serial number:** An integer value, unique within the issuing CA, that is unambiguously associated with this certificate.

● **Signature algorithm identifier:** The algorithm used to sign the certificate, together with any associated parameters. Because this information is repeated in the Signature field at the end of the certificate, this field has little, if any, utility.

● **Issuer name:** X.500 name of the CA that created and signed this certificate.

Period of validity: Consists of two dates: the first and last on which the certificate is valid.

● **Subject name:** The name of the user to whom this certificate refers. That is, this certificate certifies the public key of the subject who holds the corresponding private key.

● **Subject's public-key information:** The public key of the subject, plus an identifier of the algorithm for which this key is to be used, together with any associated parameters.

● **Issuer unique identifier:** An optional bit string field used to identify uniquely the issuing CA in the event the X.500 name has been reused for different entities.

● **Subject unique identifier:** An optional bit string field used to identify uniquely the subject in the event the X.500 name has been reused for different entities.

● **Extensions:** A set of one or more extension fields. Extensions were added in version 3.

● **Signature:** Covers all of the other fields of the certificate; it contains the hash code of the other fields, encrypted with the CA's private key. This field includes the signature algorithm identifier. The unique identifier fields were added in version 2 to handle the possible reuse of subject and/or issuer names over time. These fields are rarely used.

B.2 Obtaining a User's Certificate

User certificates generated by a CA have the following characteristics:

● Any user with access to the public key of the CA can verify the user public key that was certified.

● No party other than the certification authority can modify the certificate without this being detected.
Because certificates are unforgeable, they can be placed in a directory without the need for the directory to make special efforts to protect them.

B.3 Revocation of Certificates

Typically, a new certificate is issued just before the expiration of the old one. In addition, it may be desirable on occasion to revoke a certificate before it expires, for one of the following reasons:

1. The user's private key is assumed to be compromised.
2. The user is no longer certified by this CA.
3. The CA's certificate is assumed to be compromised.

B.4 Authentication Procedures

X.509 also includes three alternative authentication procedures that are intended for use across a variety of applications. All these procedures make use of public-key signatures. It is assumed that the two parties know each other's public key, either by obtaining each other's certificates from the directory or because the certificate is included in the initial message from each side.

B.4.1 One-Way Authentication

One way authentication involves a single transfer of information from one user (A) to another (B), and establishes the following:

1. The identity of A and that the message was generated by A
2. That the message was intended for B
3.The integrity and originality (it has not been sent multiple times) of the message

B.4.2 Two-Way Authentication

In addition to the three elements just listed, two-way authentication establishes the following elements:

4. The identity of B and that the reply message was generated by B
5. That the message was intended for A
6. The integrity and originality of the reply

Two-way authentication thus permits both parties in a communication to verify the identity of the other.

B.4.3 Three-Way Authentication

In three-way authentication, a final message from A to B is included, which contains a signed copy of the nonce rB. The intent of this design is that timestamps need not be checked: Because both nonces are echoed back by the other side, each side can check the returned nonce to detect replay attacks. This approach is needed when synchronized clocks are not available.

C. Public-Key Infrastructure(PKIX)

RFC 2822 (*Internet Security Glossary*) defines public-key infrastructure (PKI) as the set of hardware, software, people, policies, and procedures needed to create, manage, store, distribute, and revoke digital certificates based on asymmetric cryptography. The principal objective for developing a PKI is to enable secure, convenient, and efficient acquisition of public keys.

C.1 The elements of PKIX are:-

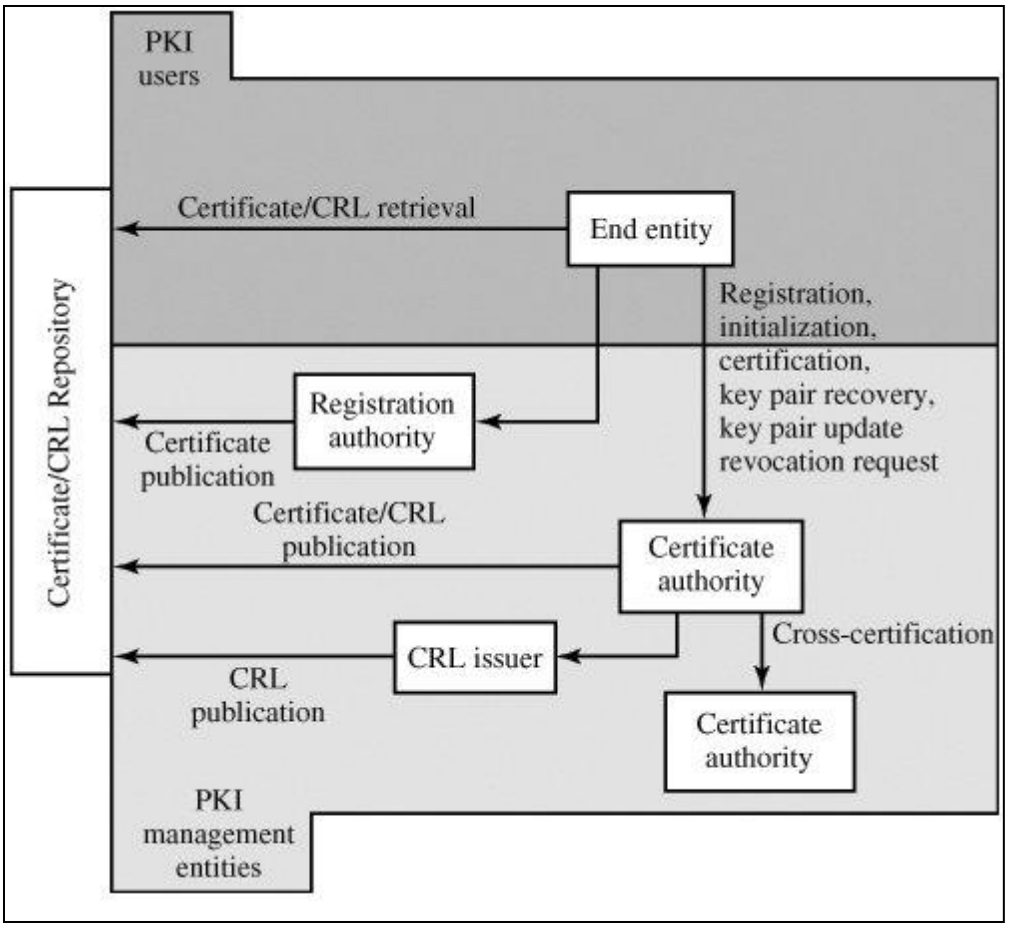
● **End entity:** A generic term used to denote end users, devices (e.g., servers, routers), or any other entity that can be identified in the subject field of a public key certificate. End entities typically consume and/or support PKI-related services.

● **Certification authority (CA):** The issuer of certificates and (usually) certificate revocation lists (CRLs). It may also support a variety of administrative functions, although these are often delegated to one or more Registration Authorities.

● **Registration authority (RA):** An optional component that can assume a number of administrative functions from the CA. The RA is often associated with the End Entity registration process, but can assist in a number of other areas as well.

● **CRL issuer:** An optional component that a CA can delegate to publish CRLs.

● **Repository:** A generic term used to denote any method for storing certificates and CRLs so that they can be retrieved by End Entities.



PKIX Architecture Model

C.2 PKIX Management Functions-

PKIX identifies a number of management functions that potentially need to be supported by management protocols.

● **Registration:** This is the process whereby a user first makes itself known to a CA (directly, or through an RA), prior to that CA issuing a certificate or certificates for that user. Registration begins the process of enrolling in a PKI. Registration usually involves some offline or online procedure for mutual authentication. Typically, the end entity is issued one or more shared secret keys used for subsequent authentication.

● **Initialization:** Before a client system can operate securely, it is necessary to install key materials that have the appropriate relationship with keys stored elsewhere in the infrastructure. For example, the client needs to be securely initialized with the public key and other assured information of the trusted CA(s), to be used in validating certificate paths.

● **Certification:** This is the process in which a CA issues a certificate for a user's public key, and returns that certificate to the user's client system and/or posts that certificate in a repository.

● **Key pair recovery:** Key pairs can be used to support digital signature creation and verification, encryption and decryption, or both. When a key pair is used for encryption/decryption, it is important to provide a mechanism to recover the necessary decryption keys when normal access to the keying material is no longer possible, otherwise it will not be possible to recover the encrypted data. Loss of access to the decryption key can result from forgotten passwords/PINs, corrupted disk drives, damage to hardware tokens, and so on. Key pair recovery allows end entities to restore their encryption/decryption key pair from an authorized key backup facility (typically, the CA that issued the End Entity's certificate).

● **Key pair update:** All key pairs need to be updated regularly (i.e., replaced with a new key pair) and new certificates issued. Update is required when the certificate lifetime expires and as a result of certificate revocation.
● **Revocation request:** An authorized person advises a CA of an abnormal situation requiring certificate revocation. Reasons for revocation include private key compromise, change in affiliation, and name change.
● **Cross certification:** Two CAs exchange information used in establishing a cross-certificate. A cross-certificate is a certificate issued by one CA to another CA that contains a CA signature key used for issuing certificates.

C.3 PKIX Management Protocols

The PKIX working group has defines two alternative management protocols between PKIX entities that support the management functions listed in the preceding subsection. RFC 2510 defines the certificate management protocols (CMP). Within CMP, each of the management functions is explicitly identified by specific protocol exchanges. CMP is designed to be a flexible protocol able to accommodate a variety of technical, operational, and business models.

RFC 2797 defines certificate management messages over CMS (CMC), where CMS refers to RFC 2630, cryptographic message syntax. CMC is built on earlier work and is intended to leverage existing implementations. Although all of the PKIX functions are supported, the functions do not all map into specific protocol exchanges.

E MAIL SECURITY

In virtually all distributed environments, electronic mail is the most heavily used network-based application. It is also the only distributed application that is widely used across all architectures and vendor platforms. Users expect to be able to, and do, send mail to others who are connected directly or indirectly to the Internet, regardless of host operating system or communications suite.
With the explosively growing reliance on electronic mail for every conceivable purpose, there grows a demand for authentication and confidentiality services. Two schemes stand out as approaches that enjoy widespread use:

- Pretty Good Privacy (PGP)
- S/MIME.

Key Points

● PGP is an open-source freely available software package for e-mail security. It provides authentication through the use of digital signature; confidentiality through the use of symmetric block encryption; compression using the ZIP algorithm; e-mail compatibility using the radix-64 encoding scheme; and segmentation and reassembly to accommodate long e-mails.
● PGP incorporates tools for developing a public-key trust model and public-key certificate management.
● S/MIME is an Internet standard approach to e-mail security that incorporates the same functionality as PGP.

A. Pretty Good Privacy

PGP is a remarkable phenomenon. Largely the effort of a single person, Phil Zimmermann, PGP provides a confidentiality and authentication service that can be used for electronic mail and file storage applications. In essence, Zimmermann has done the following:
1. Selected the best available cryptographic algorithms as building blocks
2. Integrated these algorithms into a general-purpose application that is independent of operating system and processor and that is based on a small set of easy-to-use commands
3. Made the package and its documentation, including the source code, freely available via the Internet, bulletin boards, and commercial networks such as AOL (America On Line)
4. Entered into an agreement with a company (Viacrypt, now Network Associates) to provide a fully compatible, low-cost commercial version of PGP**.**

PGP has grown explosively and is now widely used. A number of reasons can be cited for this growth:
1. It is available free worldwide in versions that run on a variety of platforms, including Windows, UNIX, Macintosh, and many more. In addition, the commercial version satisfies users who want a product that comes with vendor support.
2. It is based on algorithms that have survived extensive public review and are considered extremely secure. Specifically, the package includes RSA, DSS, and Diffie-Hellman for public-key encryption; CAST-128, IDEA, and 3DES for symmetric encryption; and SHA-1 for hash coding.
3. It has a wide range of applicability, from corporations that wish to select and enforce a standardized scheme for encrypting files and messages to individuals who wish to communicate securely with others worldwide over the Internet and other networks.
4. It was not developed by, nor is it controlled by, any governmental or standards organization. For those with an instinctive distrust of "the establishment," this makes PGP attractive.
5. PGP is now on an Internet standards track (RFC 3156). Nevertheless, PGP still has an aura of an antiestablishment endeavor.

A.1 PGP Notation

The following symbols are used:
Ks =session key used in symmetric encryption scheme
PRa =private key of user A, used in public-key encryption scheme
PUa =public key of user A, used in public-key encryption scheme

EP = public-key encryption
DP = public-key decryption
EC = symmetric encryption
DC = symmetric decryption
H = hash function
|| = concatenation
Z = compression using ZIP algorithm
R64 = conversion to radix 64 ASCII format

A.2 Operational Description

The actual operation of PGP consists of five services:-

- authentication,
- confidentiality,
- compression,
- e-mail compatibility,
- segmentation

Function	Algorithms Used	Description
Digital signature	DSS/SHA or RSA/SHA	A hash code of a message is created using SHA-1. This message digest is encrypted using DSS or RSA with the sender's private key and included with the message.
Message encryption	CAST or IDEA or Three-key Triple DES with Diffie-Hellman or RSA	A message is encrypted using CAST-128 or IDEA or 3DES with a one-time session key generated by the sender. The session key is encrypted using Diffie- Hellman or RSA with the recipient's public key and included with the message.
Compression	ZIP	A message may be compressed, for storage or transmission, using ZIP.
Email compatibility	Radix 64 conversion	To provide transparency for email applications, an encrypted message may be converted to an ASCII string using radix 64 conversion.
Segmentation		To accommodate maximum message size limitations, PGP performs segmentation and reassembly.

A.2.1 Authentication

The sequence of authentication is as follows:
1. The sender creates a message.
2. SHA-1 is used to generate a 160-bit hash code of the message.
3. The hash code is encrypted with RSA using the sender's private key, and the result is prepended to the message.
4. The receiver uses RSA with the sender's public key to decrypt and recover the hash code.
5. The receiver generates a new hash code for the message and compares it with the decrypted hash code. If the two match, the message is accepted as authentic.

A.2.2 Confidentiality

Another basic service provided by PGP is confidentiality, which is provided by encrypting messages to be transmitted or to be stored locally as files. In both cases, the symmetric encryption algorithm CAST-128

may be used. Alternatively, IDEA or 3DES may be used. The 64-bit cipher feedback (CFB) mode is used. As always, one must address the problem of key distribution. In PGP, each symmetric key is used only once. That is, a new key is generated as a random 128-bit number for each message. Thus, although this is referred to in the documentation as a session key, it is in reality a one-time key. Because it is to be used only once, the session key is bound to the message and transmitted with it. To protect the key, it is encrypted with the receiver's public key.

The sequence can be described as follows:

1. The sender generates a message and a random 128-bit number to be used as a session key for this message only.

2. The message is encrypted, using CAST-128 (or IDEA or 3DES) with the session key.

3. The session key is encrypted with RSA, using the recipient's public key, and is prepended to the message.

4. The receiver uses RSA with its private key to decrypt and recover the session key.

5. The session key is used to decrypt the message.

A.2.3 Compression

As a default, PGP compresses the message after applying the signature but before encryption. This has the benefit of saving space both for e-mail transmission and for file storage.

1.

The signature is generated before compression for two reasons:

a.

It is preferable to sign an uncompressed message so that one can store only the uncompressed message together with the signature for future verification. If one signed a compressed document, then it would be necessary either to store a compressed version of the message for later verification or to recompress the message when verification is required.

b. Even if one were willing to generate dynamically a recompressed message for verification, PGP's compression algorithm presents a difficulty. The algorithm is not deterministic; various implementations of the algorithm achieve different tradeoffs in running speed versus compression ratio and, as a result, produce different compressed forms. However, these different compression algorithms are interoperable because any version of the algorithm can correctly decompress the output of any other version. Applying the hash function and signature after compression would constrain all PGP implementations to the same version of the compression algorithm.

2. Message encryption is applied after compression to strengthen cryptographic security. Because the compressed message has less redundancy than the original plaintext, cryptanalysis is more difficult.

A.2.4 E-mail Compatibility

When PGP is used, at least part of the block to be transmitted is encrypted. If only the signature service is used, then the message digest is encrypted (with the sender's private key). If the confidentiality service is used, the message plus signature (if present) are encrypted (with a one-time symmetric key). Thus, part or all of the resulting block consists of a stream of arbitrary 8-bit octets. However, many electronic mail systems only permit the use of blocks consisting of ASCII text. To accommodate this restriction, PGP provides the service of converting the raw 8-bit binary stream to a stream of printable ASCII characters. The scheme used for this purpose is radix-64 conversion. Each group of three octets of binary data is mapped into four ASCII characters.

A.2.5 Segmentation and Reassembly

E-mail facilities often are restricted to a maximum message length. For example, many of the facilities accessible through the Internet impose a maximum length of 50,000 octets. Any message longer than that must be broken up into smaller segments, each of which is mailed separately. To accommodate this restriction, PGP automatically subdivides a message that is too large into segments that are small enough to send via e-mail. The segmentation is done after all of the other processing, including the radix-64 conversion. Thus, the session key component and signature component appear only once, at the beginning of the first segment. At the receiving end, PGP must strip off all e-mail headers and reassemble the entire original block

PGP makes use of four types of keys: one-time session symmetric keys, public keys, private keys, and passphrase-based symmetric keys.

The sending PGP entity performs the following steps:

1. Signing the message

a. PGP retrieves the sender's private key from the private-key ring using your_userid as an index. If your_userid was not provided in the command, the first private key on the ring is retrieved.

b. PGP prompts the user for the passphrase to recover the unencrypted private key.

c. The signature component of the message is constructed.

2. Encrypting the message

a.PGP generates a session key and encrypts the message.

b. PGP retrieves the recipient's public key from the public-key ring using her_userid as an index.

c. The session key component of the message is constructed.

The receiving PGP entity performs the following steps-

1. Decrypting the message

a. PGP retrieves the receiver's private key from the private-key ring, using the Key ID field in the session key component of the message as an index.

b. PGP prompts the user for the passphrase to recover the unencrypted private key.

c. PGP then recovers the session key and decrypts the message.

2. Authenticating the message

a. PGP retrieves the sender's public key from the public-key ring, using the Key ID field in the signature key component of the message as an index.

b. PGP recovers the transmitted message digest.

c. PGP computes the message digest for the received message and compares it to the transmitted message digest to authenticate.

B. S/MIME

S/MIME (Secure/Multipurpose Internet Mail Extension) is a security enhancement to the MIME Internet email format standard, based on technology from RSA Data Security. Although both PGP and S/MIME are on an IETF standards track, it appears likely that S/MIME will emerge as the industry standard for commercial and organizational use, while PGP will remain the choice for personal e-mail security for many users. S/MIME is defined in a number of documents, most importantly RFCs 3369, 3370, 3850 and 3851.

B.1 Multipurpose Internet Mail Extensions

MIME is an extension to the RFC 822 framework that is intended to address some of the problems and limitations of the use of SMTP (Simple Mail Transfer Protocol) or some other mail transfer protocol and RFC 822 for electronic mail. The following limitations of the SMTP/RFC-822 scheme:

1. SMTP cannot transmit executable files or other binary objects. A number of schemes are in use for converting binary files into a text form that can be used by SMTP mail systems, including the popular UNIX UUencode/UUdecode scheme. However, none of these is a standard or even a de facto standard.

2.SMTP cannot transmit text data that includes national language characters because these are represented by 8-bit codes with values of 128 decimal or higher, and SMTP is limited to 7-bit ASCII.

3. SMTP servers may reject mail message over a certain size.

4. SMTP gateways that translate between ASCII and the character code EBCDIC do not use a consistent set of mappings, resulting in translation problems.

5. SMTP gateways to X.400 electronic mail networks cannot handle nontextual data included in X.400 messages.

B.2 Overview

The MIME specification includes the following elements:

1. Five new message header fields are defined, which may be included in an RFC 822 header. These fields provide information about the body of the message.

2. A number of content formats are defined, thus standardizing representations that support multimedia electronic mail.
3. Transfer encodings are defined that enable the conversion of any content format into a form that is protected from alteration by the mail system.

The five header fields defined in MIME are as follows:
- **MIME-Version:** Must have the parameter value 1.0. This field indicates that the message conforms to RFCs 2045 and 2046.
- **Content-Type:** Describes the data contained in the body with sufficient detail that the receiving user agent can pick an appropriate agent or mechanism to represent the data to the user or otherwise deal with the data in an appropriate manner.
- **Content-Transfer-Encoding:** Indicates the type of transformation that has been used to represent the body of the message in a way that is acceptable for mail transport.
- **Content-ID:** Used to identify MIME entities uniquely in multiple contexts.
- **Content-Description:** A text description of the object with the body; this is useful when the object is not readable (e.g., audio data).

B.3 MIME Content Types

The bulk of the MIME specification is concerned with the definition of a variety of content types. This reflects the need to provide standardized ways of dealing with a wide variety of information representations in a multimedia environment.

Type	Subtype	Description
Text	Plain	Unformatted text; may be ASCII or ISO 8859
	Enriched	Provides greater format flexibility.
Multipart	Mixed	The different parts are independent but are to be transmitted together. They should be presented to the receiver in the order that they appear in the mail message.
	Parallel	Differs from Mixed only in that no order is defined for delivering the parts to the receiver.
	Alternative	The different parts are alternative versions of the same information. They are ordered in increasing faithfulness to the original, and the recipient's mail system should display the "best" version to the user.
	Digest	Similar to Mixed, but the default type/subtype of each part is message/ rfc822.
Message	Rfc822	The body is itself an encapsulated message that conforms to RFC 822.
	Partial	Used to allow fragmentation of large mail items, in a way that is transparent to the recipient.
	Extended Body	Contains a pointer to an object that exists elsewhere.
Image	jpeg	The image is in JPEG format, JFIF encoding.
	gif	The image is in GIF format.
Video	Mpeg	MPEG format.
Audio	Basic	Single-channel 8-bit ISDN mu-law encoding at a sample rate of 8 kHz.
Application	Postscript	Adobe Postscript
	Octet-stream	General binary data consisting of 8-bit bytes.

B.4 MIME Transfer Encodings

The other major component of the MIME specification, in addition to content type specification, is a definition of transfer encodings for message bodies. The objective is to provide reliable delivery across the largest range of environments. The MIME standard defines two methods of encoding data. The Content-Transfer-Encoding field can actually take on six values, as listed in table mentioned below

However, three of these values (7bit, 8bit, and binary) indicate that no encoding has been done but provide some information about the nature of the data. For SMTP transfer, it is safe to use the 7bit form. The 8bit and binary forms may be usable in other mail transport contexts. Another Content-Transfer-Encoding value is x-token, which indicates that some other encoding scheme is used, for which a name is to be supplied. This could be a vendor-specific or application-specific scheme. The two actual encoding schemes defined are quoted-printable and base64. Two schemes are defined to provide a choice between a transfer technique that is essentially human readable and one that is safe for all types of data in a way that is reasonably compact.

7 bit	The data are all represented by short lines of ASCII characters.
8 bit	The lines are short, but there may be non-ASCII characters (octets with the highorder bit set).
Binary	Not only may non-ASCII characters be present but the lines are not necessarily short enough for SMTP transport.
quoted-printable	Encodes the data in such a way that if the data being encoded are mostly ASCII text, the encoded form of the data remains largely recognizable by humans.
base64	Encodes data by mapping 6-bit blocks of input to 8-bit blocks of output, all of which are printable ASCII characters.
x-token	A named nonstandard encoding.

The **quoted-printable** transfer encoding is useful when the data consists largely of octets that correspond to printable ASCII characters. In essence, it represents nonsafe characters by the hexadecimal representation of their code and introduces reversible (soft) line breaks to limit message lines to 76 characters.
The **base64 transfer encoding**, also known as radix-64 encoding, is a common one for encoding arbitrary binary data in such a way as to be invulnerable to the processing by mail transport programs.

B.5 Canonical Form

An important concept in MIME and S/MIME is that of canonical form. Canonical form is a format, appropriate to the content type, that is standardized for use between systems. This is in contrast to native form, which is a format that may be peculiar to a particular system.

Native Form	The body to be transmitted is created in the system's native format. The native character set is used and, where appropriate, local end-of-line conventions are used as well. The body may be a UNIX-style text file, or a Sun raster image, or a VMS indexed file, or audio data in a system-dependent format stored only in memory, or anything else that corresponds to the local model for the representation of some form of information. Fundamentally, the data is created in the "native" form that corresponds to the type specified by the media type.
Canonical Form	The entire body, including "out-of-band" information such as record lengths and possibly file attribute information, is converted to a universal canonical form. The specific media type of the body as well as its associated attributes dictate the nature of the canonical form that is used. Conversion to the proper canonical form may involve character set conversion, transformation of audio data, compression, or various other operations specific to the various media types. If character set conversion is involved, however, care must be taken to understand the semanties of the media type, which may have strong implications for any character set conversion (e.g. with regard to syntactically meaningful characters in a text subtype other than "plain").

B.6 S/MIME Functionality

In terms of general functionality, S/MIME is very similar to PGP. Both offer the ability to sign and/or encrypt messages. In this subsection, we briefly summarize S/MIME capability. We then look in more detail at this capability by examining message formats and message preparation.

Functions

S/MIME provides the following functions:

- **Enveloped data:** This consists of encrypted content of any type and encrypted-content encryption keys for one or more recipients.
- **Signed data:** A digital signature is formed by taking the message digest of the content to be signed and then encrypting that with the private key of the signer. The content plus signature are then encoded using base64 encoding. A signed data message can only be viewed by a recipient with S/MIME capability.
- **Clear-signed data:** As with signed data, a digital signature of the content is formed. However, in this case, only the digital signature is encoded using base64. As a result, recipients without S/ MIME capability can view the message content, although they cannot verify the signature.
- **Signed and enveloped data:** Signed-only and encrypted-only entities may be nested, so that encrypted data may be signed and signed data or clear-signed data may be encrypted.

B.7 Cryptographic Algorithms used in MIME

Table shown below summarizes the cryptographic algorithms used in S/MIME. S/MIME uses the following terminology, taken from RFC 2119 to specify the requirement level:

- **Must:** The definition is an absolute requirement of the specification. An implementation must include this feature or function to be in conformance with the specification.
- **Should:** There may exist valid reasons in particular circumstances to ignore this feature or function, but it is recommended that an implementation include the feature or function.

Create a message digest to be used in forming a digital signature. Encrypt message digest to form digital signature.	MUST support SHA-1. Receiver SHOULD support MD5 for backward compatibility. Sending and receiving agents MUST support DSS. Sending agents SHOULD support RSA encryption. Receiving agents SHOULD support verification of RSA signatures with key sizes 512 bits to 1024 bits.
Encrypt session key for transmission with message. Encrypt message for transmission with one-time session key.	Sending and receiving agents SHOULD support Diffie-Hellman. Sending and receiving agents MUST support RSA encryption with key sizes 512 bits to 1024 bits. Sending and receiving agents MUST support encryption with triple DES Sending agents SHOULD support encryption with AES. Sending agents SHOULD support encryption with RC2/40.
Create a message authentication code	Receiving agents MUST support HMAC with SHA-1. Receiving agents SHOULD support HMAC with SHA-1.

S/MIME incorporates three public-key algorithms. The Digital Signature Standard (DSS is the preferred algorithm for digital signature. S/MIME lists Diffie-Hellman as the preferred algorithm for encrypting session keys; in fact, S/MIME uses a variant of Diffie-Hellman that does provide encryption/decryption, known as ElGamal. As an alternative, RSA can be used for both signatures and session key encryption. These are the same algorithms used in PGP and provide a high level of security. For the hash function used to create the digital signature, the specification requires the 160-bit SHA-1 but recommends receiver support for the 128-bit MD5 for backward compatibility with older versions of S/MIME. There is justifiable concern about the security of MD5, so SHA-1 is clearly the preferred alternative.
For message encryption, three-key triple DES (tripleDES) is recommended, but compliant implementations must support 40-bit RC2. The latter is a weak encryption algorithm but allows compliance with U.S. export controls.
The **following rules,** in the following order, should be followed by a sending agent:
1. If the sending agent has a list of preferred decrypting capabilities from an intended recipient, it SHOULD choose the first (highest preference) capability on the list that it is capable of using.
2. If the sending agent has no such list of capabilities from an intended recipient but has received one or more messages from the recipient, then the outgoing message SHOULD use the same encryption algorithm as was used on the last signed and encrypted message received from that intended recipient.
3. If the sending agent has no knowledge about the decryption capabilities of the intended recipient and is willing to risk that the recipient may not be able to decrypt the message, then the sending agent SHOULD use tripleDES.
4. If the sending agent has no knowledge about the decryption capabilities of the intended recipient and is not willing to risk that the recipient may not be able to decrypt the message, then the sending agent MUST use RC2/40. If a message is to be sent to multiple recipients and a common encryption algorithm cannot be selected for all, then the sending agent will need to send two messages. However, in that case, it is important to note that the security of the message is made vulnerable by the transmission of one copy with lower security.

B.8 Securing a MIME Entity

S/MIME secures a MIME entity with a signature, encryption, or both. A MIME entity may be an entire message (except for the RFC 822 headers), or if the MIME content type is multipart, then a MIME entity is one or more of the subparts of the message. The MIME entity is prepared according to the normal rules for MIME message preparation. Then the MIME entity plus some security-related data, such as algorithm identifiers and certificates, are processed by S/MIME to produce what is known as a PKCS object. A PKCS object is then treated as message content and wrapped in MIME (provided with appropriate MIME headers).

B.8.1 Enveloped Data

An application/pkcs7-mime subtype is used for one of four categories of S/MIME processing, each with a unique smime-type parameter. In all cases, the resulting entity, referred to as an *object*, is represented in a form known as Basic Encoding Rules (BER), which is defined in ITU-T Recommendation X.209. The BER format consists of arbitrary octet strings and is therefore binary data. Such an object should be transfer encoded with base64 in the outer MIME message. The steps for preparing an envelopedData MIME entity are as follows:
1. Generate a pseudorandom session key for a particular symmetric encryption algorithm (RC2/40 or tripleDES).
2. For each recipient, encrypt the session key with the recipient's public RSA key.
3. For each recipient, prepare a block known as RecipientInfo that contains an identifier of the recipient's public-key certificate, an identifier of the algorithm used to encrypt the session key, and the encrypted session key.
4. Encrypt the message content with the session key.

B.8.2 SignedData

The signedData smime-type can actually be used with one or more signers. For clarity, we confine our description to the case of a single digital signature. The steps for preparing a signedData MIME entity are as follows:

1. Select a message digest algorithm (SHA or MD5).
2. Compute the message digest, or hash function, of the content to be signed.
3. Encrypt the message digest with the signer's private key.
4. Prepare a block known as SignerInfo that contains the signer's public-key certificate, an identifier of the message digest algorithm, an identifier of the algorithm used to encrypt the message digest, and the encrypted message digest.

B.9 Enhanced Security Services

As of this writing, three enhanced security services have been proposed in an Internet draft. The details of these may change, and additional services may be added. The **three services** are as follows:

● **Signed receipts:** A signed receipt may be requested in a SignedData object. Returning a signed receipt provides proof of delivery to the originator of a message and allows the originator to demonstrate to a third party that the recipient received the message. In essence, the recipient signs the entire original message plus original (sender's) signature and appends the new signature to form a new S/MIME message.
● **Security labels:** A security label may be included in the authenticated attributes of a SignedData object. A security label is a set of security information regarding the sensitivity of the content that is protected by S/MIME encapsulation. The labels may be used for access control, by indicating which users are permitted access to an object. Other uses include priority (secret, confidential, restricted, and so on) or role based, describing which kind of people can see the information (e.g., patient's health-care team, medical billing agents, etc.).
Secure mailing lists: When a user sends a message to multiple recipients, a certain amount of per-recipient processing is required, including the use of each recipient's public key. The user can be relieved of this work by employing the services of an S/MIME Mail List Agent (MLA). An MLA can take a single incoming message, perform the recipient-specific encryption for each recipient, and forward the message. The originator of a message need only send the message to the MLA, with encryption performed using the MLA's public key.

IP SECURITY

The Internet community has developed application-specific security mechanisms in a number of application areas, including electronic mail (S/MIME, PGP), client/server (Kerberos), Web access (Secure Sockets Layer), and others. However, users have some security concerns that cut across protocol layers. For example, an enterprise can run a secure, private TCP/IP network by disallowing links to untrusted sites, encrypting packets that leave the premises, and authenticating packets that enter the premises. By implementing security at the IP level, an organization can ensure secure networking not only for applications that have security mechanisms but also for the many security-ignorant applications.

Key Points

● IP security (IPSec) is a capability that can be added to either current version of the Internet Protocol (IPv4 or IPv6), by means of additional headers.
● IPSec encompasses three functional areas: authentication, confidentiality, and key management.
● Authentication makes use of the HMAC message authentication code. Authentication can be applied to the entire original IP packet (tunnel mode) or to all of the packet except for the IP header (transport mode).
● Confidentiality is provided by an encryption format known as encapsulating security payload. Both tunnel and transport modes can be accommodated.
● IPSec defines a number of techniques for key management.

IP-level security **encompasses three functional areas**:

- **authentication**
- **confidentiality**
- **key management**

The authentication mechanism assures that a received packet was, in fact, transmitted by the party identified as the source in the packet header. In addition, this mechanism assures that the packet has not been altered in transit. The confidentiality facility enables communicating nodes to encrypt messages to prevent eavesdropping by third parties. The key management facility is concerned with the secure exchange of keys.

A.1 IP Security Overview

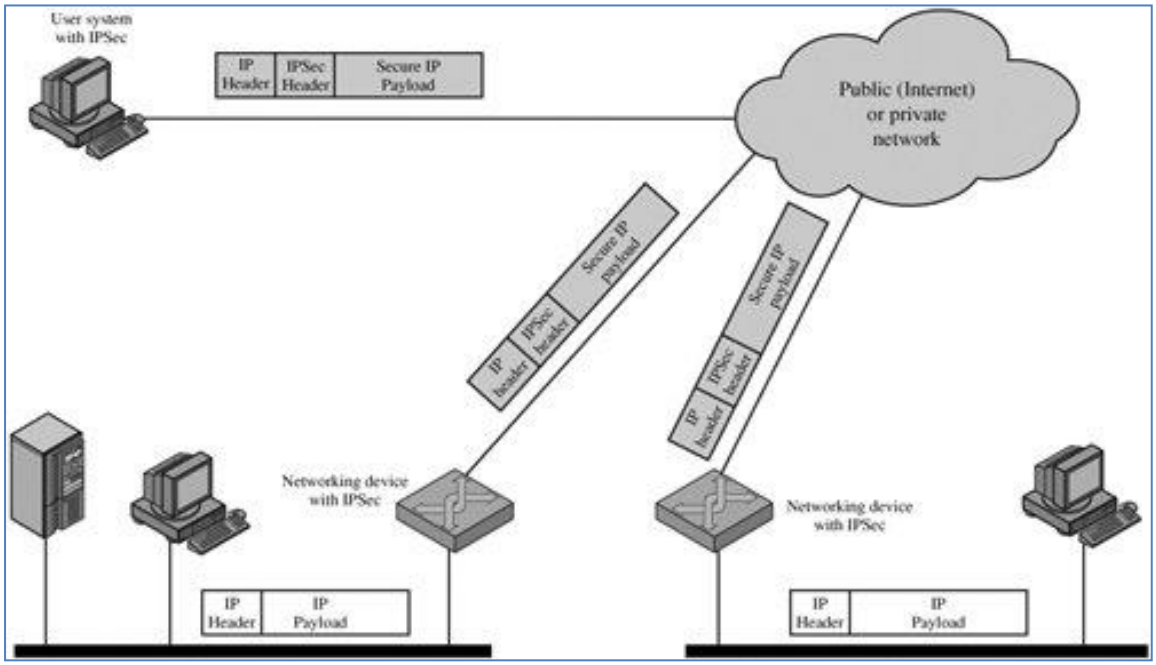
In response to these issues, the IAB included authentication and encryption as necessary security features in the next-generation IP, which has been issued as IPv6. Fortunately, these security capabilities were designed to be usable both with the current IPv4 (Internet Protocol Version 4) and the future IPv6 (Internet Protocol Version 6). This means that vendors can begin offering these features now, and many vendors do now have some IPSec capability in their products.

A.1.1 Applications of IPSec

IPSec provides the capability to secure communications across a LAN, across private and public WANs, and across the Internet. Examples of its use include the following:

● **Secure branch office connectivity over the Internet:** A company can build a secure virtual private network over the Internet or over a public WAN. This enables a business to rely heavily on the Internet and reduce its need for private networks, saving costs and network management overhead.
● **Secure remote access over the Internet:** An end user whose system is equipped with IP security protocols can make a local call to an Internet service provider (ISP) and gain secure access to a company network. This reduces the cost of toll charges for traveling employees and telecommuters.
● **Establishing extranet and intranet connectivity with partners:** IPSec can be used to secure communication with other organizations, ensuring authentication and confidentiality and providing a key exchange mechanism.
● **Enhancing electronic commerce security:** Even though some Web and electronic commerce applications have built-in security protocols, the use of IPSec enhances that security. The principal feature of IPSec that enables it to support these varied applications is that it can encrypt and/or authenticate *all*

traffic at the IP level. Thus, all distributed applications, including remote logon, client/server, e-mail, file transfer, Web access, and so on, can be secured.



An IP Security Scenario

A.1.2.Benefits of IPSec

Following are the benefits of IPSec:

● When IPSec is implemented in a firewall or router, it provides strong security that can be applied to all traffic crossing the perimeter. Traffic within a company or workgroup does not incur the overhead of security-related processing.

● IPSec in a firewall is resistant to bypass if all traffic from the outside must use IP, and the firewall is the only means of entrance from the Internet into the organization.

● IPSec is below the transport layer (TCP, UDP) and so is transparent to applications. There is no need to change software on a user or server system when IPSec is implemented in the firewall or router. Even if IPSec is implemented in end systems, upper-layer software, including applications, is not affected.

● IPSec can be transparent to end users. There is no need to train users on security mechanisms, issue keying material on a per-user basis, or revoke keying material when users leave the organization.

● IPSec can provide security for individual users if needed. This is useful for offsite workers and for setting up a secure virtual subnetwork within an organization for sensitive applications.

A.1.3 Routing Applications

In addition to supporting end users and protecting premises systems and networks, IPSec can play a vital role in the routing architecture required for internetworking. [HUIT98] lists the following examples of the use of IPSec. IPSec can assure that

● A router advertisement (a new router advertises its presence) comes from an authorized router

● A neighbor advertisement (a router seeks to establish or maintain a neighbor relationship with a router in another routing domain) comes from an authorized router.

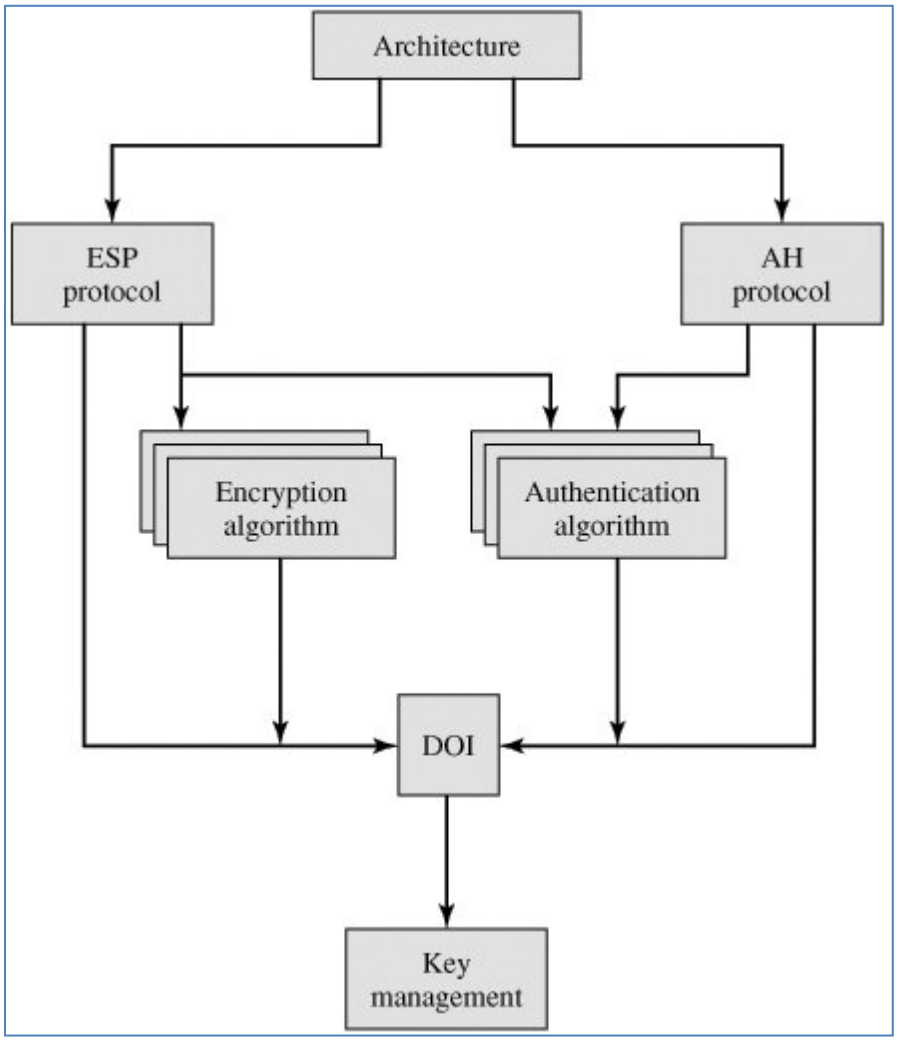
● A redirect message comes from the router to which the initial packet was sent.

● A routing update is not forged. Without such security measures, an opponent can disrupt communications or divert some traffic. Routing protocols such as OSPF should be run on top of security associations between routers that are defined by IPSec.

A.2 IP Security Architecture

The IPSec specification consists of numerous documents. The documents are divided into seven groups:-

Architecture: Covers the general concepts, security requirements, definitions, and mechanisms defining IPSec technology.
Encapsulating Security Payload (ESP): Covers the packet format and general issues related to the use of the ESP for packet encryption and, optionally, authentication.
Authentication Header (AH): Covers the packet format and general issues related to the use of AH for packet authentication.
Encryption Algorithm: A set of documents that describe how various encryption algorithms are used for ESP.
Authentication Algorithm: A set of documents that describe how various authentication algorithms are used for AH and for the authentication option of ESP.
Key Management: Documents that describe key management schemes.
Domain of Interpretation (DOI): Contains values needed for the other documents to relate to each other. These include identifiers for approved encryption and authentication algorithms, as well as operational parameters such as key lifetime.



IPSec Document Overview

A.3 IPSec Services

IPSec provides security services at the IP layer by enabling a system to select required security protocols, determine the algorithm(s) to use for the service(s), and put in place any cryptographic keys required to provide the requested services. Two protocols are used to provide security: an authentication protocol designated by the header of the protocol, Authentication Header (AH); and a combined encryption/authentication protocol designated by the format of the packet for that protocol, Encapsulating Security Payload (ESP). The services are

- Access control
- Connectionless integrity
- Data origin authentication
- Rejection of replayed packets (a form of partial sequence integrity)
- Confidentiality (encryption)
- Limited traffic flow confidentiality

A.3.1 Security Associations

A key concept that appears in both the authentication and confidentiality mechanisms for IP is the security association (SA). An association is a one-way relationship between a sender and a receiver that affords security services to the traffic carried on it. If a peer relationship is needed, for two-way secure exchange, then two security associations are required. Security services are afforded to an SA for the use of AH or ESP, but not both.

A security association is uniquely identified by three parameters:

● **Security Parameters Index (SPI):** A bit string assigned to this SA and having local significance only. The SPI is carried in AH and ESP headers to enable the receiving system to select the SA under which a received packet will be processed.

● **IP Destination Address:** Currently, only unicast addresses are allowed; this is the address of the destination endpoint of the SA, which may be an end user system or a network system such as a firewall or router.

● **Security Protocol Identifier:** This indicates whether the association is an AH or ESP security association.

Hence, in any IP packet, the security association is uniquely identified by the Destination Address in the IPv4 or IPv6 header and the SPI in the enclosed extension header (AH or ESP).

SA Parameters

In each IPSec implementation, there is a nominal Security Association Database that defines the parameters associated with each SA. A security association is normally defined by the following parameters:

● **Sequence Number Counter:** A 32-bit value used to generate the Sequence Number field in AH or ESP headers,.

● **Sequence Counter Overflow:** A flag indicating whether overflow of the Sequence Number Counter should generate an auditable event and prevent further transmission of packets on this SA (required for all implementations).

● **Anti-Replay Window:** Used to determine whether an inbound AH or ESP packet is a replay.

● **AH Information:** Authentication algorithm, keys, key lifetimes, and related parameters being used with AH (required for AH implementations).

ESP Information: Encryption and authentication algorithm, keys, initialization values, key lifetimes, and related parameters being used with ESP (required for ESP implementations).

● **Lifetime of This Security Association:** A time interval or byte count after which an SA must be replaced with a new SA (and new SPI) or terminated, plus an indication of which of these actions should occur (required for all implementations).

● **IPSec Protocol Mode:** Tunnel, transport, or wildcard (required for all implementations). These modes are discussed later in this section.

● **Path MTU:** Any observed path maximum transmission unit (maximum size of a packet that can be transmitted without fragmentation) and aging variables (required for all implementations).

The key management mechanism that is used to distribute keys is coupled to the authentication and privacy mechanisms only by way of the Security Parameters Index. Hence, authentication and privacy have been specified independent of any specific key management mechanism.

A.3.2 SA Selectors

IPSec provides the user with considerable flexibility in the way in which IPSec services are applied to IP traffic. As we will see later, SAs can be combined in a number of ways to yield the desired user configuration. Furthermore, IPSec provides a high degree of granularity in discriminating between traffic that is afforded IPSec protection and traffic that is allowed to bypass IPSec, in the former case relating IP traffic to specific SAs.

The means by which IP traffic is related to specific SAs (or no SA in the case of traffic allowed to bypass IPSec) is the nominal Security Policy Database (SPD). In its simplest form, an SPD contains entries, each of which defines a subset of IP traffic and points to an SA for that traffic. In more complex environments, there may be multiple entries that potentially relate to a single SA or multiple SAs associated with a single SPD entry. The reader is referred to the relevant IPSec documents for a full discussion. Each SPD entry is defined by a set of IP and upper-layer protocol field values, called *selectors*. In effect, these selectors are used to filter outgoing traffic in order to map it into a particular SA. Outbound processing obeys the following general sequence for each IP packet:

1. Compare the values of the appropriate fields in the packet (the selector fields) against the SPD to find a matching SPD entry, which will point to zero or more SAs.

2. Determine the SA if any for this packet and its associated SPI.

3. Do the required IPSec processing (i.e., AH or ESP processing).

The following selectors determine an SPD entry:

● **Destination IP Address:** This may be a single IP address, an enumerated list or range of addresses, or a wildcard (mask) address. The latter two are required to support more than one destination system sharing the same SA (e.g., behind a firewall).

Source IP Address: This may be a single IP address, an enumerated list or range of addresses, or a wildcard (mask) address. The latter two are required to support more than one source system sharing the same SA (e.g., behind a firewall).

● **UserID:** A user identifier from the operating system. This is not a field in the IP or upper-layer headers but is available if IPSec is running on the same operating system as the user.

● **Data Sensitivity Level:** Used for systems providing information flow security (e.g., Secret or Unclassified).

● **Transport Layer Protocol:** Obtained from the IPv4 Protocol or IPv6 Next Header field. This may be an individual protocol number, a list of protocol numbers, or a range of protocol numbers.

● **Source and Destination Ports:** These may be individual TCP or UDP port values, an enumerated list of ports, or a wildcard port.

A.4 Transport and Tunnel Modes

Both AH and ESP support two modes of use: transport and tunnel mode.

A.4.1 Transport Mode

Transport mode provides protection primarily for upper-layer protocols. That is, transport mode protection extends to the payload of an IP packet. Examples include a TCP or UDP segment or an ICMP packet, all of which operate directly above IP in a host protocol stack. Typically, transport mode is used for end-to-end communication between two hosts (e.g., a client and a server, or twoworkstations). When a host runs AH or ESP over IPv4, the payload is the data that normally follow the IP header. For IPv6, the payload is the data that normally follow both the IP header and any IPv6 extensions headers that are present, with the possible exception of the destination options header, which may be included in the protection. ESP in transport mode encrypts and optionally authenticates the IP payload but not the IP header. AH in transport mode authenticates the IP payload and selected portions of the IP header.

A.4.2 Tunnel Mode

Tunnel mode provides protection to the entire IP packet. To achieve this, after the AH or ESP fields are added to the IP packet, the entire packet plus security fields is treated as the payload of new "outer" IP

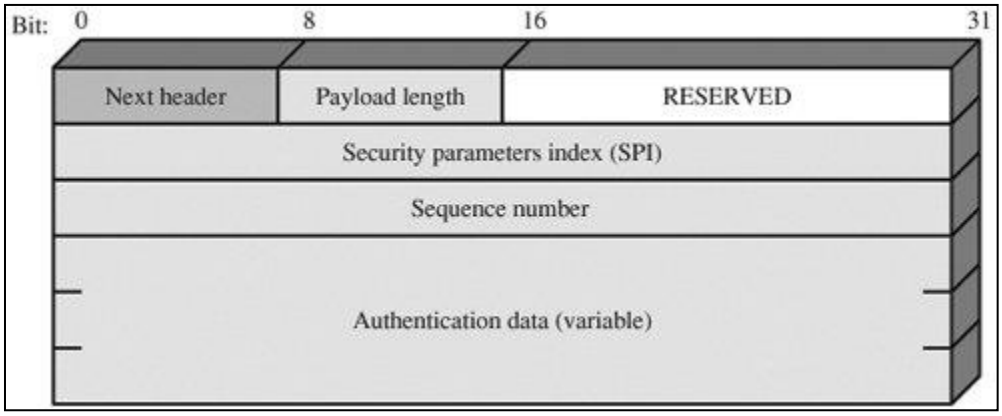
packet with a new outer IP header. The entire original, or inner, packet travels through a "tunnel" from one point of an IP network to another; no routers along the way are able to examine the inner IP header. Because the original packet is encapsulated, the new, larger packet may have totally different source and destination addresses, adding to the security. Tunnel mode is used when one or both ends of an SA are a security gateway, such as a firewall or router that implements IPSec. With tunnel mode, a number of hosts on networks behind firewalls may engage in secure communications without implementing IPSec. The unprotected packets generated by such hosts are tunneled through external networks by tunnel mode SAs set up by the IPSec software in the firewall or secure router at the boundary of the local network.

A.5 Authentication Header

The Authentication Header provides support for data integrity and authentication of IP packets. The data integrity feature ensures that undetected modification to a packet's content in transit is not possible. The authentication feature enables an end system or network device to authenticate the user or application and filter traffic accordingly; it also prevents the address spoofing attacks observed in today's Internet. The AH also guards against the replay attack. Authentication is based on the use of a message authentication code (MAC)hence the two parties must share a secret key.

The Authentication Header consists of the following fields:-

- **Next Header (8 bits):** Identifies the type of header immediately following this header.
- **Payload Length (8 bits):** Length of Authentication Header in 32-bit words, minus 2. For example, the default length of the authentication data field is 96 bits, or three 32-bit words. With a three-word fixed header, there are a total of six words in the header, and the Payload Length field has a value of 4.
- **Reserved (16 bits):** For future use.
- **Security Parameters Index (32 bits):** Identifies a security association.
- **Sequence Number (32 bits):** A monotonically increasing counter value.
- **Authentication Data (variable):** A variable-length field (must be an integral number of 32-bitwords) that contains the Integrity Check Value (ICV), or MAC, for this packet.



IPSec Authentication Header

A.5.1 Anti-Replay Service

A replay attack is one in which an attacker obtains a copy of an authenticated packet and later transmits it to the intended destination. The receipt of duplicate, authenticated IP packets may disrupt service in some way or may have some other undesired consequence. The Sequence Number field is designed to thwart such attacks.

When a new SA is established, the **sender** initializes a sequence number counter to 0. Each time that a packet is sent on this SA, the sender increments the counter and places the value in the Sequence Number field. Thus, the first value to be used is 1. If anti-replay is enabled (the default), the sender must not allow the sequence number to cycle past 232 1 back to zero. Otherwise, there would be multiple valid packets with the same sequence number. If the limit of 232 1 is reached, the sender
should terminate this SA and negotiate a new SA with a new key.

Because IP is a connectionless, unreliable service, the protocol does not guarantee that packets will be delivered in order and does not guarantee that all packets will be delivered. Therefore, the IPSec authentication document dictates that the **receiver** should implement a window of size W, with a default of $W = 64$. The right edge of the window represents the highest sequence number, N, so far received for a valid packet. For any packet with a sequence number in the range from N $W + 1$ to N that has been correctly received (i.e., properly authenticated), the corresponding slot in the window is marked Inbound processing proceeds as follows when a packet is received:

1. If the received packet falls within the window and is new, the MAC is checked. If the packet is authenticated, the corresponding slot in the window is marked.
2. If the received packet is to the right of the window and is new, the MAC is checked. If the packet is authenticated, the window is advanced so that this sequence number is the right edge of the window, and the corresponding slot in the window is marked.
3. If the received packet is to the left of the window, or if authentication fails, the packet is discarded; this is an auditable event.

A.5.2 Integrity Check Value

The Authentication Data field holds a value referred to as the Integrity Check Value. The ICV is a message authentication code or a truncated version of a code produced by a MAC algorithm. The current specification dictates that a compliant implementation must support

- HMAC-MD5-96
- HMAC-SHA-1-96

Both of these use the HMAC algorithm, the first with the MD5 hash code and the second with the SHA-1 hash code.In both cases, the full HMAC value is calculated but then truncated by using the first 96 bits, which is the default length for the Authentication Data field.

A.6 Key Management

The key management portion of IPSec involves the determination and distribution of secret keys. A typical requirement is four keys for communication between two applications: transmit and receive pairs for both AH and ESP. The IPSec Architecture document mandates support for two types of key management:

- **Manual:** A system administrator manually configures each system with its own keys and with the keys of other communicating systems. This is practical for small, relatively static environments.
- **Automated:** An automated system enables the on-demand creation of keys for SAs and facilitates the use of keys in a large distributed system with an evolving configuration. The default automated key management protocol for IPSec is referred to as ISAKMP/Oakley and consists of the following elements:
    - **Oakley Key Determination Protocol**: Oakley is a key exchange protocol based on the Diffie-Hellman algorithm but providing added security. Oakley is generic in that it does not dictate specific formats.
    - **Internet Security Association and Key Management Protocol (ISAKMP):** ISAKMP provides a framework for Internet key management and provides the specific protocol support, including formats, for negotiation of security attributes.

ISAKMP by itself does not dictate a specific key exchange algorithm; rather, ISAKMP consists of a set of message types that enable the use of a variety of key exchange algorithms. Oakley is the specific key exchange algorithm mandated for use with the initial version of ISAKMP.

WEB SECURITY

Virtually all businesses, most government agencies, and many individuals now have Web sites. The number of individuals and companies with Internet access is expanding rapidly and all of these have graphical Web browsers. As a result, businesses are enthusiastic about setting up facilities on the Web for electronic commerce. But the reality is that the Internet and the Web are extremely vulnerable to compromises of various sorts. As businesses wake up to this reality, the demand for secure Web services grows.

Key Points

● Secure socket layer (SSL) provides security services between TCP and applications that use TCP. The Internet standard version is called transport layer service (TLS).

● SSL/TLS provides confidentiality using symmetric encryption and message integrity using a message authentication code.

● SSL/TLS includes protocol mechanisms to enable two TCP users to determine the security mechanisms and services they will use.

● Secure electronic transaction (SET) is an open encryption and security specification designed to protect credit card transactions on the Internet.

Web Security Considerations

The World Wide Web is fundamentally a client/server application running over the Internet and TCP/IP intranets. As such, the security tools and approaches discussed so far in this book are relevant to the issue of Web security. But, as pointed out in [GARF97], the Web presents new challenges not generally appreciated in the context of computer and network security:

● The Internet is two way. Unlike traditional publishing environments, even electronic publishing systems involving teletext, voice response, or fax-back, the Web is vulnerable to attacks on the Web servers over the Internet.

● The Web is increasingly serving as a highly visible outlet for corporate and product information and as the platform for business transactions. Reputations can be damaged and money can be lost if the Web servers are subverted.

• Although Web browsers are very easy to use, Web servers are relatively easy to configure and manage, and Web content is increasingly easy to develop, the underlying software is extraordinarily complex. This complex software may hide many potential security flaws. The short history of the Web is filled with examples of new and upgraded systems, properly installed, that are vulnerable to a variety of security attacks.

• A Web server can be exploited as a launching pad into the corporation's or agency's entire computer complex. Once the Web server is subverted, an attacker may be able to gain access to data and systems not part of the Web itself but connected to the server at the local site.

• Casual and untrained (in security matters) users are common clients for Web-based services. Such users are not necessarily aware of the security risks that exist and do not have the tools or knowledge to take effective countermeasures.

A. Web Security Threats

Following table provides a summary of the types of security threats faced in using the Web. One way to group these threats is in terms of passive and active attacks. Passive attacks include eavesdropping on network traffic between browser and server and gaining access to information on a Web site that is supposed to be restricted. Active attacks include impersonating another user, altering messages in transit between client and server, and altering information on a Web site.

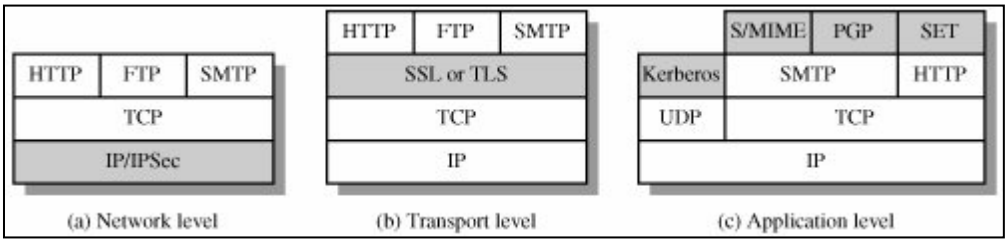
	Threat	Consequences	Countermeasures
Integrity	• Modification of user data • Trojan horse browser • Modification of memory • Modification of message	• Loss of information ● Compromise of machine ● Vulnerabilty to all other threats	Cryptographic checksums

	traffic in transit		
Confidentiality	Eavesdropping on the Net ● Theft of info from server ● Theft of data from client ● Info about network configuration ● Info about which client talks to server	● Loss of information ● Loss of privacy	Encryption, web proxies
Denial of Services	• Killing of user threads ● Flooding machine with bogus requests ● Filling up disk or memory ● Isolating machine by DNS attacks	• Disruptive ● Annoying ● Prevent user from getting work done	Difficult to prevent
Authentication	● Impersonation of legitimate users ● Data forgery	● Misrepresentation of user ● Belief that false information is valid	Cryptographic techniques

Comparison of Threats on the Web

B. Web Traffic Security Approaches

A number of approaches to providing Web security are possible. The various approaches that have been considered are similar in the services they provide and, to some extent, in the mechanisms that they use, but they differ with respect to their scope of applicability and their relative location within the TCP/ IP protocol stack.



Relative Location of Security Facilities in the TCP/IP Protocol Stack

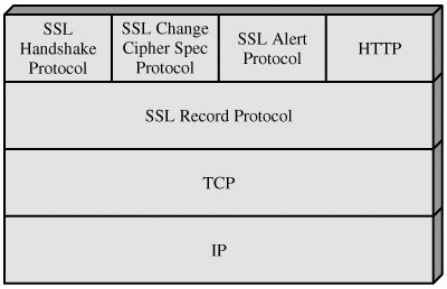
One way to provide Web security is to use IP Security. The advantage of using IPSec is that it is transparent to end users and applications and provides a general-purpose solution. Further, IPSec includes a filtering capability so that only selected traffic need incur the overhead of IPSec processing. Another relatively general-purpose solution is to implement security just above TCP. The foremost example of this approach is the Secure Sockets Layer (SSL) and the follow-on Internet standard known as Transport Layer Security (TLS).

B.1 Secure Socket Layer and Transport Layer Security

Netscape originated SSL. Version 3 of the protocol was designed with public review and input from industry and was published as an Internet draft document. Subsequently, when a consensus was reached to submit the protocol for Internet standardization, the TLS working group was formed within IETF to develop a common standard. This first published version of TLS can be viewed as essentially an SSLv3.1 and is very close to and backward compatible with SSLv3.

a) SSL Architecture

SSL is designed to make use of TCP to provide a reliable end-to-end secure service. SSL is not a single protocol but rather two layers of protocols,



SSL Protocol Stack

The SSL Record Protocol provides basic security services to various higher-layer protocols. In particular, the Hypertext Transfer Protocol (HTTP), which provides the transfer service for Web client/server interaction, can operate on top of SSL. Three higher-layer protocols are defined as part of SSL: the Handshake Protocol, The Change Cipher Spec Protocol, and the Alert Protocol. These SSL-specific protocols are used in the management of SSL exchanges.

Two important SSL concepts are the SSL session and the SSL connection, which are defined in the specification as follows:

● **Connection:** A connection is a transport (in the OSI layering model definition) that provides a suitable type of service. For SSL, such connections are peer-to-peer relationships. The connections are transient. Every connection is associated with one session.

● **Session:** An SSL session is an association between a client and a server. Sessions are created by the Handshake Protocol. Sessions define a set of cryptographic security parameters, which can be shared among multiple connections. Sessions are used to avoid the expensive negotiation of new security parameters for each connection.

Between any pair of parties (applications such as HTTP on client and server), there may be multiple secure connections.

There are actually a number of states associated with each session. Once a session is established, there is a current operating state for both read and write (i.e., receive and send). In addition, during the Handshake Protocol, pending read and write states are created. Upon successful conclusion of the Handshake Protocol, the pending states become the current states. A session state is defined by the following parameters:-

Session identifier: An arbitrary byte sequence chosen by the server to identify an active or resumable session state.

● **Peer certificate:** An X509.v3 certificate of the peer. This element of the state may be null.

● **Compression method:** The algorithm used to compress data prior to encryption.

● **Cipher spec:** Specifies the bulk data encryption algorithm (such as null, AES, etc.) and a hash algorithm (such as MD5 or SHA-1) used for MAC calculation. It also defines cryptographic attributes such as the hash_size.

Master secret: 48-byte secret shared between the client and server.

● **Is resumable:** A flag indicating whether the session can be used to initiate new connections.

A connection state is defined by the following parameters:

● **Server and client random:** Byte sequences that are chosen by the server and client for each connection.

● **Server write MAC secret:** The secret key used in MAC operations on data sent by the server.

● **Client write MAC secret:** The secret key used in MAC operations on data sent by the client.

● **Server write key:** The conventional encryption key for data encrypted by the server and decrypted by the client.

● **Client write key:** The conventional encryption key for data encrypted by the client and decrypted by the server.

● **Initialization vectors:** When a block cipher in CBC mode is used, an initialization vector (IV) is maintained for each key. This field is first initialized by the SSL Handshake Protocol. Thereafter the final ciphertext block from each record is preserved for use as the IV with the following record.

● **Sequence numbers:** Each party maintains separate sequence numbers for transmitted and received messages for each connection. When a party sends or receives a change cipher spec message, the appropriate sequence number is set to zero. Sequence numbers may not exceed 2^{64} 1.

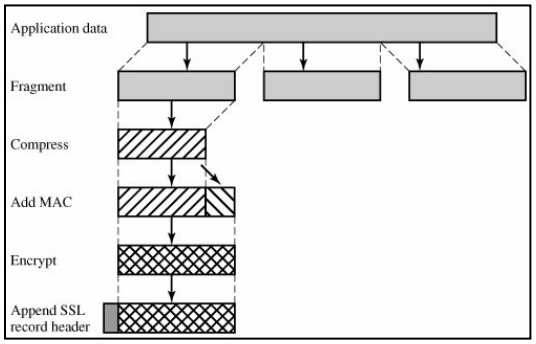
a.1) SSL Record Protocol

The SSL Record Protocol provides two services for SSL connections:

● **Confidentiality:** The Handshake Protocol defines a shared secret key that is used for conventional encryption of SSL payloads.

● **Message Integrity:** The Handshake Protocol also defines a shared secret key that is used to form a message authentication code (MAC).

Below figure indicates the overall operation of the SSL Record Protocol. The Record Protocol takes an application message to be transmitted, fragments the data into manageable blocks, optionally compresses the data, applies a MAC, encrypts, adds a header, and transmits the resulting unit in a TCP segment. Received data are decrypted, verified, decompressed, and reassembled and then delivered to higher-level users.



SSL Record Protocol Operation

Three SSL-specific protocols that use the SSL Record Protocol are :-

i) Change Cipher Spec Protocol-This protocol consists of a single message, which consists of a single byte with the value 1. The sole purpose of this message is to cause the pending state to be copied into the current state, which updates the cipher suite to be used on this connection.

ii) Alert Protocol-The Alert Protocol is used to convey SSL-related alerts to the peer entity. As with other applications that use SSL, alert messages are compressed and encrypted, as specified by the current state. Each message in this protocol consists of two bytes. The first byte takes the value warning(1) or fatal(2) to convey the severity of the message. If the level is fatal, SSL immediately terminates the connection. Other connections on the same session may continue, but no new connections on this session may be established. The second byte contains a code that indicates the specific alert.

iii) **Handshake Protocol-**The most complex part of SSL is the Handshake Protocol. This protocol allows the server and client to authenticate each other and to negotiate an encryption and MAC algorithm and cryptographic keys to be used to protect data sent in an SSL record. The Handshake Protocol is used before any application data is transmitted. The Handshake Protocol consists of a series of messages exchanged by client and server.

b). Transport Layer Security

TLS is an IETF standardization initiative whose goal is to produce an Internet standard version of SSL. TLS is defined as a Proposed Internet Standard in RFC 2246. RFC 2246 is very similar to SSLv3.

b.1 Version Number

The TLS Record Format is the same as that of the SSL Record Format, and the fields in the header have the same meanings. The one difference is in version values. For the current version of TLS, the Major Version is 3 and the Minor Version is 1.

b.2 Message Authentication Code

There are two differences between the SSLv3 and TLS MAC schemes: the actual algorithm and the scope of the MAC calculation. TLS makes use of the HMAC algorithm defined in RFC 2104.

b.3 Pseudorandom Function

TLS makes use of a pseudorandom function referred to as PRF to expand secrets into blocks of data for purposes of key generation or validation. The objective is to make use of a relatively small shared secret value but to generate longer blocks of data in a way that is secure from the kinds of attacks made on hash functions and MACs.

b.4 Alert Codes

TLS supports all of the alert codes defined in SSLv3 with the exception of no_certificate. A number of additional codes are defined in TLS; some of these are always fatal:

- **decryption_failed:** A ciphertext decrypted in an invalid way; either it was not an even multiple of the block length or its padding values, when checked, were incorrect.
- **record_overflow:** A TLS record was received with a payload (ciphertext) whose length exceeds 214 + 2048 bytes, or the ciphertext decrypted to a length of greater than 214 + 1024 bytes.
- **unknown_ca:** A valid certificate chain or partial chain was received, but the certificate was not accepted because the CA certificate could not be located or could not be matched with a known, trusted CA.
- **access_denied:** A valid certificate was received, but when access control was applied, the sender decided not to proceed with the negotiation.

b.5 Cipher Suites

There are several small differences between the cipher suites available under SSLv3 and under TLS:

- **Key Exchange:** TLS supports all of the key exchange techniques of SSLv3 with the exception of Fortezza.
- **Symmetric Encryption Algorithms:** TLS includes all of the symmetric encryption algorithms found in SSLv3, with the exception of Fortezza.

C. Secure Electronic Transaction (SET)

SET is an open encryption and security specification designed to protect credit card transactions on the Internet. The current version, SETv1, emerged from a call for security standards by MasterCard and Visa in February 1996. A wide range of companies were involved in developing the initial specification, including IBM, Microsoft, Netscape, RSA, Terisa, and Verisign. Beginning in 1996, there have been numerous tests of the concept, and by 1998 the first wave of SET-compliant products was available.

SET is not itself a payment system. Rather it is a set of security protocols and formats that enables users to employ the existing credit card payment infrastructure on an open network, such as the Internet, in a secure fashion. In essence, SET provides three services:

- Provides a secure communications channel among all parties involved in a transaction
- Provides trust by the use of X.509v3 digital certificates
- Ensures privacy because the information is only available to parties in a transaction when and where necessary

C.1 SET Overview

SET specification lists the following business requirements for secure payment processing with credit cards over the Internet and other networks:

- **Provide confidentiality of payment and ordering information:** It is necessary to assure cardholders that this information is safe and accessible only to the intended recipient. Confidentiality also reduces the risk of fraud by either party to the transaction or by malicious third parties. SET uses encryption to provide confidentiality.
- **Ensure the integrity of all transmitted data:** That is, ensure that no changes in content occur during transmission of SET messages. Digital signatures are used to provide integrity.
- **Provide authentication that a cardholder is a legitimate user of a credit card account:** A mechanism that links a cardholder to a specific account number reduces the incidence of fraud and the overall cost of payment processing. Digital signatures and certificates are used to verify that a cardholder is a legitimate user of a valid account.
- **Provide authentication that a merchant can accept credit card transactions through its relationship with a financial institution:** This is the complement to the preceding requirement.

Cardholders need to be able to identify merchants with whom they can conduct secure transactions. Again, digital signatures and certificates are used.

● **Ensure the use of the best security practices and system design techniques to protect all legitimate parties in an electronic commerce transaction:** SET is a well-tested specification based on highly secure cryptographic algorithms and protocols.

● **Create a protocol that neither depends on transport security mechanisms nor prevents their use:** SET can securely operate over a "raw" TCP/IP stack. However, SET does not interfere with the use of other security mechanisms, such as IPSec and SSL/TLS.

● **Facilitate and encourage interoperability among software and network providers:** The SET protocols and formats are independent of hardware platform, operating system, and Web software.

c.2 Key Features of SET

To meet the requirements just outlined, SET incorporates the following features:

● **Confidentiality of information:** Cardholder account and payment information is secured as it travels across the network. An interesting and important feature of SET is that it prevents the merchant from learning the cardholder's credit card number; this is only provided to the issuing bank. Conventional encryption by DES is used to provide confidentiality.

● **Integrity of data:** Payment information sent from cardholders to merchants includes order information, personal data, and payment instructions. SET guarantees that these message contents are not altered in transit. RSA digital signatures, using SHA-1 hash codes, provide message integrity. Certain messages are also protected by HMAC using SHA-1.

● **Cardholder account authentication:** SET enables merchants to verify that a cardholder is a legitimate user of a valid card account number. SET uses X.509v3 digital certificates with RSA signatures for this purpose.

● **Merchant authentication:** SET enables cardholders to verify that a merchant has a relationship with a financial institution allowing it to accept payment cards. SET uses X.509v3 digital certificates with RSA signatures for this purpose.

C.3 SET Participants

● **Cardholder:** In the electronic environment, consumers and corporate purchasers interact with merchants from personal computers over the Internet. A cardholder is an authorized holder of a payment card (e.g., MasterCard, Visa) that has been issued by an issuer.

● **Merchant:** A merchant is a person or organization that has goods or services to sell to the cardholder. Typically, these goods and services are offered via a Web site or by electronic mail. A merchant that accepts payment cards must have a relationship with an acquirer.

● **Issuer**: This is a financial institution, such as a bank, that provides the cardholder with the payment card. Typically, accounts are applied for and opened by mail or in person. Ultimately, it is the issuer that is responsible for the payment of the debt of the cardholder.

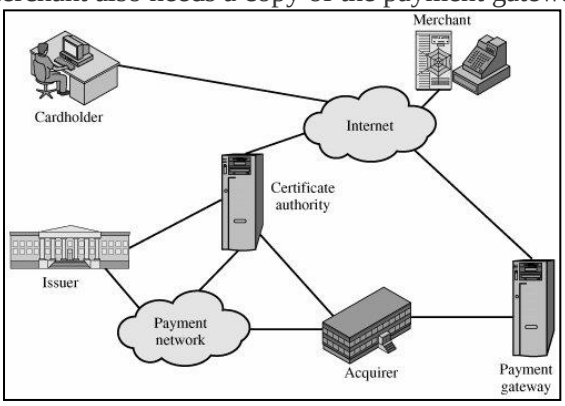
● **Acquirer**: This is a financial institution that establishes an account with a merchant and processes payment card authorizations and payments. Merchants will usually accept more than one credit card brand but do not want to deal with multiple bankcard associations or with multiple individual issuers. The acquirer provides authorization to the merchant that a given card account is active and that the proposed purchase does not exceed the credit limit. The acquirer also provides electronic transfer of payments to the merchant's account. Subsequently, the acquirer is reimbursed by the issuer over some sort of payment network for electronic funds transfer.

● **Payment gateway**: This is a function operated by the acquirer or a designated third party that processes merchant payment messages. The payment gateway interfaces between SET and the existing bankcard payment networks for authorization and payment functions. The merchant exchanges SET messages with the payment gateway over the Internet, while the payment gateway has some direct or network connection to the acquirer's financial processing system.

● **Certification authority (CA):** This is an entity that is trusted to issue X.509v3 public-key certificates for cardholders, merchants, and payment gateways. The success of SET will depend on the existence of a CA infrastructure available for this purpose.

C.4 sequence of events that are required for a transaction

1. **The customer opens an account.** The customer obtains a credit card account, such as MasterCard or Visa, with a bank that supports electronic payment and SET.
2. **The customer receives a certificate.** After suitable verification of identity, the customer receives an X.509v3 digital certificate, which is signed by the bank. The certificate verifies the customer's RSA public key and its expiration date. It also establishes a relationship, guaranteed by the bank, between the customer's key pair and his or her credit card.
3. Merchants have their own certificates. A merchant who accepts a certain brand of card must be in possession of two certificates for two public keys owned by the merchant: one for signing messages, and one for key exchange. The merchant also needs a copy of the payment gateway's public-key certificate.



Secure Electronic Commerce Components

4. **The customer places an order.** This is a process that may involve the customer first browsing through the merchant's Web site to select items and determine the price. The customer then sends a list of the items to be purchased to the merchant, who returns an order form containing the list of items, their price, a total price, and an order number.
5. The merchant is verified. In addition to the order form, the merchant sends a copy of its certificate, so that the customer can verify that he or she is dealing with a valid store.
6.The order and payment are sent. The customer sends both order and payment information to the merchant, along with the customer's certificate. The order confirms the purchase of the items in the order form. The payment contains credit card details. The payment information is encrypted in such a way that it cannot be read by the merchant. The customer's certificate enables the merchant to verify the customer.
7. The merchant requests payment authorization. The merchant sends the payment information to the payment gateway, requesting authorization that the customer's available credit is sufficient for this purchase.
8. The merchant confirms the order. The merchant sends confirmation of the order to the customer.
9. The merchant provides the goods or service. The merchant ships the goods or provides the service to the customer.
10. The merchant requests payment. This request is sent to the payment gateway, which handles all of the payment processing.

SYSTEM SECURITY

Following three topics are covered in this section-
Intruders,
Malicious Software,
Firewalls

Security is a concern of organizations with assets that are controlled by computer systems. By accessing or altering data, an attacker can steal tangible assets or lead an organization to take actions it would not otherwise take. By merely examining data, an attacker can gain a competitive advantage, without the owner of the data being any the wiser.

The developers of secure software cannot adopt the various probabilistic measures of quality that developers of other software often can. For many applications, it is quite reasonable to tolerate a flaw that is rarely exposed and to assume that its having occurred once does not increase the likelihood that it will occur again. It is also reasonable to assume that logically independent failures will be statistically independent and not happen in concert. In contrast, a security vulnerability, once discovered, will be rapidly disseminated among a community of attackers and can be expected to be exploited on a regular basis until it is fixed.

Key Points

● Unauthorized intrusion into a computer system or network is one of the most serious threats to computer security.
● Intrusion detection systems have been developed to provide early warning of an intrusion so that defensive action can be taken to prevent or minimize damage.
● Intrusion detection involves detecting unusual patterns of activity or patterns of activity that are known to correlate with intrusions.
● One important element of intrusion prevention is password management, with the goal of preventing unauthorized users from having access to the passwords of others.

A significant security problem for networked systems is hostile, or at least unwanted, trespass by users or software. User trespass can take the form of unauthorized logon to a machine or, in the case of an authorized user, acquisition of privileges or performance of actions beyond those that have been authorized. Software trespass can take the form of a virus, worm, or Trojan horse.

All these attacks relate to network security because system entry can be achieved by means of a network. However, these attacks are not confined to network-based attacks. A user with access to a local terminal may attempt trespass without using an intermediate network. A virus or Trojan horse may be introduced into a system by means of a diskette. Only the worm is a uniquely network phenomenon. Thus, system trespass is an area in which the concerns of network security and computer security overlap.

A. Intruders

One of the two most publicized threats to security is the intruder (the other is viruses), generally referred to as a hacker or cracker. In an important early study of intrusion, Anderson identified three classes of intruders:

● **Masquerader:** An individual who is not authorized to use the computer and who penetrates a system's access controls to exploit a legitimate user's account
● **Misfeasor:** A legitimate user who accesses data, programs, or resources for which such access is not authorized, or who is authorized for such access but misuses his or her privileges
● **Clandestine user:** An individual who seizes supervisory control of the system and uses this control to evade auditing and access controls or to suppress audit collection

The masquerader is likely to be an outsider; the misfeasor generally is an insider; and the clandestine user can be either an outsider or an insider. Intruder attacks range from the benign to the serious. At the benign end of the scale, there are many people who simply wish to explore internets and see what is out there. At the serious end are individuals who are attempting to read privileged data, perform unauthorized

modifications to data, or disrupt the system. In 1990 there was a nationwide crackdown on illicit computer hackers, with arrests, criminal charges, one dramatic show trial, several guilty pleas, and confiscation of massive amounts of data and computer equipment. Many people believed that the problem had been brought under control. In fact, the problem has not been brought under control. To cite one example, a group at Bell Labs has reported persistent and frequent attacks on its computer complex via the Internet over an extended period and from a variety of sources. At the time of these reports, the Bell group was experiencing the following:

- Attempts to copy the password file (discussed later) at a rate exceeding once every other day
- Suspicious remote procedure call (RPC) requests at a rate exceeding once per week
- Attempts to connect to nonexistent "bait" machines at least every two weeks.

Benign intruders might be tolerable, although they do consume resources and may slow performance for legitimate users. However, there is no way in advance to know whether an intruder will be benign or malign. Consequently, even for systems with no particularly sensitive resources, there is a motivation to control this problem. In August 1992, the computer center there was notified that one of its machines was being used to attack computers at another location via the Internet. By monitoring activity, the computer center personnel learned that there were several outside intruders involved, who were running password-cracking routines on various computers (the site consists of a total of 12,000 interconnected machines). The center disconnected affected machines, plugged known security holes, and resumed normal operation. A few days later, one of the local system managers detected that the intruder attack had resumed. It turned out that the attack was far more sophisticated than had been originally believed. Files were found containing hundreds of captured passwords, including some on major and supposedly secure servers. In addition, one local machine had been set up as a hacker bulletin board, which the hackers used to contact each other and to discuss techniques and progress.

An analysis of this attack revealed that there were actually two levels of hackers. The high level were sophisticated users with a thorough knowledge of the technology; the low level were the "foot soldiers" who merely used the supplied cracking programs with little understanding of how they worked. This teamwork combined the two most serious weapons in the intruder armory: sophisticated knowledge of how to intrude and a willingness to spend countless hours "turning doorknobs" to probe for weaknesses.

One of the results of the growing awareness of the intruder problem has been the establishment of a number of computer emergency response teams (CERTs). These cooperative ventures collect information about system vulnerabilities and disseminate it to systems managers. Unfortunately, hackers can also gain access to CERT reports. In the Texas A&M incident, later analysis showed that the hackers had developed programs to test the attacked machines for virtually every vulnerability that had been announced by CERT. If even one machine had failed to respond promptly to a CERT advisory, it was wide open to such attacks.

In addition to running password-cracking programs, the intruders attempted to modify login software to enable them to capture passwords of users logging on to systems. This made it possible for them to build up an impressive collection of compromised passwords, which was made available on the bulletin board set up on one of the victim's own machines.

A.1 Intrusion Techniques

The objective of the intruder is to gain access to a system or to increase the range of privileges accessible on a system. Generally, this requires the intruder to acquire information that should have been protected. In some cases, this information is in the form of a user password. With knowledge of some other user's password, an intruder can log in to a system and exercise all the privileges accorded to the legitimate user. Typically, a system must maintain a file that associates a password with each authorized user. If such a file is stored with no protection, then it is an easy matter to gain access to it and learn passwords. The password file can be protected in one of two ways:

- **One-way function:** The system stores only the value of a function based on the user's password. When the user presents a password, the system transforms that password and compares it with the stored value. In practice, the system usually performs a one-way transformation (not reversible) in which the password is used to generate a key for the one-way function and in which a fixed-length output is produced.

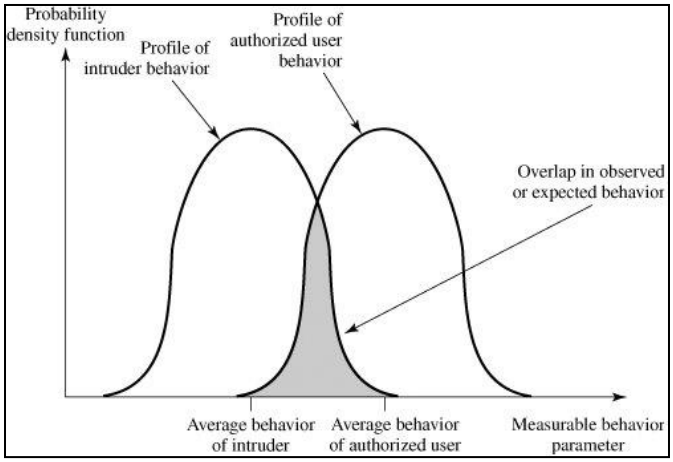
Access control: Access to the password file is limited to one or a very few accounts. If one or both of these countermeasures are in place, some effort is needed for a potential intruder to learn passwords. On the basis of a survey of the literature and interviews with a number of password crackers, [ALVA90] reports the following techniques for learning passwords:

1. Try default passwords used with standard accounts that are shipped with the system. Many administrators do not bother to change these defaults.
2. Exhaustively try all short passwords (those of one to three characters).
3. Try words in the system's online dictionary or a list of likely passwords. Examples of the latter are readily available on hacker bulletin boards.
4. Collect information about users, such as their full names, the names of their spouse and children, pictures in their office, and books in their office that are related to hobbies.
5. Try users' phone numbers, Social Security numbers, and room numbers.
6. Try all legitimate license plate numbers for this state.
7. Use a Trojan horse (described in Section 18.2) to bypass restrictions on access.
8. Tap the line between a remote user and the host system.

A.1.1 Intrusion Detection

Inevitably, the best intrusion prevention system will fail. A system's second line of defense is intrusion detection, and this has been the focus of much research in recent years. This interest is motivated by a number of considerations, including the following:

1. If an intrusion is detected quickly enough, the intruder can be identified and ejected from the system before any damage is done or any data are compromised. Even if the detection is not sufficiently timely to preempt the intruder, the sooner that the intrusion is detected, the less the amount of damage and the more quickly that recovery can be achieved.
2. An effective intrusion detection system can serve as a deterrent, so acting to prevent intrusions.
3. Intrusion detection enables the collection of information about intrusion techniques that can be used to strengthen the intrusion prevention facility. Intrusion detection is based on the assumption that the behavior of the intruder differs from that of a legitimate user in ways that can be quantified. Of course, we cannot expect that there will be a crisp, exact distinction between an attack by an intruder and the normal of resources by an authorized user. Rather, we must expect that there will be some overlap.



Profiles of Behavior of Intruders and Authorized Users

Approaches to intrusion detection

1. Statistical anomaly detection: Involves the collection of data relating to the behavior of legitimate users over a period of time. Then statistical tests are applied to observed behavior to determine with a high level of confidence whether that behavior is not legitimate user behavior.

a. Threshold detection: This approach involves defining thresholds, independent of user, for the frequency of occurrence of various events.

Profile based: A profile of the activity of each user is developed and used to detect changes in the behavior of individual accounts.

2. Rule-based detection: Involves an attempt to define a set of rules that can be used to decide that a given behavior is that of an intruder.
a. Anomaly detection: Rules are developed to detect deviation from previous usage patterns.
b. Penetration identification: An expert system approach that searches for suspicious behavior.
In a nutshell, statistical approaches attempt to define normal, or expected, behavior, whereas rule based approaches attempt to define proper behavior.

B). Malicious Software

Key Points

● Malicious software is software that is intentionally included or inserted in a system for a harmful purpose.
● A virus is a piece of software that can "infect" other programs by modifying them; the modification includes a copy of the virus program, which can then go on to infect other programs.
● A worm is a program that can replicate itself and send copies from computer to computer across network connections. Upon arrival, the worm may be activated to replicate and propagate again. In addition to propagation, the worm usually performs some unwanted function.
● A denial of service (DoS) attack is an attempt to prevent legitimate users of a service from using that service.
● A distributed denial of service attack is launched from multiple coordinated sources.

Viruses and Related Threats

Perhaps the most sophisticated types of threats to computer systems are presented by programs that exploit vulnerabilities in computing systems. In this context, we are concerned with application programs as well as utility programs, such as editors and compilers. We begin this section with an overview of the spectrum of such software threats. The remainder of the section is devoted to viruses and worms.

Malicious Programs

The terminology in this area presents problems because of a lack of universal agreement on all of the terms and because some of the categories overlap.

Terminology of Malicious Programs

Name	Description
Virus	Attaches itself to a program and propagates copies of itself to other programs
Worm	Program that propagates copies of itself to other computers
Logic bomb	Triggers action when condition occurs
Trojan horse	Program that contains unexpected additional functionality
Backdoor (trapdoor)	Program modification that allows unauthorized access to functionality
Exploits	Code specific to a single vulnerability or set of vulnerabilities
Downloaders	Program that installs other items on a machine that is under attack. Usually, a downloader is sent in an e-mail.
Auto-rooter	Malicious hacker tools used to break into new machines remotely
Kit (virus generator)	Set of tools for generating new viruses automatically
Spammer	programs Used to send large volumes of unwanted e-mail
Flooders	Used to attack networked computer systems with a large volume of traffic to carry out a denial of service (DoS) attack
Keyloggers	Captures keystrokes on a compromised system
Rootkit	Set of hacker tools used after attacker has broken into a computer system and gained root-level access
Zombie	Program activated on an infected machine that is activated to launch attacks on other machines

Malicious software can be divided into two categories:

a) those that need a host program
b) those that are independent.

The former are essentially fragments of programs that cannot exist independently of some actual application program, utility, or system program. Viruses, logic bombs, and backdoors are examples. The latter are self-contained programs that can be scheduled and run by the operating system. Worms and zombie programs are examples.

Malicious programs

Backdoor

A backdoor, also known as a trapdoor, is a secret entry point into a program that allows someone that is aware of the backdoor to gain access without going through the usual security access procedures.

Programmers have used backdoors legitimately for many years to debug and test programs. This usually is done when the programmer is developing an application that has an authentication procedure, or a long setup, requiring the user to enter many different values to run the application. To debug the program, the developer may wish to gain special privileges or to avoid all the necessary setup and authentication. The programmer may also want to ensure that there is a method of activating the program should something be wrong with the authentication procedure that is being built into the application. The backdoor is code that recognizes some special sequence of input or is triggered by being run from a certain user ID or by an unlikely sequence of events. Backdoors become threats when unscrupulous programmers use them to gain unauthorized access. The backdoor was the basic idea for the vulnerability portrayed in the movie ***War Games***.

Logic Bomb

One of the oldest types of program threat, predating viruses and worms, is the logic bomb. The logic bomb is code embedded in some legitimate program that is set to "explode" when certain conditions are met. Examples of conditions that can be used as triggers for a logic bomb are the presence or absence of certain files, a particular day of the week or date, or a particular user running the application. Once triggered, a bomb may alter or delete data or entire files, cause a machine halt, or do some other damage.

Trojan Horses

A Trojan horse is a useful, or apparently useful, program or command procedure containing hidden code that, when invoked, performs some unwanted or harmful function. Trojan horse programs can be used to accomplish functions indirectly that an unauthorized user could not accomplish directly. For example, to gain access to the files of another user on a shared system, a user could create a Trojan horse program that, when executed, changed the invoking user's file permissions so that the files are readable by any user. The author could then induce users to run the program by placing it in a common directory and naming it such that it appears to be a useful utility.

Zombie

A zombie is a program that secretly takes over another Internet-attached computer and then uses that computer to launch attacks that are difficult to trace to the zombie's creator. Zombies are used in denial-of- service attacks, typically against targeted Web sites. The zombie is planted on hundreds of computers belonging to unsuspecting third parties, and then used to overwhelm the target Web site by launching an overwhelming onslaught of Internet traffic.

The Nature of Viruses

A virus is a piece of software that can "infect" other programs by modifying them; the modification includes a copy of the virus program, which can then go on to infect other programs.

Biological viruses are tiny scraps of genetic code DNA or RNAthat can take over the machinery of a living cell and trick it into making thousands of flawless replicas of the original virus. Like its biological counterpart, a computer virus carries in its instructional code the recipe for making perfect copies of itself. The typical virus becomes embedded in a program on a computer. Then, whenever the infected computer comes into contact with an uninfected piece of software, a fresh copy of the virus passes into the new program. Thus, the infection can be spread from computer to computer by unsuspecting users who either swap disks or send programs to one another over a network. In a network environment, the ability to access applications and system services on other computers provides a perfect culture for the spread of a virus.

A virus can do anything that other programs do. The only difference is that it attaches itself to another program and executes secretly when the host program is run. Once a virus is executing, it can perform any function, such as erasing files and programs.

During its lifetime, a typical virus goes through the following four phases:

● **Dormant phase:** The virus is idle. The virus will eventually be activated by some event, such as a date, the presence of another program or file, or the capacity of the disk exceeding some limit. Not all viruses have this stage.

● **Propagation phase:** The virus places an identical copy of itself into other programs or into certain system areas on the disk. Each infected program will now contain a clone of the virus, which will itself enter a propagation phase.

● **Triggering phase:** The virus is activated to perform the function for which it was intended. As with the dormant phase, the triggering phase can be caused by a variety of system events, including a count of the number of times that this copy of the virus has made copies of itself.

● **Execution phase:** The function is performed. The function may be harmless, such as a message on the screen, or damaging, such as the destruction of programs and data files.

Types of Viruses

There has been a continuous arms race between virus writers and writers of antivirus software since viruses first appeared. As effective countermeasures have been developed for existing types of viruses, new types have been developed. [STEP93] suggests the following categories as being among the most significant types of viruses:

● **Parasitic virus:** The traditional and still most common form of virus. A parasitic virus attaches itself to executable files and replicates, when the infected program is executed, by finding other executable files to infect.

● **Memory-resident virus:** Lodges in main memory as part of a resident system program. From that point on, the virus infects every program that executes.

● **Boot sector virus:** Infects a master boot record or boot record and spreads when a system is booted from the disk containing the virus.

● **Stealth virus:** A form of virus explicitly designed to hide itself from detection by antivirus software.

● **Polymorphic virus:** A virus that mutates with every infection, making detection by the "signature" of the virus impossible.

● **Metamorphic virus:** As with a polymorphic virus, a metamorphic virus mutates with every infection. The difference is that a metamorphic virus rewrites itself completely at each iteration, increasing the difficulty of detection. Metamorphic viruses my change their behavior as well as their appearance.

One example of a **stealth virus**: a virus that uses compression so that the infected program is exactly the same length as an uninfected version. Far more sophisticated techniques are possible. For example, a virus can place intercept logic in disk I/O routines, so that when there is an attempt to read suspected portions of the disk using these routines, the virus will present back the original, uninfected program. Thus, *stealth* is not a term that applies to a virus as such but, rather, is a technique used by a virus to evade detection.

A **polymorphic virus** creates copies during replication that are functionally equivalent but have distinctly different bit patterns. As with a stealth virus, the purpose is to defeat programs that scan for viruses. In this case, the "signature" of the virus will vary with each copy. To achieve this variation, the virus may randomly insert superfluous instructions or interchange the order of independent instructions.

A more effective approach is to use encryption. A portion of the virus, generally called a *mutation engine*, creates a random encryption key to encrypt the remainder of the virus. The key is stored with the virus, and the mutation engine itself is altered. When an infected program is invoked, the virus uses the stored random key to decrypt the virus. When the virus replicates, a different random key is selected. Another weapon in the virus writers' armory is the virus-creation toolkit. Such a toolkit enables a relative novice to create quickly a number of different viruses. Although viruses created with toolkits tend to be less sophisticated than viruses designed from scratch, the sheer number of new viruses that can be generated creates a problem for antivirus schemes.

Macro Viruses

In the mid-1990s, macro viruses became by far the most prevalent type of virus. Macro viruses are particularly threatening for a number of reasons:

1. A macro virus is platform independent. Virtually all of the macro viruses infect Microsoft Word documents. Any hardware platform and operating system that supports Word can be infected.
2. Macro viruses infect documents, not executable portions of code. Most of the information introduced onto a computer system is in the form of a document rather than a program.
3. Macro viruses are easily spread. A very common method is by electronic mail.
Macro viruses take advantage of a feature found in Word and other office applications such as Microsoft Excel, namely the macro. In essence, a macro is an executable program embedded in a word processing document or other type of file. Typically, users employ macros to automate repetitive tasks and thereby save keystrokes. The macro language is usually some form of the Basic programming language. A user might define a sequence of keystrokes in a macro and set it up so that the macro is invoked when a function key or special short combination of keys is input. Successive releases of Word provide increased protection against macro viruses. For example, Microsoft offers an optional Macro Virus Protection tool that detects suspicious Word files and alerts the customer
to the potential risk of opening a file with macros. Various antivirus product vendors have also developed tools to detect and correct macro viruses. As in other types of viruses, the arms race continues in the field of macro viruses, but they no longer are the predominant virus threat.

E-mail Viruses

A more recent development in malicious software is the e-mail virus. The first rapidly spreading e-mail viruses, such as Melissa, made use of a Microsoft Word macro embedded in an attachment. If the recipient opens the e-mail attachment, the Word macro is activated. Then
1. The e-mail virus sends itself to everyone on the mailing list in the user's e-mail package.
2. The virus does local damage.
Thevirus uses the Visual Basic scripting language supported by the e-mail package.
Thus we see a new generation of malware that arrives via e-mail and uses e-mail software features to replicate itself across the Internet. The virus propagates itself as soon as activated (either by opening an e-mail attachment of by opening the e-mail) to all of the e-mail addresses known to the infected host. As a result, whereas viruses used to take months or years to propagate, they now do so in hours. This
makes it very difficult for antivirus software to respond before much damage is done. Ultimately, a greater degree of security must be built into Internet utility and application software on PCs to counter the growing threat.

Worms

A worm is a program that can replicate itself and send copies from computer to computer across network connections. Upon arrival, the worm may be activated to replicate and propagate again. In addition to propagation, the worm usually performs some unwanted function. An e-mail virus has some of the characteristics of a worm, because it propagates itself from system to system. However, we can
still classify it as a virus because it requires a human to move it forward. A worm actively seeks out more machines to infect and each machine that is infected serves as an automated launching pad for attacks on other machines. Network worm programs use network connections to spread from system to system. Once active within a system, a network worm can behave as a computer virus or bacteria, or it could implant Trojan horse programs or perform any number of disruptive or destructive actions. To replicate itself, a network worm uses some sort of network vehicle. Examples include the following:
● **Electronic mail facility:** A worm mails a copy of itself to other systems.
● **Remote execution capability:** A worm executes a copy of itself on another system.
● **Remote login capability:** A worm logs onto a remote system as a user and then uses commands to copy itself from one system to the other.
A network worm exhibits the same characteristics as a computer virus:

- a dormant phase,
- a propagation phase,
- a triggering phase,
- an execution phase.

The propagation phase generally performs the following functions:

1. Search for other systems to infect by examining host tables or similar repositories of remote system addresses.

2. Establish a connection with a remote system.
3. Copy itself to the remote system and cause the copy to be run.

State of Worm Technology

The state of the art in worm technology includes the following:

● **Multiplatform:** Newer worms are not limited to Windows machines but can attack a variety of platforms, especially the popular varieties of UNIX.
● **Multiexploit:** New worms penetrate systems in a variety of ways, using exploits against Web servers, browsers, e-mail, file sharing, and other network-based applications.
● **Ultrafast spreading:** One technique to accelerate the spread of a worm is to conduct a prior Internet scan to accumulate Internet addresses of vulnerable machines.
● **Polymorphic:** To evade detection, skip past filters, and foil real-time analysis, worms adopt the virus polymorphic technique. Each copy of the worm has new code generated on the fly using functionally equivalent instructions and encryption techniques.
● **Metamorphic:** In addition to changing their appearance, metamorphic worms have a repertoire of behavior patterns that are unleashed at different stages of propagation.
● **Transport vehicles:** Because worms can rapidly compromise a large number of systems, they are ideal for spreading other distributed attack tools, such as distributed denial of service zombies.
● **Zero-day exploit:** To achieve maximum surprise and distribution, a worm should exploit an unknown vulnerability that is only discovered by the general network community when the worm is launched.

Virus Countermeasures

a) Antivirus Approaches

The ideal solution to the threat of viruses is prevention: Do not allow a virus to get into the system in the first place. This goal is, in general, impossible to achieve, although prevention can reduce the number of successful viral attacks. The next best approach is to be able to do the following:

● **Detection:** Once the infection has occurred, determine that it has occurred and locate the virus.
● **Identification:** Once detection has been achieved, identify the specific virus that has infected a program.
● **Removal:** Once the specific virus has been identified, remove all traces of the virus from the infected program and restore it to its original state. Remove the virus from all infected systems so that the disease cannot spread further.

b) Advanced Antivirus Techniques

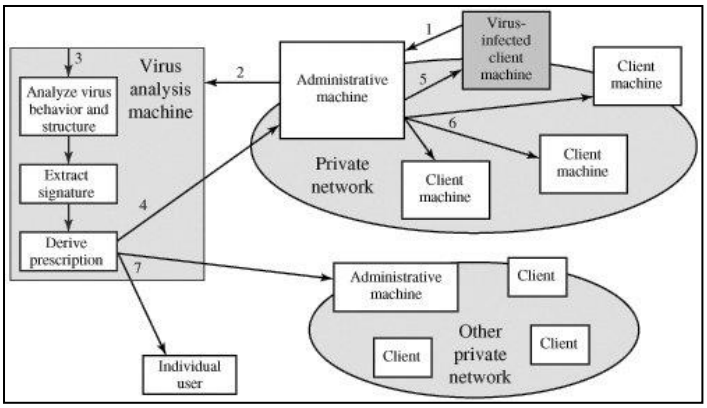
Generic Decryption

Generic decryption (GD) technology enables the antivirus program to easily detect even the most complex polymorphic viruses, while maintaining fast scanning speeds. Recall that when a file containing a polymorphic virus is executed, the virus must decrypt itself to activate. In order to detect such a structure, executable files are run through a GD scanner, which contains the following elements:

● **CPU emulator:** A software-based virtual computer. Instructions in an executable file are interpreted by the emulator rather than executed on the underlying processor. The emulator includes software versions of all registers and other processor hardware, so that the underlying processor is unaffected by programs interpreted on the emulator.
● **Virus signature scanner:** A module that scans the target code looking for known virus signatures.
● **Emulation control module:** Controls the execution of the target code.

c) Digital Immune System

The digital immune system is a comprehensive approach to virus protection developed by IBM. The motivation for this development has been the rising threat of Internet-based virus propagation.



Digital Immune System

The above figure illustrates the typical steps in digital immune system operation:

1. A monitoring program on each PC uses a variety of heuristics based on system behavior, suspicious changes to programs, or family signature to infer that a virus may be present. The monitoring program forwards a copy of any program thought to be infected to an administrative machine within the organization.
2. The administrative machine encrypts the sample and sends it to a central virus analysis machine.
3. This machine creates an environment in which the infected program can be safely run for analysis. Techniques used for this purpose include emulation, or the creation of a protected environment within which the suspect program can be executed and monitored. The virus analysis machine then produces a prescription for identifying and removing the virus.
4. The resulting prescription is sent back to the administrative machine.
5. The administrative machine forwards the prescription to the infected client.
6. The prescription is also forwarded to other clients in the organization.
7. Subscribers around the world receive regular antivirus updates that protect them from the new virus.

d) **Behavior-Blocking Software**

Unlike heuristics or fingerprint-based scanners, behavior-blocking software integrates with the operating system of a host computer and monitors program behavior in real-time for malicious actions. The behavior blocking software then blocks potentially malicious actions before they have a chance to affect the system. Monitored behaviors can include the following:

- Attempts to open, view, delete, and/or modify files;
- Attempts to format disk drives and other unrecoverable disk operations;
- Modifications to the logic of executable files or macros;
- Modification of critical system settings, such as start-up settings;
- Scripting of e-mail and instant messaging clients to send executable content; and
- Initiation of network communications.

C. Firewalls

Firewalls can be an effective means of protecting a local system or network of systems from network based security threats while at the same time affording access to the outside world via wide area networks and the Internet.

Key Points

- A firewall forms a barrier through which the traffic going in each direction must pass. A firewall security policy dictates which traffic is authorized to pass in each direction.
- A firewall may be designed to operate as a filter at the level of IP packets, or may operate at a higher protocol layer.

● A trusted system is a computer and operating system that can be verified to implement a given security policy. Typically, the focus of a trusted system is access control. A policy is implemented that dictates what objects may be accessed by what subjects.
● The common criteria for information technology security is an international standards initiative to define a common set of security requirements and a systematic means of evaluating products against those requirements.

C.1 Firewall Design Principles

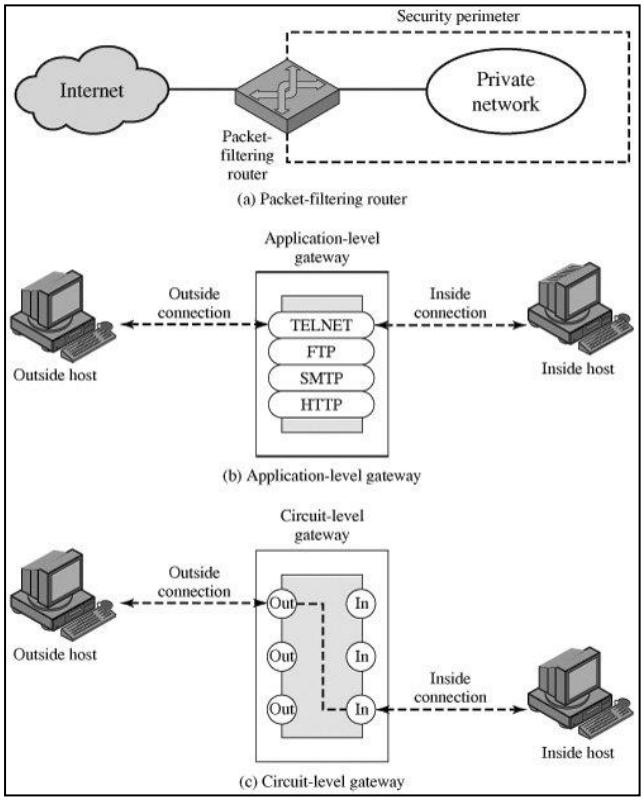
Information systems in corporations, government agencies, and other organizations have undergone a steady evolution:
● Centralized data processing system, with a central mainframe supporting a number of directly connected terminals
● Local area networks (LANs) interconnecting PCs and terminals to each other and the mainframe
● Premises network, consisting of a number of LANs, interconnecting PCs, servers, and perhaps a mainframe or two Enterprise-wide network, consisting of multiple, geographically distributed premises networks interconnected by a private wide area network (WAN)
● Internet connectivity, in which the various premises networks all hook into the Internet and may or may not also be connected by a private WAN.

C.2 Firewall Characteristics

1. All traffic from inside to outside, and vice versa, must pass through the firewall. This is achieved by physically blocking all access to the local network except via the firewall.
2. Only authorized traffic, as defined by the local security policy, will be allowed to pass. Various types of firewalls are used, which implement various types of security policies.
3. The firewall itself is immune to penetration. This implies that use of a trusted system with a secure operating system.

C.3 Types of Firewalls

There are three common types of firewalls:
a) packet filters,
b) application-level gateways,
c) circuit-level gateways.



Firewall and its types

a) Packet-Filtering Router

A packet-filtering router applies a set of rules to each incoming and outgoing IP packet and then forwards or discards the packet. The router is typically configured to filter packets going in both directions (from and to the internal network). Filtering rules are based on information contained in a network packet:

- **Source IP address:** The IP address of the system that originated the IP packet

Destination IP address: The IP address of the system the IP packet is trying to reach

Source and destination transport-level address: The transport level (e.g., TCP or UDP) port number, which defines applications such as SNMP or TELNET

IP protocol field: Defines the transport protocol

- **Interface:** For a router with three or more ports, which interface of the router the packet came from or which interface of the router the packet is destined for

b) Application-Level Gateway

An application-level gateway, also called a proxy server, acts as a relay of application-level traffic The user contacts the gateway using a TCP/IP application, such as Telnet or FTP, and the gateway asks the user for the name of the remote host to be accessed. When the user responds and provides a valid user ID and authentication information, the gateway contacts the application on the remote host and relays TCP segments containing the application data between the two endpoints. If the gateway does not implement the proxy code for a specific application, the service is not supported and cannot be forwarded across the firewall. Further, the gateway can be configured to support only specific features of an application that the network administrator considers acceptable while denying all other features. Application-level gateways tend to be more secure than packet filters. Rather than trying to deal with the numerous possible combinations that are to be allowed and forbidden at the TCP and IP level, the application-level gateway need only scrutinize a few allowable applications. In addition, it is easy to log and audit all incoming traffic at the application level.

A prime **disadvantage** of this type of gateway is the additional processing overhead on each connection. In effect, there are two spliced connections between the end users, with the gateway at the splice point, and the gateway must examine and forward all traffic in both directions.

c) Circuit-Level Gateway

third type of firewall is the circuit-level gateway (Figure 20.1c). This can be a stand-alone system or it can be a specialized function performed by an application-level gateway for certain applications. A circuit-level gateway does not permit an end-to-end TCP connection; rather, the gateway sets up two TCP connections, one between itself and a TCP user on an inner host and one between itself and a TCP user on an outside host. Once the two connections are established, the gateway typically relays TCP segments from one connection to the other without examining the contents. The security function consists of determining which connections will be allowed. A typical use of circuit-level gateways is a situation in which the system administrator trusts the internal users. The gateway can be configured to support application-level or proxy service on inbound connections and circuit-level functions for outbound connections. In this configuration, the gateway can incur the processing overhead of examining incoming application data for forbidden functions but does not incur that overhead on outgoing data.

C.4 Techniques to Control Access and Enforce Site's Security

There are four general techniques that firewalls use to control access and enforce the site's security policy. Originally, firewalls focused primarily on service control, but they have since evolved to provide all four:

- **Service control:** Determines the types of Internet services that can be accessed, inbound or outbound. The firewall may filter traffic on the basis of IP address and TCP port number; may provide proxy software that receives and interprets each service request before passing it on; or may host the server software itself, such as a Web or mail service.

Direction control: Determines the direction in which particular service requests may be initiated and allowed to flow through the firewall.

- **User control:** Controls access to a service according to which user is attempting to access it. This feature is typically applied to users inside the firewall perimeter (local users). It may also be applied to incoming traffic from external users; the latter requires some form of secure authentication technology.

● **Behavior control:** Controls how particular services are used. For example, the firewall may filter e-mail to eliminate spam, or it may enable external access to only a portion of the information on a local Web server.

C.5 Capabilities of Firewall

The following capabilities are within the scope of a firewall:

1. A firewall defines a single choke point that keeps unauthorized users out of the protected network, prohibits potentially vulnerable services from entering or leaving the network, and provides protection from various kinds of IP spoofing and routing attacks. The use of a single choke point simplifies security management because security capabilities are consolidated on a single system or set of systems.

2. A firewall provides a location for monitoring security-related events. Audits and alarms can be implemented on the firewall system.

3. A firewall is a convenient platform for several Internet functions that are not security related. These include a network address translator, which maps local addresses to Internet addresses and a network management function that audits or logs Internet usage.

4. A firewall can serve as the platform for IPSec. Using the tunnel mode capability, the firewall can be used to implement virtual private networks.

C.6 Limitations of Firewall

Firewalls have their limitations, including the following:

1. The firewall cannot protect against attacks that bypass the firewall. Internal systems may have dial-out capability to connect to an ISP. An internal LAN may support a modem pool that provides dial-in capability for traveling employees and telecommuters.

2. The firewall does not protect against internal threats, such as a disgruntled employee or an employee who unwittingly cooperates with an external attacker.

3. The firewall cannot protect against the transfer of virus-infected programs or files. Because of the variety of operating systems and applications supported inside the perimeter, it would be impractical and perhaps impossible for the firewall to scan all incoming files, e-mail, and messages for viruses.