CRYPTOGRAPHY
CONCEPTS

INTRODUCTION

Cryptography is technique of securing information and communications through use of codes so that only those person for whom the information is intended can understand it and process it. Thus preventing unauthorized access to information. The prefix "crypt" means "hidden" and suffix graphy means "writing".One is confidentiality which basically means that we need to be sure that nobody will see our information as it travels across a network. Authentication and access control is also another capability provided by cryptography. Some other capabilities provided by cryptography are non-repudiation and integrity.

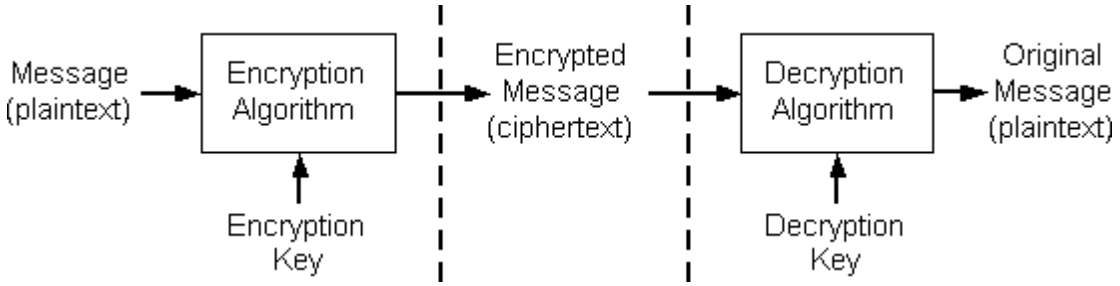
In Cryptography the techniques which are use to protect information are obtained from mathematical concepts and a set of rule based calculations known as algorithms to convert messages in ways that make it hard to decode it. These algorithms are used for cryptographic key generation, digital signing, verification to protect data privacy, web browsing on internet and to protect confidential transactions such as credit card and debit card transactions.

Basic Concepts

Cryptography The art or science encompassing the principles and methods of transforming anintelligible message into one that is unintelligible, and then retransforming that message back to itsoriginal form

Plaintext can refer to anything which humans can understand and/or relate to. This may be as simple as English sentences, a script, or Java code. If you can make sense of what is written, then it is in plaintext.

Ciphertext, or encrypted text, is a series of randomized letters and numbers which humans cannot make any sense of. An encryption algorithm takes in a plaintext message, runs the algorithm on the plaintext, and produces a ciphertext. The ciphertext can be reversed through the process of decryption, to produce the original plaintext.



Key Some critical information used by the cipher, known only to the sender& receiver.

The Basic Principles

1. Encryption

In a simplest form, encryption is to convert the data in some unreadable form. This helps in protecting the privacy while sending the data from sender to receiver. On the receiver side, the data can be decrypted and can be brought back to its original form. The reverse of encryption is called as decryption. The concept of encryption and decryption requires some extra information for encrypting and decrypting the data. This information is known as key. There may be cases when same key can be used for both encryption and decryption while in certain cases, encryption and decryption may require different keys.

2. Authentication

This is another important principle of cryptography. In a layman's term, authentication ensures that the message was originated from the originator claimed in the message. Suppose, Alice sends a message to Bob and now Bob wants proof that the message has been indeed sent by Alice. This can be made possible if Alice performs some action on message that Bob knows only Alice can do. Well, this forms the basic fundamental of Authentication.

3. Integrity

Now, one problem that a communication system can face is the loss of integrity of messages being sent from sender to receiver. This means that Cryptography should ensure that the messages that are received by the receiver are not altered anywhere on the communication path. This can be achieved by using the concept of cryptographic hash.

4. Non Repudiation

What happens if Alice sends a message to Bob but denies that she has actually sent the message? Cases like these may happen and cryptography should prevent the originator or sender to act this way. One popular way to achieve this is through the use of digital signatures.

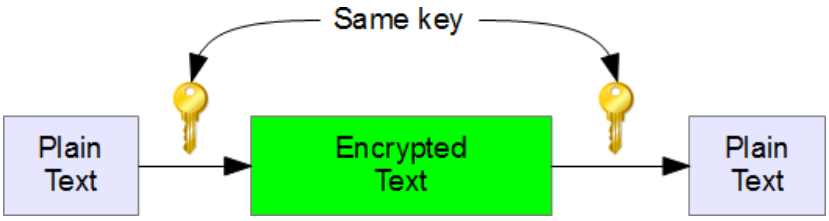
Types of Cryptography

There are three types of cryptography techniques :

1. Secret key Cryptography
2. Public key cryptography
3. Hash Functions

1. Secret Key Cryptography

This type of cryptography technique uses just a single key. The sender applies a key to encrypt a message while the receiver applies the same key to decrypt the message. Since only single key is used so we say that this is a symmetric encryption.



The biggest problem with this technique is the distribution of key as this algorithm makes use of single key for encryption or decryption.

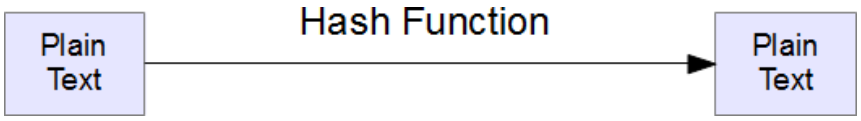
2. Public Key Cryptography

This type of cryptography technique involves two key crypto system in which a secure communication can take place between receiver and sender over insecure communication channel. Since a pair of keys is applied here so this technique is also known as asymmetric encryption.

In this method, each party has a private key and a public key. The private is secret and is not revealed while the public key is shared with all those whom you want to communicate with. If Alice wants to send a message to bob, then Alice will encrypt it with Bob's public key and Bob can decrypt the message with its private key.

This is what we use when we setup public key authentication in openssh to login from one server to another server in the backend without having to enter the password.

3. Hash Functions



This technique does not involve any key. Rather it uses a fixed length hash value that is computed on the basis of the plain text message. Hash functions are used to check the integrity of the message to ensure that the message has not be altered,compromised or affected by virus.

So we see that how different types of cryptography techniques (described above) are used to implement the basic principles that we discussed earlier. In the future article of this series, we'll cover more advanced topics on Cryptography.

THE NEED FOR SECURITY

Most initial computer applications had no or at best, very little security.

The need for security:

1. **Protecting the functionality of the organization:**

   The decision maker in organizations must set policy and operates their organization in compliance with the complex, shifting legislation, efficient and capable applications.

2. **Enabling the safe operation of applications:**

   The organization is under immense pressure to acquire and operates integrated, efficient and capable applications. The modern organization needs to create an environment that safeguards application using the organizations IT systems, particularly those application that serves as important elements of the infrastructure of the organization.

3. **Protecting the data that the organization collect and use:**

   Data in the organization can be in two forms are either in rest or in motion, the motion of data signifies that data is currently used or processed by the system. The values of the data motivated the attackers to steal or corrupts the data. This is essential for the integrity and the values of the organization's data. Information security ensures the protection of both data in motion as well as data in rest.

4. **Safeguarding technology assets in organizations:**

   The organization must add intrastate services based on the size and scope of the organization. Organizational growth could lead to the need for public key infrastructure, PKI an integrated system of the software, encryption methodologies. The information security mechanism used by large organizations is complex in comparison to a small organization. The small organization generally prefers symmetric key encryption of data.

SECURITY APPROACHES

1. **Trusted Systems:**

A trusted system is a computer system that can be trusted to a specified extent to enforce aspecified security policy.

Trusted systems were initially of primary interest to the military. However, these days, the concept hasspanned across various areas, most prominently in the banking and financial community, but the conceptnever caught on. Trusted systems often use the term reference monitor.

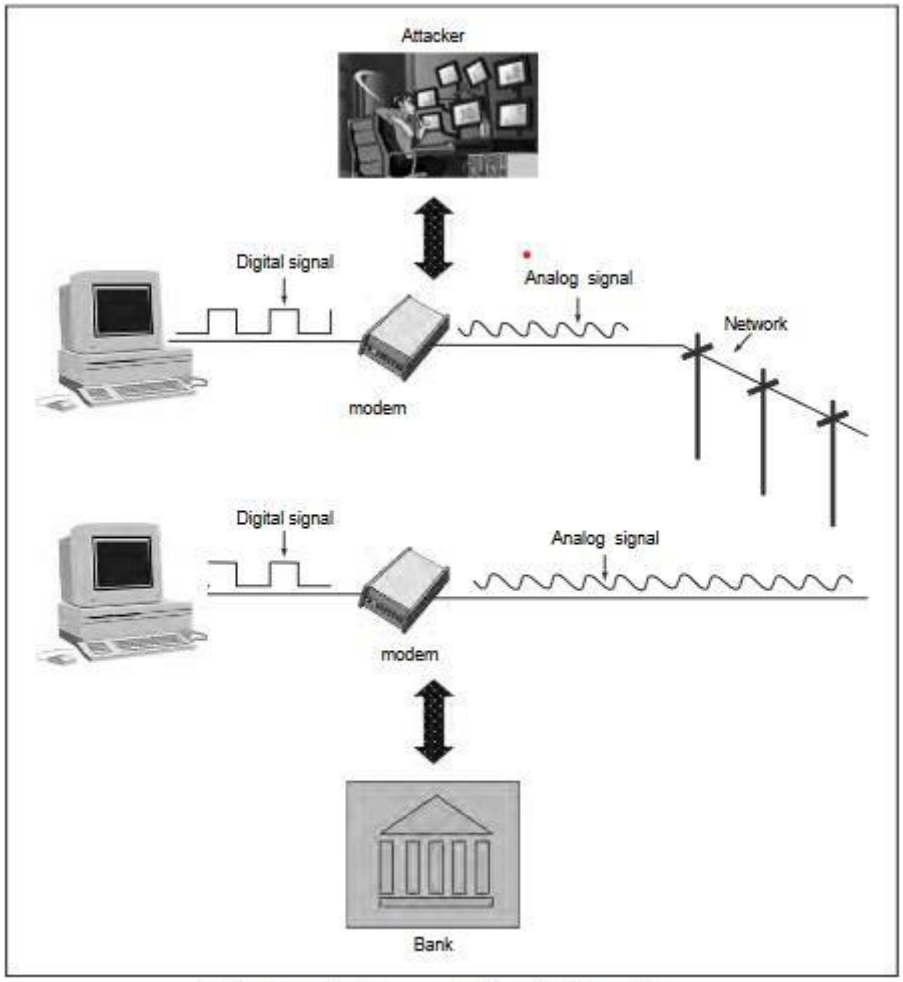


Fig. 1.3 *Attacks can now be launched from a distance*

It is mainly responsible for all the decisions related to access controls. Naturally, following are the expectations from the reference monitor:

(a) It should be tamperproof

(b) It should always be invoked

(c) It should be small enough so that it can be independently tested

2. Security Models

An organization can take several approaches to implement its security model. Let us summarize theseapproaches.

- **No security**In this simplest case, the approach could be a decision to implement no security at all.
- **Security through obscurity**In this model, a system is secure simply because nobody knows about its existence and contents. This approach cannot work for too long, as there are many ways an attackercan come to know about it.

- **Host security**In this scheme, the security for each host is enforced individually. This is a very safe approach, but the trouble is that it cannot scale well. The complexity and diversity of modern sites/organizations makes the task even harder.
- **Network security** Host security is tough to achieve as organizations grow and become more diverse. In this technique, the focus is to control network access to various hosts and their services, ratherthan individual host security. This is a very efficient and scalable model

3. Security Management Practices

Good security management practices always talk of a security policy being in place. Putting a securitypolicy in place is actually quite tough.

A good security policy generally takes careoffour key aspects, as follows:

- Affordability Cost and effort in security implementation.
- Functionality Mechanism of providing security.
- Cultural issues Whether the policy gels well with people's expectations, working style and beliefs.
- Legality Whether the policy meets the legal requirements.

Once a security policy is in place, the following points should be ensured.

(a) Explanation of the policy to all concerned.
(b) Outline everybody's responsibilities.
(c) Use simple language in all communications.
(d) Establishment of accountability.
(e) Provision for exceptions and periodic reviews.

PRINCIPLES OF SECURITY

There are six principles

1. Confidentiality.
2. Authentication.
3. Integrity.
4. Non-repudiation.
5. Access control
6. Availability

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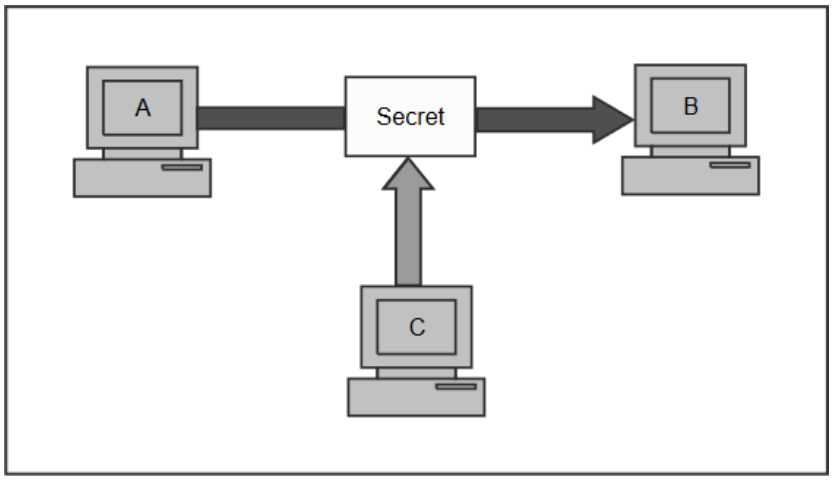
1. **Confidentiality**

The principle of confidentiality specifies that only the sender and the intended recipient(s) should be ableto access the contents of a message. Confidentiality gets compromised if an unauthorized person is ableto access a message. Example of compromising the confidentiality of a message is shown in Fig. Here, the user of computer A sends a message to user of computer B.



Loss of confidentiality

Another user C gets access to this message, which is not desired andtherefore, defeats the purpose of confidentiality. Example of this could be a confidential email messagesent by A to B, which is accessed by C without the permission or knowledge of A and B. This type ofattack is called as interception.

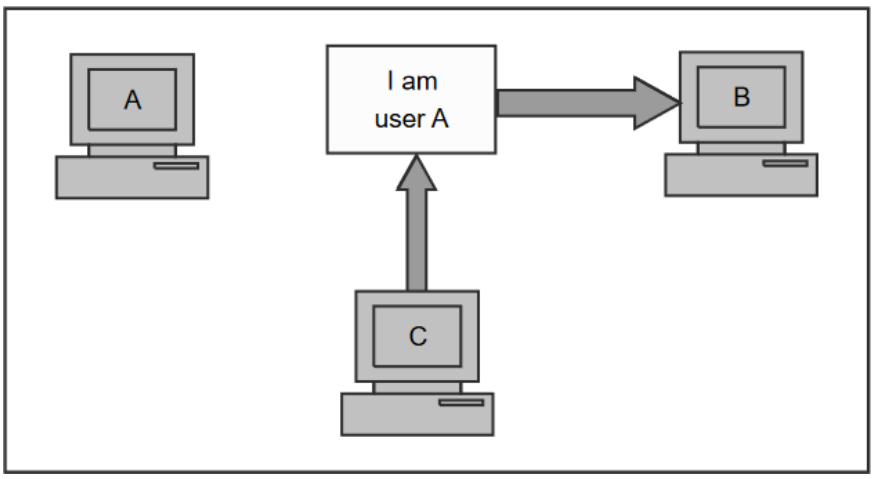
Interception causes loss of message confidentiality.

2. **Authentication**

Authentication mechanisms help establish proof of identities. The authentication process ensures thatthe origin of a electronic message or document is correctly identified.

suppose that user Csends an electronic document over the Internet to user B. However, the trouble is that user C had posedas user A when she sent this document to user B.

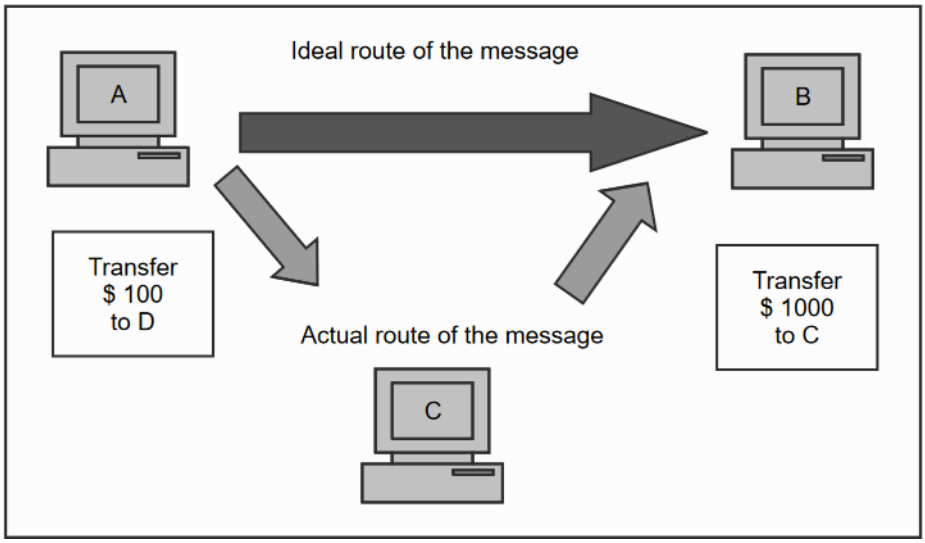
A real life example of this could be the case of a user C, posing asuser A, sending a funds transfer request (from A's account to C's account) to bank B. The bank mighthappily transfer the funds from A's account to C's account – after all, it would think that user A hasrequested for the funds transfer! This concept is shown in Fig.



Absence of authentication

3. Integrity

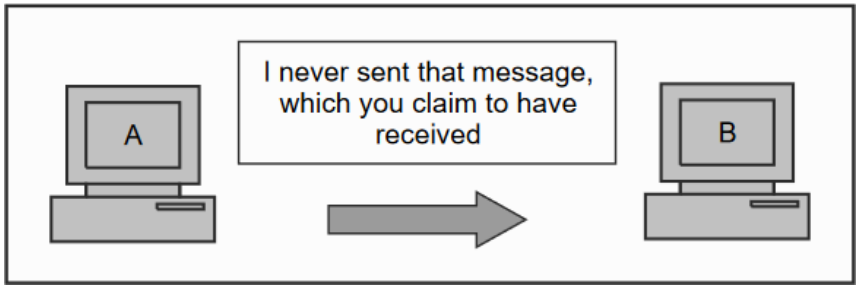
When the contents of a message are changed after the sender sends it, but before it reaches the intendedrecipient, we say that the integrity of the message is lost. For example, suppose you write a check forRs. 100 to pay for the goods bought from the US. However, when you see your next account statement, youare startled to see that the check resulted in a payment of Rs. 1000. This is the case for loss of messageintegrity. Conceptually, this is shown in Fig.



Loss of integrity

4. Non-repudiation

There are situations where a user sends a message and later on refuses that she had sent that message. Forinstance, user A could send a funds transfer request to bank B over the Internet. After the bank performsthe funds transfer as per A's instructions, A could claim that she never sent the funds transfer instructionto the bank! Thus, A repudiates or denies, her funds transfer instruction. The principle of non-repudiation defeats such possibilities of denying something, having done it. This is shown in Fig.



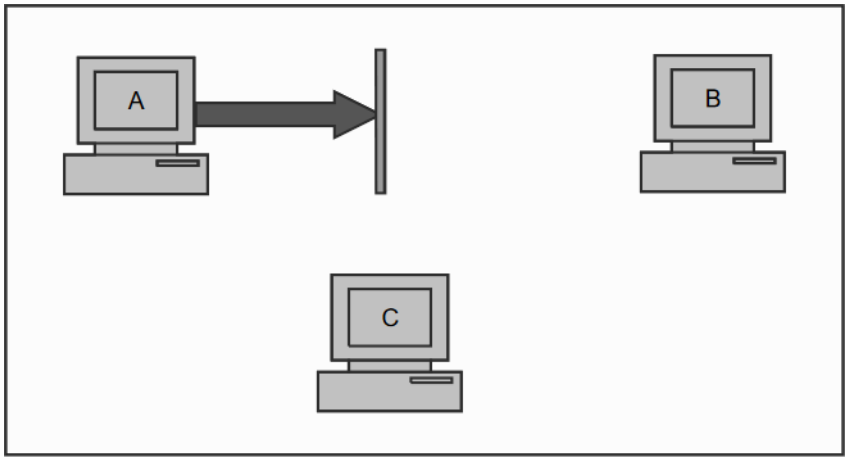
Establishing the non-repudiation

5. **Access Control**

The principle of access control determines who should be able to access what. For instance, we shouldbe able to specify that user A can view the records in a database, but cannot update them. However, userB might be allowed to make updates as well. An access control mechanism can be set up to ensure this.Access control is broadly related to two areas: role management and rule management. Rolemanagement concentrates on the user side (which user can do what), whereas rule management focuseson the resources side (which resource is accessible and under what circumstances).

6. **Availability**

The principle of availability states that resources (i.e. information) should be available to authorizedparties at all times. For example, due to the intentional actions of an unauthorized user C, an authorizeduser A may not be able to contact a server computer B, as shown in Fig.



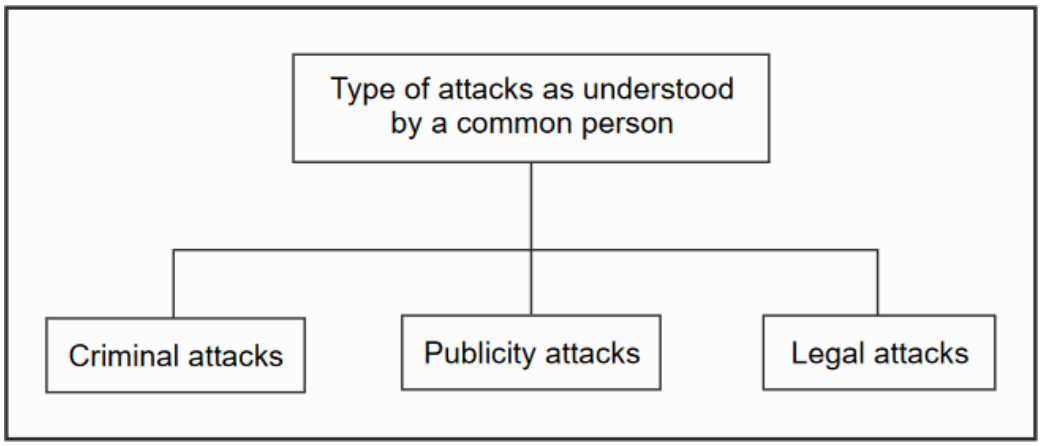
Attack on availability

TYPES OF SECURITY ATTACKS

We shall classify attacks with respect to two views: the common **person's view** and a **technologist's view**.

1. **General Attacks:**

   A General ViewFrom a common person's point of view, we can classify attacks into three categories, as shown inFig.



Classification of attacks in general terms

Criminal Attacks Criminal attacks are the simplest to understand. Here, the sole aim of the attackersis to maximize financial gain by attacking computer systems. The **following table gives** some of the criminal attacks.

Publicity Attacks Publicity attacks occur because the attackers want to see their names appear ontelevision news channels and newspapers. History suggests that these types of attackers are usually nothardcore criminals. They are people such as students in universities or employees in large organizations,
who seek publicity by adopting a novel approach of attacking computer systems.

Legal Attacks This form of attack is quite novel and unique. Here, the attacker tries to make the judgeor the jury doubtful about the security of a computer system. This works as follows. The attacker attacksthe computer system and the attacked party (say a bank or an organization) manages to take the attacker
to the court.

Attack	*Description*
Fraud	Modern fraud attacks concentrate on manipulating some aspects of electronic currency, credit cards, electronic stock certificates, checks, letters of credit, purchase orders, ATMs, etc.
Scams	Scams come in various forms, some of the most common ones being sale of services, auctions, multi-level marketing schemes, general merchandise and business opportunities, etc. People are enticed to send money in return of great profits, but end up losing their money. A very common example is the *Nigeria scam*, where an email from Nigeria (and other African countries) entices people to deposit money into a bank account with a promise of hefty gains. Whosoever gets caught in this scam loses money heavily.
Destruction	Some sort of grudge is the motive behind such attacks. For example, unhappy employees attack their own organization, whereas terrorists strike at much bigger levels. For example, in the year 2000, there was an attack against popular Internet sites such as Yahoo!, CNN, eBay, Buy.com, Amazon.com and e*Trade where authorized users of these sites failed to log in or access these sites.
Identity theft	This is best understood with a quote from Bruce Schneier: *Why steal from someone when you can just become that person?* In other words, an attacker does not steal anything from a legitimate user – he *becomes* that legitimate user! For example, it is much easier to manage to get the password of someone else's bank account or to actually be able to get a credit card on someone else's name. Then that privilege can be misused until it gets detected.
Intellectual property theft	Intellectual property theft ranges from stealing companies' trade secrets, databases, digital music and videos, electronic documents and books, software and so on.
Brand theft	It is quite easy to set up fake Web sites that look like real Web sites. How would a common user know if she is visiting the HDFC Bank site or an attacker's site? Innocent users end up providing their secrets and personal details on these fake sites to the attackers. The attackers use these details to then access the real site, causing an *identity theft*.

2. ATTACKS: A TECHNICAL VIEW

From the technical point of view, we can classify the types of attacks on computers and network systemsinto two categories for better understanding: (a) Theoretical concepts behind these attacks.

(b)Practical approaches used by the attackers.

(a) Theoretical Concepts

These attacks are generally classified into four categories.

- **Interception** –It means that an unauthorizedparty has gained access to a resource. The party can be a person, program or computer-basedsystem. Examples of interception are copying of data or programs and listening to network traffic.
- **Fabrication** –This involves creation of illegalobjects on a computer system. For example, the attacker may add fake records to a database.
    - **Modification** –For example the attacker may modifythe values in a database.

- **Interruption** – Here, the resource becomesunavailable, lost or unusable. Examples of interruption are causing problems to a hardware device,erasing program, data or operating system components.

These attacks are further grouped into twotypes:

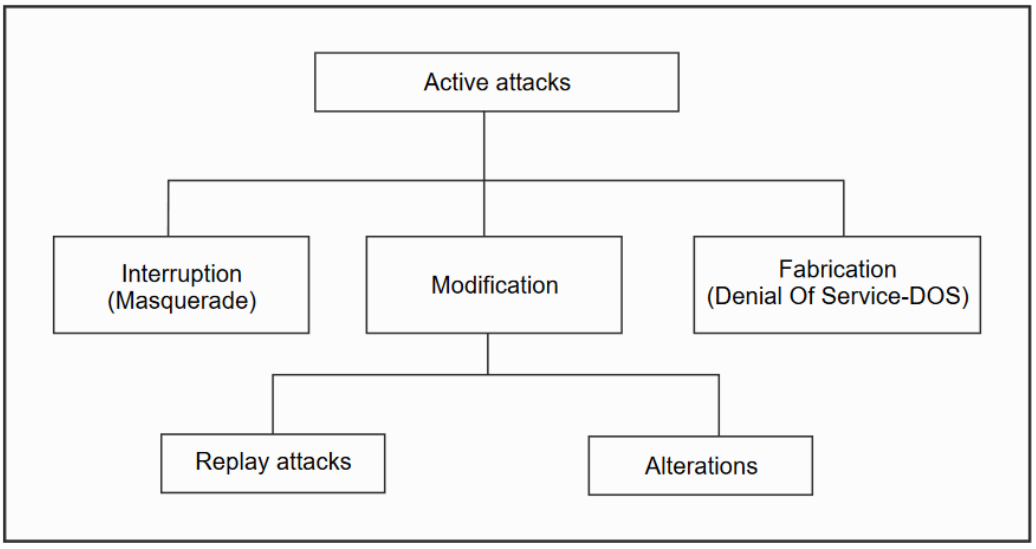
- Passive attacks.
- Active attacks.

Passive attacks: Passive attacks are those,wherein the attacker indulges in eavesdropping ormonitoring of data transmission. In other words,the attacker aims to obtain information that is intransit. The term passive indicates that the attackerdoes not attempt to perform any modifications tothe data.

Passive attacks do not involve any modifications to the contents of an original message.

Active attacks Unlike passive attacks, the active attacks are based on modification of the originalmessage in some manner or the creation of a false message. These attacks cannot be prevented easily.However, they can be detected with some effort and attempts can be made to recover from them. Theseattacks can be in the form of interruption, modification and fabrication.

In active attacks, the contents of the original message are modified in some way.



Active attacks

Masquerade is caused when an unauthorized entity pretends to be another entity.

Replay attack, a user captures a sequence of events or some data units and re-sends them.

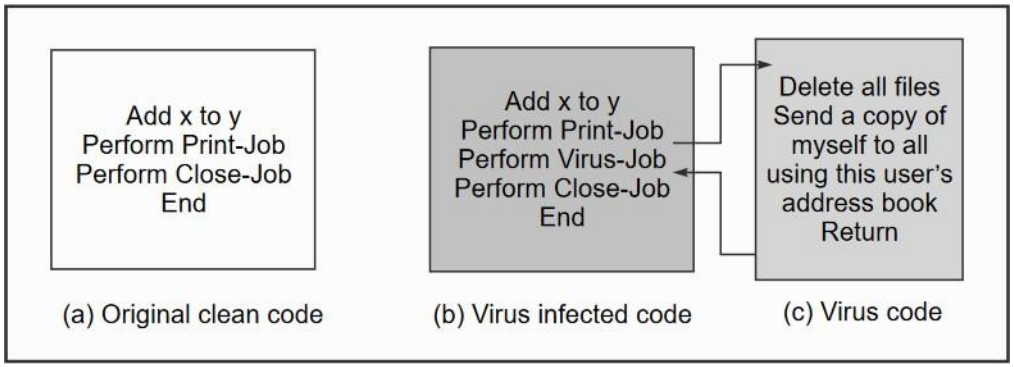
Alteration of messages involves some change to the original message. For instance, suppose user Asends an electronic message Transfer $1000 to D's account to bank B. User C might capture this andchange it to Transfer $10000 to C's account.

Denial Of Service (DOS) attacks make an attempt to prevent legitimate users from accessing someservices, which they are eligible for. For instance, an unauthorized user might send too many loginrequests to a server using random user ids one after the other in quick succession, so as to flood thenetwork and deny other legitimate users from using the network facilities.

3. PROGRAMS THAT ATTACK

Let us now discuss a few programs that attack computer systems to cause some damage or to createconfusion.

Virus One can launch an application-level attack or a network level attack using a virus. In simpleterms, a ***virus*** *is a piece of program code that attaches itself to legitimate program code and runs whenthe legitimate program runs. It can then infect other programs in that computer or programs that are inother computers but on the same network.*



Virus

A virus is a computer program that attaches itself to another legitimate program and causes damageto the computer system or to the network.

During its lifetime, a virus goes through four phases:

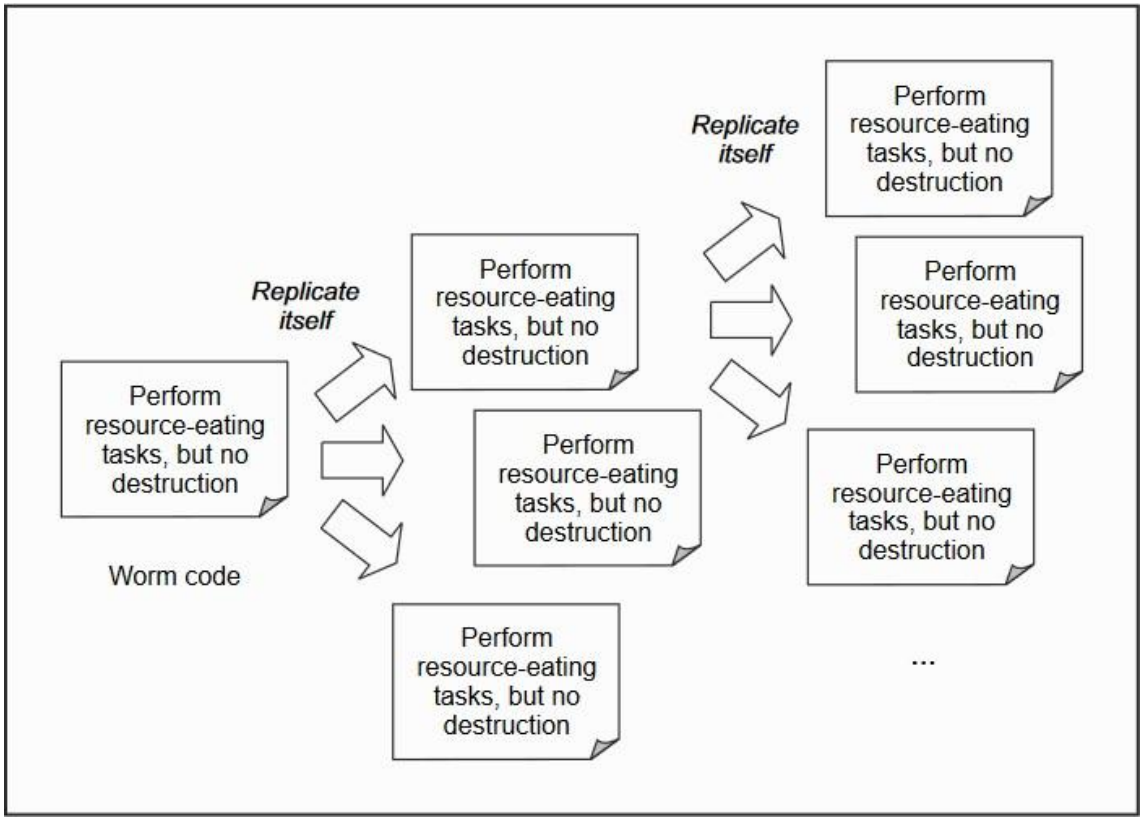
(a) **Dormant phase:** Here, the virus is idle. It gets activated based on certain action or event (e.g. theuser typing a certain key or certain date or time is reached, etc). This is an optional phase.

(b) **Propagation phase:** In this phase, a virus copies itself and each copy starts creating more copies ofself, thus propagating the virus.

(c) **Triggering phase:** A dormant virus moves into this phase when the action/event for which it waswaiting is initiated.

(d) **Execution phase:** This is the actual work of the virus, which could be harmless (display somemessage on the screen) or destructive (delete a file on the disk).

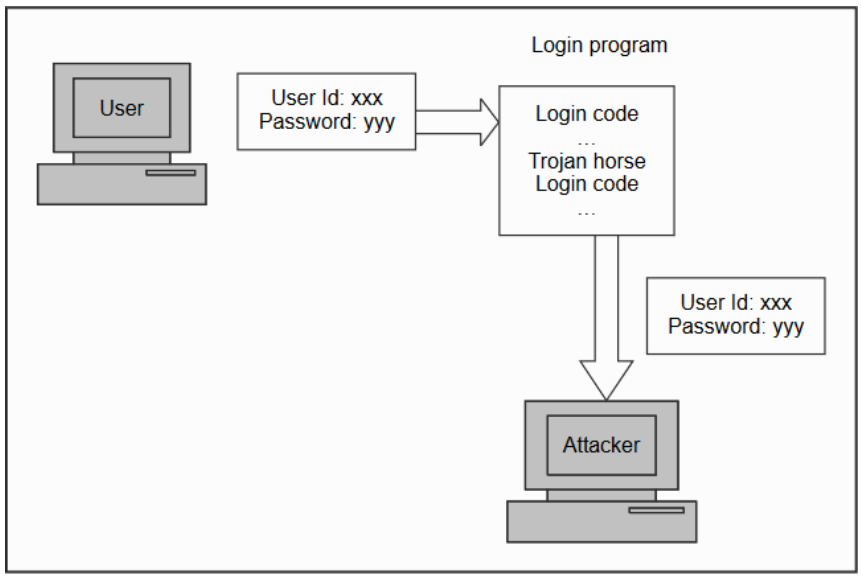
Worm Similar in concept to a virus, a worm is actually different in implementation. A virus modifiesa program (i.e. it attaches itself to the program under attack). A worm, however, does not modify aprogram. Instead, it replicates itself again and again.



Worm

Trojan HorseA Trojan horse is a hidden piece of code, like a virus. However, the purpose of aTrojan horse is different. Whereas the main purpose of a virus is to make some sort of modifications tothe target computer or network, a Trojan horse attempts to reveal confidential information to an attacker.

A Trojan horse allows an attacker to obtain some confidential information about a computeror a network.



Trojan horse

4. Specific Attacks

There are two specific attacks.

1. Sniffing
2. Spoofing

On the Internet, computers exchange messages with each other in the form of small blocks of data, called as packets. A packet, like a postal envelope contains the actual data to besent and the addressing information. Attackers target these packets, as they travel from the sourcecomputer to the destination computer over the Internet.

These attacks take two main forms:

(a) Packetsniffing

(b) Packet spoofing

(a) Packet sniffing: Packet sniffing is a passive attack on an on-going conversation. An attacker neednot hijack a conversation, but instead, can simply observe (i.e. sniff) packets as they pass by.

Clearly, to prevent an attacker from sniffing packets, the information that is passing needs to beprotected in some ways.

This can be done at two levels:

(i) The data that is traveling can be encoded in some ways

(ii) The transmission link itself can be encoded.

To read a packet, theattacker somehow needs to access it in the first place.

(B) Packet spoofing: In this technique, an attacker sends packets with a false source address. Whenthis happens, the receiver (i.e. the party who receives these packets containing false address)would inadvertently send replies back to this forged address (called as spoofed address) and not tothe attacker.

This can lead to three possible cases:

(i) The attacker can intercept the reply – If the attacker is between the destination and theforged source, the attacker can see the reply and use that information for hijacking attacks.

(ii) The attacker need not see the reply – If the attacker's intention was a Denial Of Service(DOS) attack, the attacker need not bother about the reply.

(iii) The attacker does not want the reply – The attacker could simply be angry with the host,so it may put that host's address as the forged source address and send the packet to thedestination.

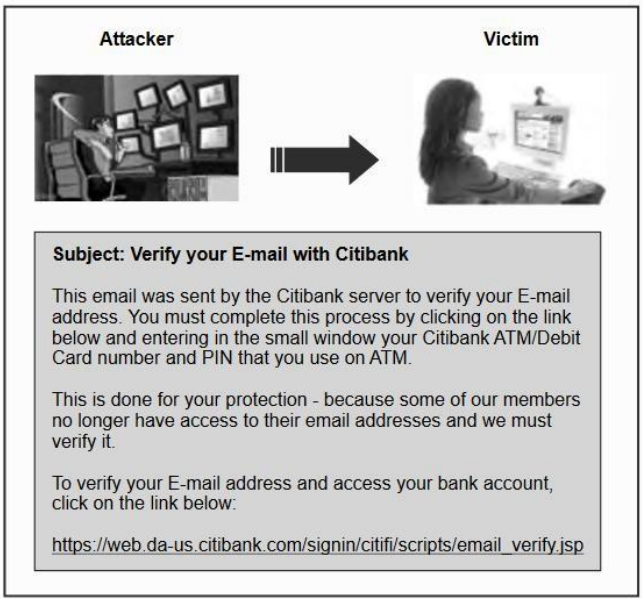
Phishing has become a big problem in recent times.

The attacker's module works as follows

- The attacker decides to create her own Web site, which looks very identical to a real Web site.Forexample, the attacker can clone Citibank's

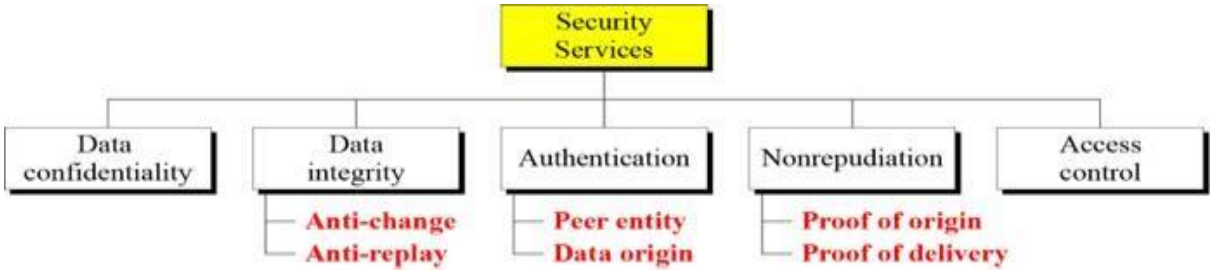
Web site. The cloning is so clever that human eye willnot be able to distinguish between the real (Citibank's) and fake (attacker's) sites now

- The attacker can use many techniques to attack the bank's customers.
- When the customer (i.e. the victim) innocently clicks on the URL specified in the email, she istaken to the attacker's site and not the bank's original site.



- There, the customer is prompted to enterconfidential information, such as her password or PIN. Since the attacker's fake site looks exactlyike the original bank site, the customer provides this information.

SECURITY SERVICES

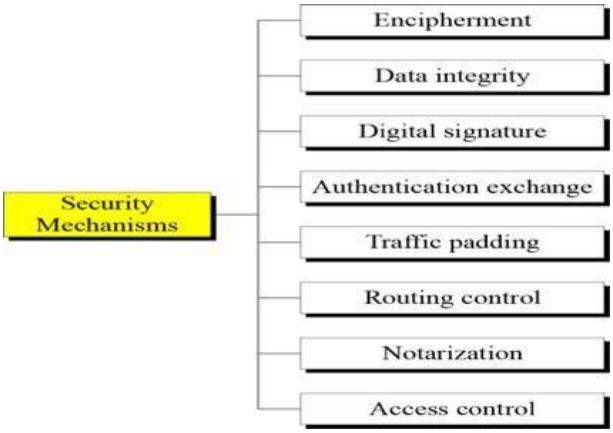


- **Authentication:** assures recipient that the **message is from the source** that it **claims to** be from.
- **Access Control:** controls who can have **access to resource** under what **condition**
- **Availability:** available to authorized entities for 24/7.
- **Confidentiality:** information is not made available to unauthorized individual
- **Integrity:** assurance that the message is unaltered

- **Non-Repudiation:** protection against denial of sending or receiving in the communication

SECURITY MECHANISMS

Network Security is field in computer technology that deals with ensuring security of computer network infrastructure. As the network is very necessary for sharing of information whether it is at hardware level such as printer, scanner, or at software level.



1. **Encipherment :**

   This security mechanism deals with hiding and covering of data which helps data to become confidential. It is achieved by applying mathematical calculations or algorithms which reconstruct information into not readable form. It is achieved by two famous techniques named Cryptography and Encipherment. Level of data encryption is dependent on the algorithm used for encipherment.

2. **Access Control :**

   This mechanism is used to stop unattended access to data which you are sending. It can be achieved by various techniques such as applying passwords, using firewall, or just by adding PIN to data.

3. **Notarization :**

   This security mechanism involves use of trusted third party in communication. It acts as mediator between sender and receiver so that if any chance of conflict is reduced. This mediator keeps record of requests made by sender to receiver for later denied.

4. **Data Integrity :**

This security mechanism is used by appending value to data to which is created by data itself. It is similar to sending packet of information known to both sending and receiving parties and checked before and after data is received. When this packet or data which is appended is checked and is the same while sending and receiving data integrity is maintained.

5. **Authentication exchange :**

   This security mechanism deals with identity to be known in communication. This is achieved at the TCP/IP layer where two-way handshaking mechanism is used to ensure data is sent or not

6. **Bit stuffing :**

   This security mechanism is used to add some extra bits into data which is being transmitted. It helps data to be checked at the receiving end and is achieved by Even parity or Odd Parity.

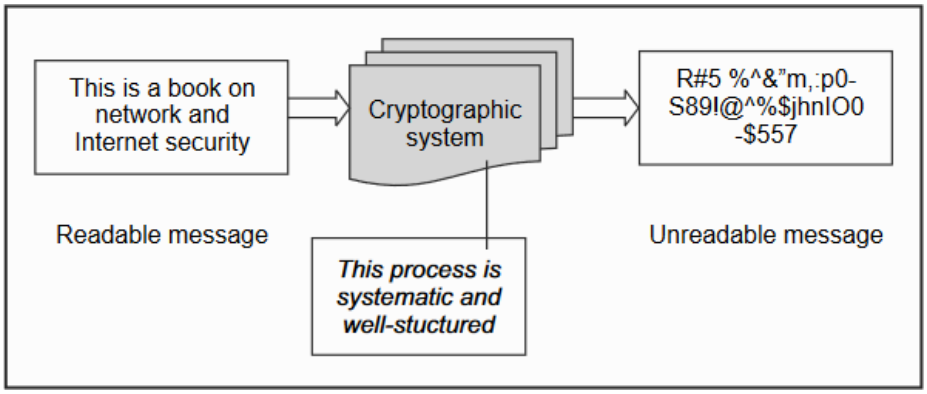
7. **Digital Signature :**

   This security mechanism is achieved by adding digital data that is not visible to eyes. It is form of electronic signature which is added by sender which is checked by receiver electronically. This mechanism is used to preserve data which is not more confidential but sender's identity is to be notified.

CRYPTOGRAPHY CONCEPTS AND TECHNIQUES

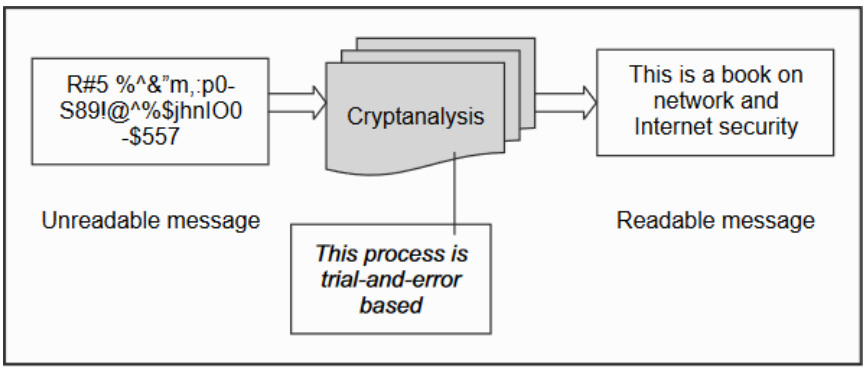
INTRODUCTION:

Cryptography is the art and science of achieving security by encoding messages to makethem non-readable.



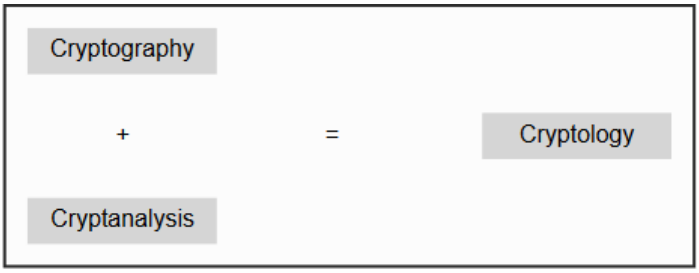
Cryptographic system

Cryptanalysis is the technique of decoding messages from a non-readable format back toreadable format without knowing how they were initially converted from readable format tonon-readable format.



Cryptanalysis

Cryptology is a combination of cryptography and cryptanalysis.



PLAIN TEXT AND CIPHER TEXT

Plain text or clear text is a message that can be understood by anybody knowing the languageas long as the message is not codified in any manner.

Clear text or plain text signifies a message that can be understood by the sender, the recipientand also by anyone else who gets an access to that message.

an example, they replace each alphabet with the alphabet that is actually three alphabetsdown the order. So, each A will be replaced by D, B will be replaced by E, C will be replaced by F andso on. To complete the cycle, each W will be replaced by Z, each X will be replaced by A, each Y will bereplaced by B and each Z will be replaced by C. We can summarize this scheme as shown in Fig.Thefirst row shows the original alphabets and the second row shows what each original alphabet will bereplaced with.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C

A scheme for codifying messages by replacing each alphabet with an alphabet threeplaces down the line

ANNAMACHARYA can be coded as ***DQQDPDFKDUBD***

A	N	N	A	M	A	C	H	A	R	Y	A
D	Q	Q	D	P	D	F	K	D	U	B	D

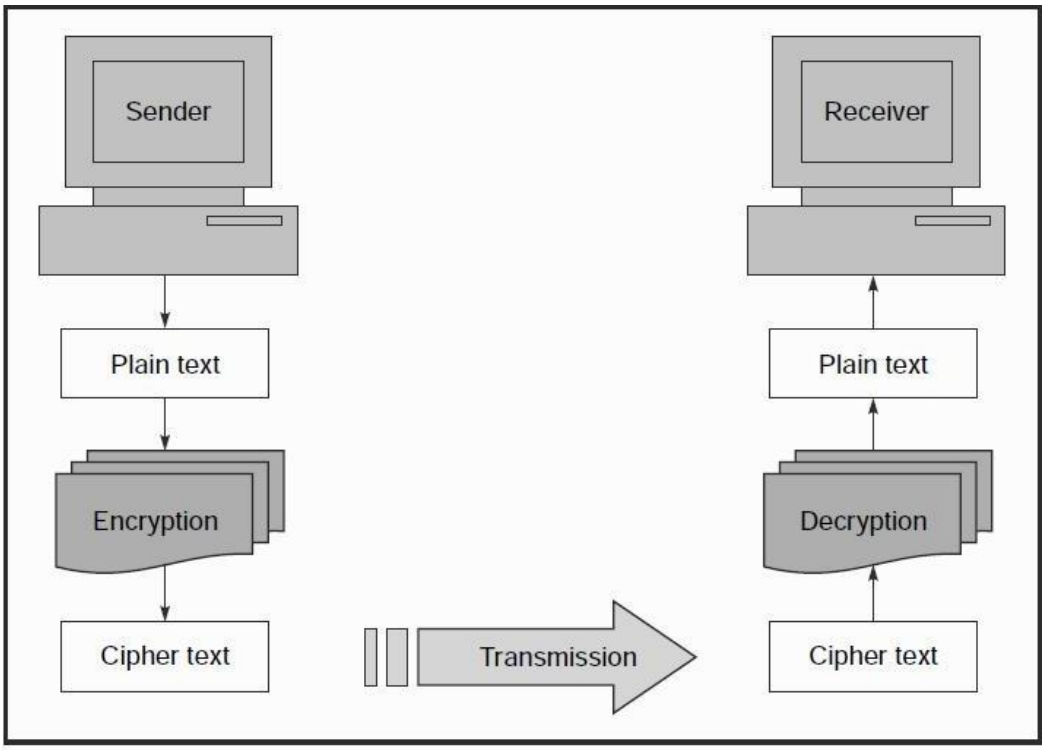
Each alphabet in the original message can be replaced by another to hidethe original contents of the message. The codified message is called as **cipher text.** Cipher means a codeor a secret message.

When a plain text message is codified using any suitable scheme, the resulting message iscalled as cipher text.

SUBSTITUTION TECHNIQUES

1. CAESAR CIPHER

This was first proposed by **Julius Caesar** and is termed as **Caesar Cipher.** Caesar Cipher is a special case of substitution techniques wherein eachalphabet in a message is replaced by an alphabet three places down the line. For instance, using theCaesar Cipher, the plain text ATUL will become cipher text DWXO.



Elements of cryptographic operations

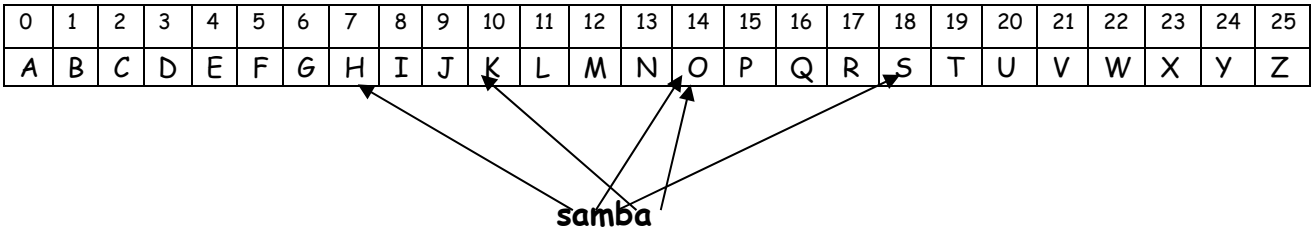
In the **substitution cipher technique**, the characters of a plain text message are replaced byother *characters, numbers or symbols.*

An attack on a cipher text message,wherein the attacker attempts to use all possible permutations and combinations, is called as a **Bruteforceattack**. The process of trying to break any cipher text message to obtain the original plain textmessage itself is called as **Cryptanalysis** and the person attempting a cryptanalysis is called as a**cryptanalyst**.

MONO-ALPHABETIC CIPHER

Mono-alphabetic ciphers pose a difficult problem for a cryptanalyst because it can be verydifficult to crack thanks to the high number of possible permutations and combinations.

Use random substitution. This means that in a given plain text message**, each A can be replaced by any other alphabet (B through Z), each B can also be replaced by any other random alphabet (A or C through Z) and so on.** The crucial difference being, there is no relation between thereplacement of B and replacement of A. That is, if we have decided to replace each A with D, we neednot necessarily replace each B with E – we can replace each B with any other character!



the Cipher text is : *HOSKO*

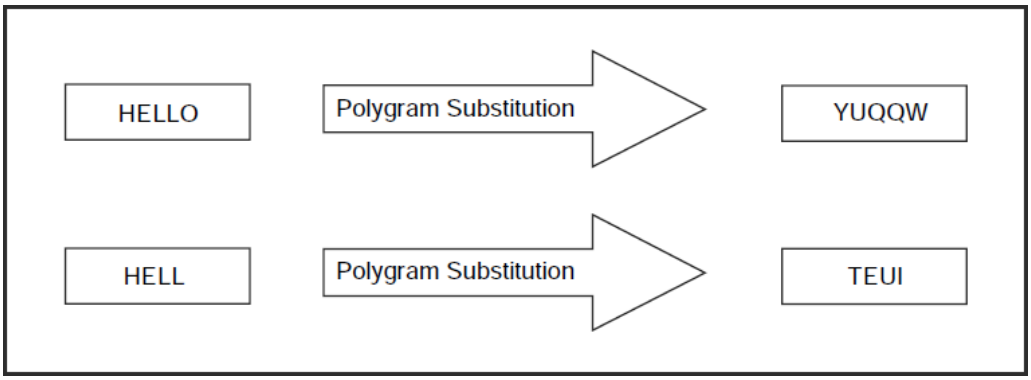
Homophonic Substitution Cipher

Homophonic Substitution Cipher also involves substitution of one plain text character with acipher text character at a time, however the cipher text character can be any one of thechosen set.

The Homophonic Substitution Cipher is very similar to Mono-alphabetic Cipher. Like a plainsubstitution cipher technique, we replace one alphabet with another in this scheme. However, thedifference between the two techniques is that whereas the replacement alphabet set in case of the simplesubstitution techniques is fixed (e.g. replace A with D, B with E, etc.), in the case of HomophonicSubstitutionCipher**, one plain text alphabet can map to more than one cipher text alphabet**. For instance,A can be replaced by D, H, P, R; B can be replaced by E, I,Q, S, etc.

Polygram Substitution Cipher

In Polygram Substitution Cipher technique, **rather than replacing one plain text alphabet with one cipher text alphabet at a time, a block of alphabets** is replaced with another block. For instance, HELLOcould be replaced by YUQQW, but HELL could be replaced by a totally different cipher text block TEUI, as shown in Fig.



Polyalphabetic Substitution Cipher

A poly-alphabetic cipher is any cipher based on substitution, using several substitution alphabets. In polyalphabetic substitution ciphers, the plaintext letters are enciphered differently based upon their installation in the text. Rather than being a one-to-one correspondence, there is a one-to-many relationship between each letter and its substitutes.

For example, 'a' can be enciphered as 'd' in the starting of the text, but as 'n' at the middle. The polyalphabetic ciphers have the benefit of hiding the letter frequency of the basic language. Therefore attacker cannot use individual letter frequency static to divide the ciphertext.

As the name polyalphabetic recommend this is achieved by **using multiple keys rather than only one key**. This implies that the key should be a stream of subkeys, in which each subkey depends somehow on the position of the plaintext character that needs subkey for encipherment.

Vigenere cipher is one of the simplest and popular algorithms in polyalphabetic cipher. In this approach, the alphabetic text is encrypted using a sequence of **multiple Caesar ciphers** based on the letters of a keyword.
The Vigenère cipher includes several simple substitution ciphers in sequence with several shift values. In this cipher, the keyword is repeated just before it connects with the duration of the plaintext.

Encryption Process:

$C_i=(P_i+K_i) \bmod 26$

In this process sum of i^{th} position of plain text and i^{th} position of key will be added and applied modulus 26 on the result , the generated positional value will be considered as Cipher text.

Decryption Process

$P_i=(C_i-K_i) \bmod 26$

In this process sum of i^{th} position of Cipher text and i^{th} position of key will be subtracted and applied modulus 26 on the result , the generated positional value will be considered as Plain text.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

Key: samba

Plain text: hello students how are you

Cipher text:

Key	s	a	m	B	a	s	a	m	b	a	s	a	m	b	a	s	a	m	b	a	s	A
PT	h	e	l	L	o	s	t	u	d	e	n	t	s	h	o	w	a	r	e	y	o	U
CT	z	e	x	M	o	k	t	g	E	e	f	t	e	i	o	o	a	c	f	y	g	U

Apply Encryption process to generate cipher text

That is 's' position is 18 and 'h' position is 7 so now

$C_1=(p_1+k_1) \bmod 26$

$= (18+7) \text{mpd} 26$

$=(25) \bmod 26$

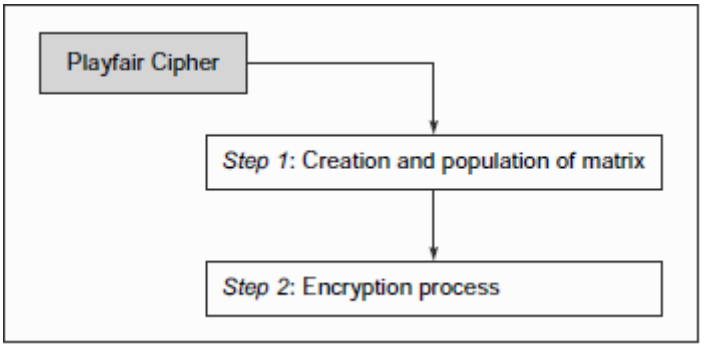
=25 (which is equalent to 'z')

Like wise generate the table accordingly.

Playfair Cipher:

The Playfair Cipher, also called as **Playfair Square**, is a cryptographic technique that is used formanual encryption of data.

The Playfair encryption scheme uses two main processes, as shown in Fig



Playfair cipher steps

Step 1: Creation Population of Matrix and The Playfair Cipher makes use of a 5 x 5 matrix(table), which is used to store a keyword or phrase that becomes the key for encryption and decryption.
The way this is entered into the 5 x 5 matrix is based on some simple rules, as shown below

1. Enter the keyword in the matrix row-wise: left-to-right, and then top-to-bottom.
2. Drop duplicate letters.
3. Fill the remaining spaces in the matrix with the rest of the English alphabets (A-Z)that were not a part of our keyword. While doing so, combine I and J in the same cell of the table. In otherwords, if I or J is a part of the keyword, disregard both I and J while filling the remaining slots.

Algorithm to encrypt the plain text: The plaintext is split into pairs of two letters (digraphs). If there is an odd number of letters, a Z is added to the last letter.
For example:

PlainText: "instruments"
After Split: 'in' 'st' 'ru' 'me' 'nt' 'sz'

1. Pair cannot be made with same letter. Break the letter in single and add a bogus letter to the previous letter.
Plain Text: "hello"
After Split: 'he' 'lx' 'lo'
Here **'x'** is the bogus letter.

2. If the letter is standing alone in the process of pairing, then add an extra bogus letter with the alone letter
Plain Text: "helloe"
AfterSplit: 'he' 'lx' 'lo' 'ez'

Here '**z**' is the bogus letter.

Rules for Encryption:

- **If both the letters are in the same column**: Take the letter below each one (going back to the top if at the bottom).
  For example:

Diagraph: "me"
Encrypted Text: cl
Encryption:
m -> c
e -> l

M	O	N	A	R
C	H	Y	B	D
E	F	G	I	K
L	P	Q	S	T
U	V	W	X	Z

If both the letters are in the same row: Take the letter to the right of each one (going back to the leftmost if at the rightmost position).
Diagraph: "ST"
Encrypted Text: TL
Encryption:
S -> T
T -> L

M	O	N	A	R
C	H	Y	B	D
E	F	G	I	K
L	P	Q	S	T
U	V	W	X	Z

If neither of the above rules is true: Form a rectangle with the two letters and take the letters on the horizontal opposite corner of the rectangle.
For example:

Diagraph: "nt"
Encrypted Text:rq
Encryption:
n -> r
t -> q

M	O	N	A	R
C	H	Y	B	D
E	F	G	I	K
L	P	Q	S	T
U	V	W	X	Z

Plain Text: "instrumentsz"

Encrypted Text: gatlmzclrqtx

Encryption:

i -> g

n -> a

s -> t

t -> l

r -> m

u -> z

m -> c

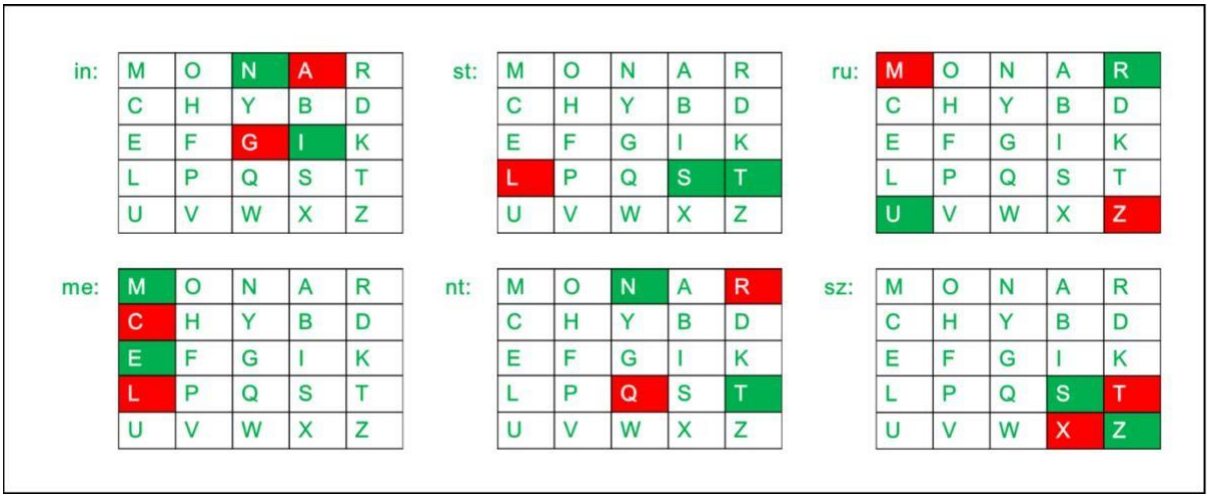
e -> l

n -> r

t -> q

s -> t

z -> x

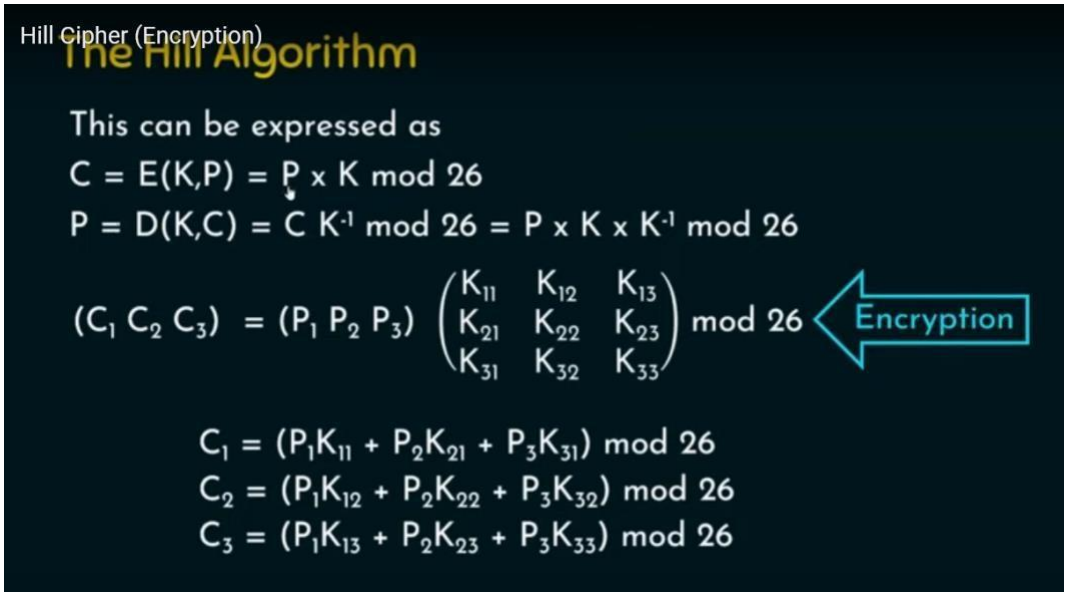


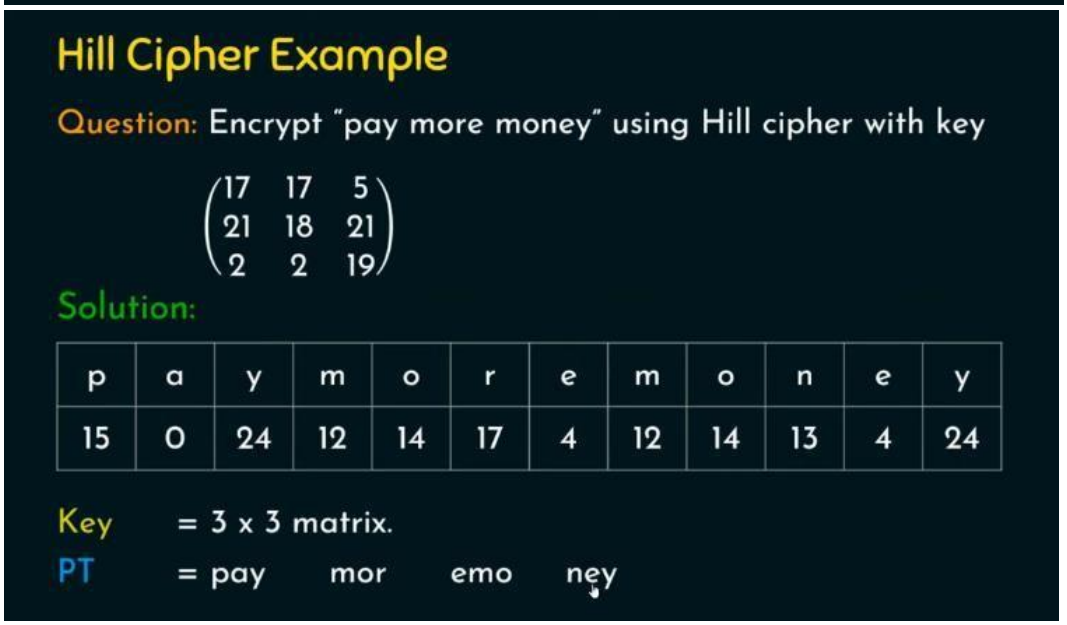
Hill Cipher

Hill cipher is a polygraphic substitution cipher based on linear algebra.Each letter is represented by a number modulo 26. Often the simple scheme A = 0, B= 1, …, Z = 25 is used, but this is not an essential feature of the cipher. To encrypt a message, each block of n letters (considered as an n-component vector) is multiplied by an invertible n × n matrix, against modulus 26. To decrypt the

message, each block is multiplied by the inverse of the matrix used for encryption.

The matrix used for encryption is the cipher key, and it should be chosen randomly from the set of invertible n × n matrices (modulo 26).





Hill Cipher Example

Encrypting: pay

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (15\ 0\ 24) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (15x17+0x21+24x2 \quad 15x17+0x18+24x2 \quad 15x5+0x21+24x19) \bmod 26$$

$$= (303\ 303\ 531) \bmod 26$$

$$= (17\ 17\ 11)$$

$$= (R\ R\ L)$$

Hill Cipher Example

Encrypting: mor

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (12\ 14\ 17) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (12x17+14x21+17x2 \quad 12x17+14x18+17x2 \quad 12x5+14x21+17x19) \bmod 26$$

$$= (532\ 490\ 677) \bmod 26$$

$$= (12\ 22\ 1)$$

$$= (M\ W\ B)$$

NESO ACADEMY

Hill Cipher Example

Encrypting: emo

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (4\ 12\ 14) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (4x17+12x21+14x2 \quad 4x17+12x18+14x2 \quad 4x5+12x21+14x19) \bmod 26$$

$$= (348\ 312\ 538) \bmod 26$$

$$= (10\ 0\ 18)$$

$$= (K\ A\ S)$$

NESO ACADEMY

Hill Cipher Example

Encrypting: ney

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (13\ 4\ 24) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (13x17+4x21+24x2 \quad 13x17+4x18+24x2 \quad 13x5+4x21+24x19) \bmod 26$$

$$= (348\ 312\ 538) \bmod 26$$

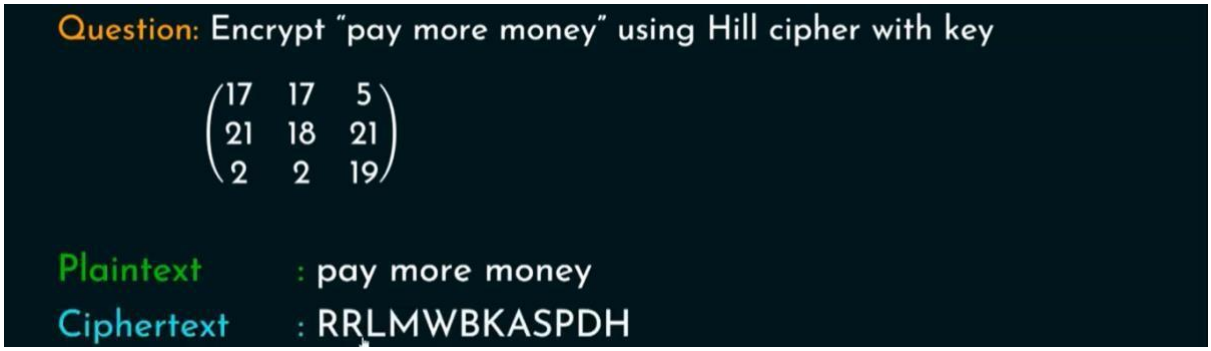
$$= (15\ 3\ 7)$$

$$= (P\ D\ H)$$

NESO ACADEMY

Hill Cipher Example

PT	p	a	y	m	o	r	e	m	o	n	e	y
CT	R	R	L	M	W	B	K	A	S	P	D	H



TRANSPOSITION TECHNIQUES

Transposition techniques differ from substitution techniques in the way that they do not simplyreplace one alphabet with another: they also perform some permutation over the plain text alphabets.

Rail Fence Technique

Rail fence technique involves writing plain text as sequence of diagonals and then reading itrow-by-row to produce cipher text.
Suppose that we have a plain textmessage Come home tomorrow. How would we transform that into a cipher text message using the RailFence Technique? This is shown in Fig.

1. Write down the plain text message as a sequence of diagonals.
2. Read the plain text written in Step 1 as a sequence of rows.
3. here depth=2

Original plain text message: ***Come home tomorrow***

1. After we arrange the plain text message as a sequence of diagonals, it would look as follows (write the first character on the first line i.e. *C*, then second character on the second line, i.e. *o*, then the third character on the first line, i.e. *m*, then the fourth character on the second line, i.e. *e*, and so on). This creates a zigzag sequence, as shown below.

C m h m t m r o
o e o e o o r w

2. Now read the text row-by-row, and write it sequentially. Thus, we have: ***Cmhmtmrooeoeoorw*** as the cipher text.

Example of rail technique

Simple Columnar Transposition Technique

Basic Technique Variations of the basic transposition technique such as Rail Fence Technique exist.Such a scheme call as Simple Columnar Transposition Technique.

- Write the plain text message row-by-row in a rectangle of a pre-defined size.
- Read the message column-by-column. However, it need not be in the order of columns 1,2, 3 etc. It can be any random order such as 2, 3, 1, etc.
- The message thus obtained is the cipher text message.

The Simple Columnar Transposition Technique simply arranges the plain text as a sequenceof rows of a rectangle that are read in columns randomly.

Original plain text message: ***Come home tomorrow***

1. Let us consider a rectangle with six columns. Therefore, when we write the message in the rectangle row-by-row (suppressing spaces), it would look as follows:

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
C	o	m	e	h	o
m	e	t	o	m	o
r	r	o	w		

2. Now, let us decide the order of columns as some random order, say 4, 6, 1, 2, 5 and 3. Then read the text in the order of these columns.
3. The cipher text thus obtained would be ***eowoocmroerhmmto***.

Example of simple columnar technique

A MODEL FOR NETWORK SECURITY

A message is to be transferred from one party to another across some sort of internet. Thetwo parties, who are the principals in this transaction, must cooperate for the exchange to takeplace. A logical information channel is established by defining a route through the internetfrom source to destination and by the cooperative use of communication protocols (e.g.,TCP/IP) by the two principals. Security aspects come into play when it is necessary ordesirable to protect the information transmission from an opponent who may present a threatto confidentiality, authenticity, and so on.

All the techniques for providing security have twocomponents:

A security-related transformation on the information to be sent. Examples include the encryption of the message, which scrambles the message so that it is unreadable bythe opponent, and the addition of a code based on the contents of the message, whichcan be used to verify the identity of the sender Some secret

information shared by thetwo principals and, it is hoped, unknown to the opponent. An example is an encryptionkey used in conjunction with the transformation to scramble the message beforetransmission and unscramble it on reception.

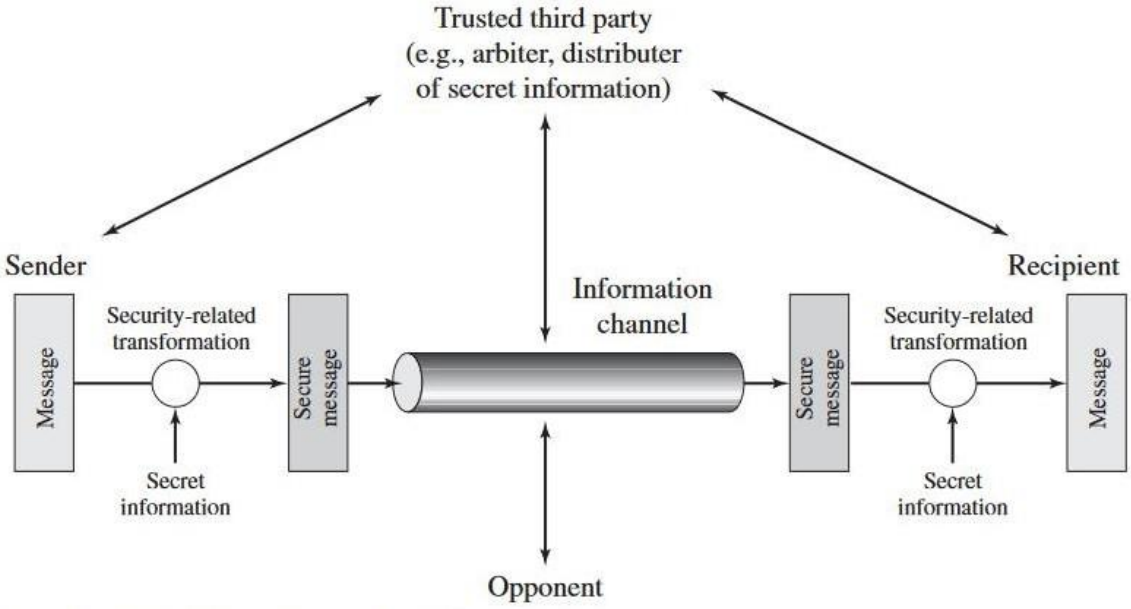


Figure 1.4 Model for Network Security

The general model shows that there are four basic tasks in designing a particular securityservice:

1. Design an algorithm for performing the security-related transformation. Thealgorithm should be such that an opponent cannot defeat its purpose.
2. Generate the secret information to be used with the algorithm .
3. Develop methods for the distribution and sharing of the secret information.
4. Specify a protocol to be used by the two principals that makes use of the securityalgorithm and the secret information to achieve a particular security service

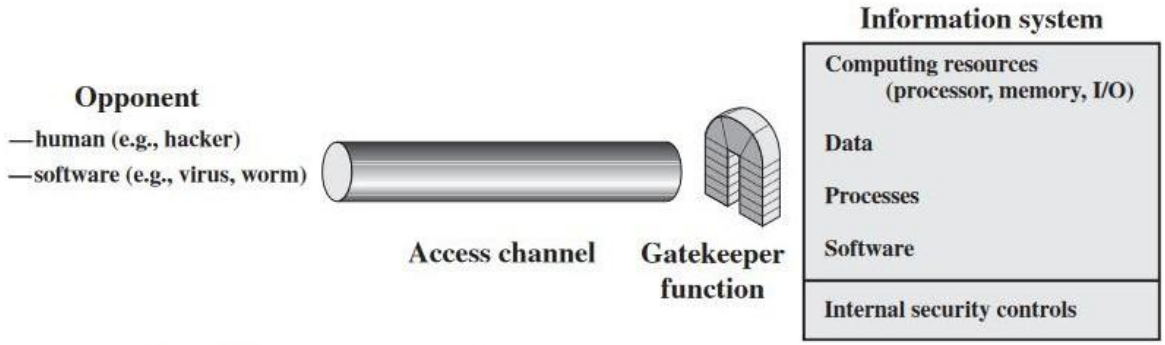


Figure 1.5 Network Access Security Model

A general model is illustrated by the above Figure 1.6, which reflects a concern forprotecting an information system from unwanted access. Most readers are

familiar with theconcerns caused by the existence of hackers, who attempt to penetrate systems that can beaccessed over a network. The hacker can be someone who, with no malign intent, simply getssatisfaction from breaking and entering a computer system. Or, the intruder can be adisgruntled employee who wishes to do damage, or a criminal who seeks to exploit computerassets for financial gain.

ENCRYPTION AND DECRYPTION

The process of encoding plain text messagesinto cipher text messages is called as **encryption**.

The process of transforming cipher textmessages back to plain text messages is called as**decryption**.

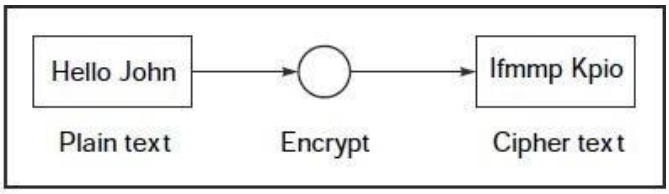


Fig. 2.40 *Encryption*

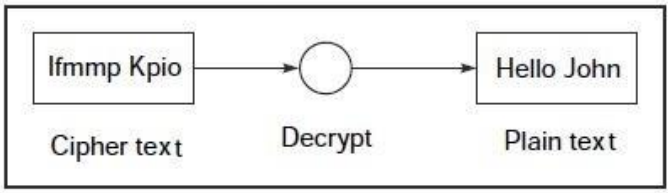
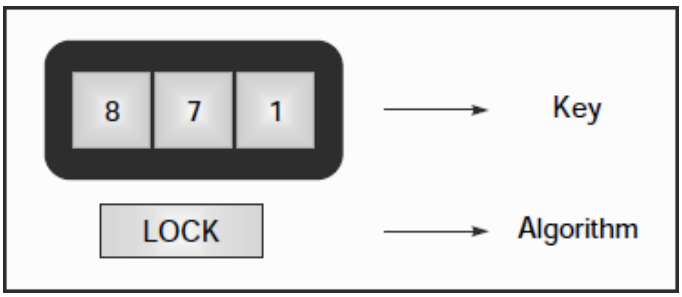


Fig. 2.41 *Decryption*

Every encryption and decryption process has two aspects: the **algorithm** and the **key** used forencryption and decryption.

let us take the example ofa combination lock, which we use in real life. We need to remember the combination (which is a number, suchas 871) needed to open up the lock. The facts that it is acombination lock and how to open it (algorithm) arepieces of public knowledge. However, the actual valueof the key required for opening a specific lock (key),which is 871 in this case, is kept secret. The idea isillustrated in Fig

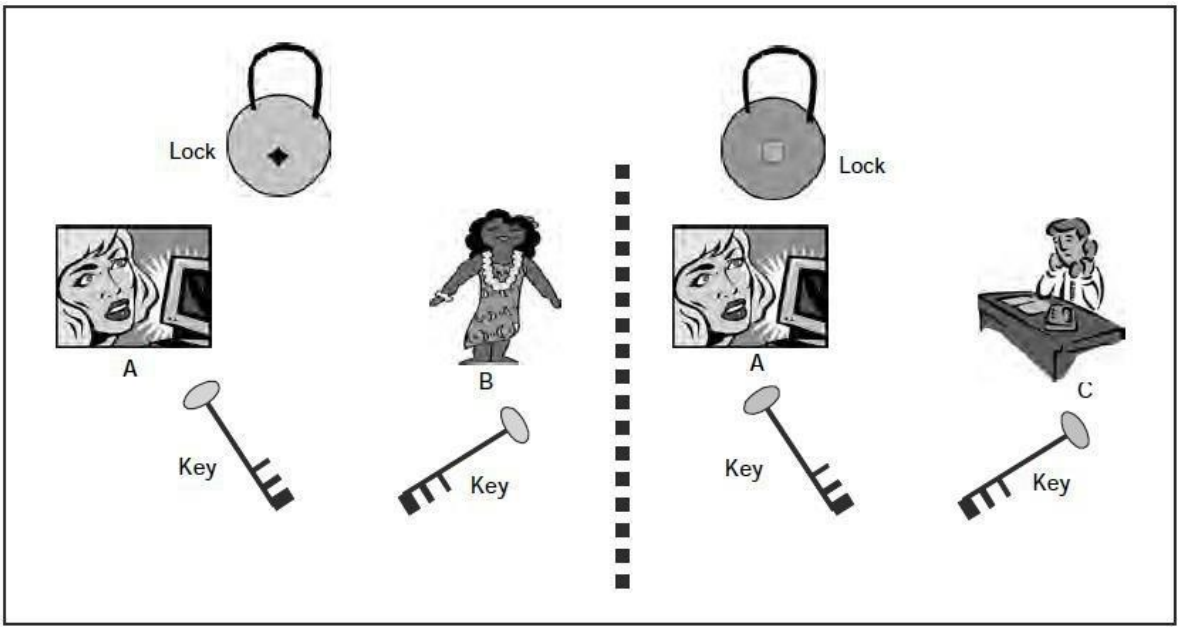


Broadly, there are two cryptographic mechanisms, depending on **what keys are used.** If the same keyis used for encryption and decryption, we call the mechanism as **Symmetric Key Cryptography**.However, if two different keys are used in a cryptographic mechanism, wherein one key is used forencryption and another, different key is used for decryption; we call the mechanism as **Asymmetric KeyCryptography**.

Symmetric and Asymmetric Key Cryptography

The sender andthe receiver will use the same key to lock and unlock, this is called as symmetric key operation (whenused in the context of cryptography, this operation is called as **symmetric key cryptography**).
Person A wants to send a highly confidential letter to another person B. A and B both residein the same city, but are separated by a few miles and for some reason, cannot meet eachother.
With the symmetric key cryptography A can send securely to the B.

Let us now imagine that not only A and B but also thousands of people want to send such confidentialletters securely to each other. What would happen if they decide to go for symmetric key operation? Ifwe examine this approach more closely, we can see that it has one big drawback if the number of peoplethat want to avail of its services is very large.



Use of separate locks and keys per communication pair
we have the following situation:

- When A wanted to communicate only with B, we needed one lock-and-key pair (A-B).
- When A wants to communicate with B and C, we need two lock-and-key pairs (A-B and A-C).

Thus, we need one lock-and-key pair per person with whom A wants to communicate. If B alsowants to communicate with C, we have B-C as the third communicating pair, requiring its ownlock-and-key pair. Thus, we would need three lock-and-key pairs to serve the needs of threecommunicating pairs.

Therefore, can we see that, in general, for n persons, the number of lock-and-key pairs is$\frac{n*(n-1)}{2}$

Parties involved	Number of lock-and-key pairs required
2 (A, B)	1 (A-B)
3 (A, B, C)	3 (A-B, A-C, B-C)
4 (A, B, C, D)	6 (A-B, A-C, A-D, B-C, B-D, C-D)
5 (A, B, C, D, E)	10 (A-B, A-C, A-D, A-E, B-C, B-D, B-E, C-D, C-E, D-E)

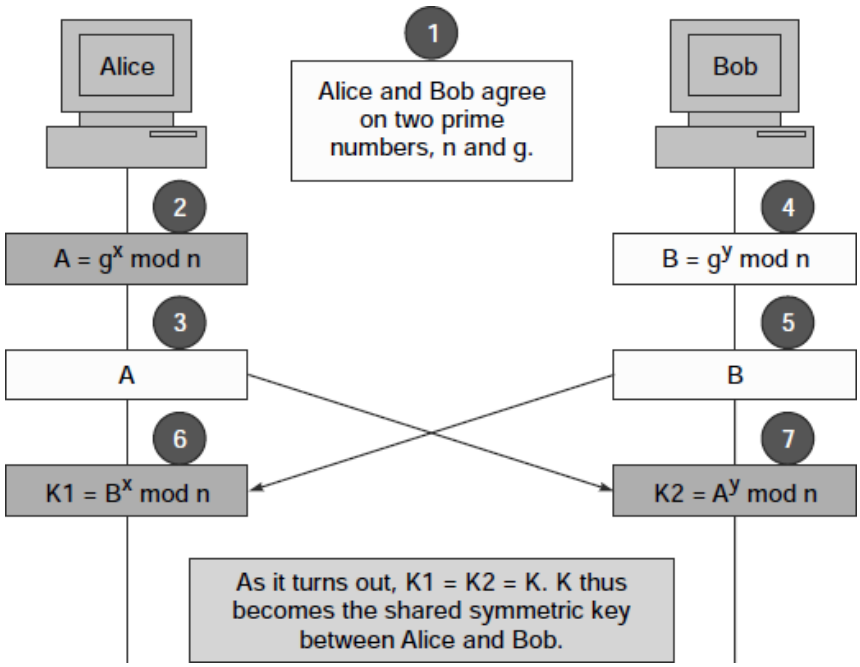
Diffie–Hellman Key Exchange/Agreement Algorithm

In this scheme the two parties, who want to communicatesecurely, can agree on a **symmetric key** using this technique. This key can then be used for encryption/ decryption. However, we must note that Diffie–Hellman key exchange algorithm can be used only forkey agreement, but not for encryption or decryption of messages. Once both the parties agree on the keyto be used, they need to use other symmetric key encryption algorithms for actual encryption or decryption of messages.

Description of the Algorithm

1. Firstly, Alice and Bob agree on two large prime numbers, n and g. These two integers need not be kept secret. Alice and Bob can use an insecure channel to agree on them.
2. Alice chooses another large random number x, and calculates A such that:
   $A = g^x \bmod n$
3. Alice sends the number A to Bob.
4. Bob independently chooses another large random integer y and calculates B such that:
   $B = g^y \bmod n$
5. Bob sends the number B to Alice.
6. A now computes the secret key K1 as follows:
   $K1 = B^x \bmod n$
7. B now computes the secret key K2 as follows:
   $K2 = A^y \bmod n$

Diffie–Hellman key exchange algorithm



Example of the Algorithm

1. Firstly, Alice and Bob agree on two large prime numbers, n and g. These two integers need not be kept secret. Alice and Bob can use an insecure channel to agree on them.

   Let $n = 11, g = 7$.

2. Alice chooses another large random number x, and calculates A such that:
   $A = g^x \bmod n$

   Let $x = 3$. Then, we have, $A = 7^3 \bmod 11 = 343 \bmod 11 = 2$.

3. Alice sends the number A to Bob.

   Alice sends 2 to Bob.

4. Bob independently chooses another large random integer y and calculates B such that:
   $B = g^y \bmod n$

   Let $y = 6$. Then, we have, $B = 7^6 \bmod 11 = 117649 \bmod 11 = 4$.

5. Bob sends the number B to Alice.

   Bob sends 4 to Alice.

6. A now computes the secret key K1 as follows:
   $K1 = B^x \bmod n$

   We have, $K1 = 4^3 \bmod 11 = 64 \bmod 11 = 9$.

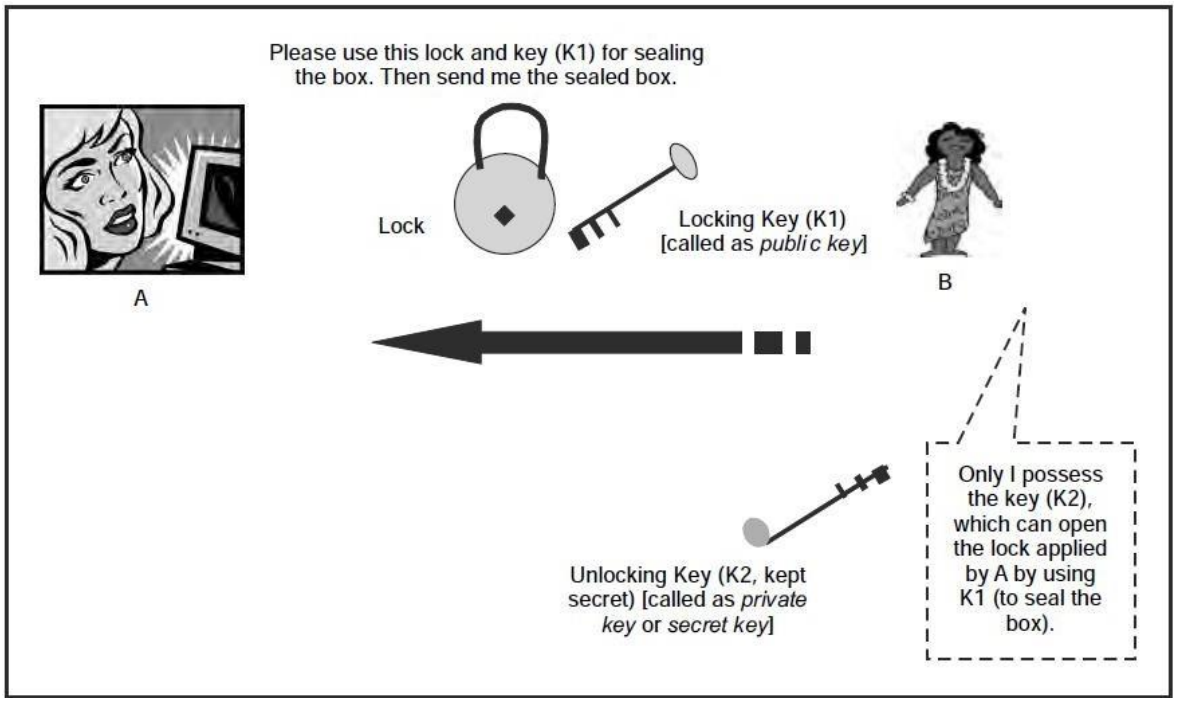
7. B now computes the secret key K2 as follows:
   $K2 = A^y \bmod n$

   We have, $K2 = 2^6 \bmod 11 = 64 \bmod 11 = 9$.

Asymmetric Key Operation

In this scheme, (Alice) A and (Bob) B do not have to jointly approach (Tom) T for a lock-and-key pair. Instead, B aloneapproaches T, obtains a lock and a key (K1) that can seal the lock and sends the lock and key K1 to A. Btells A that A can use that lock and key to seal the box before sending the sealed box to B.

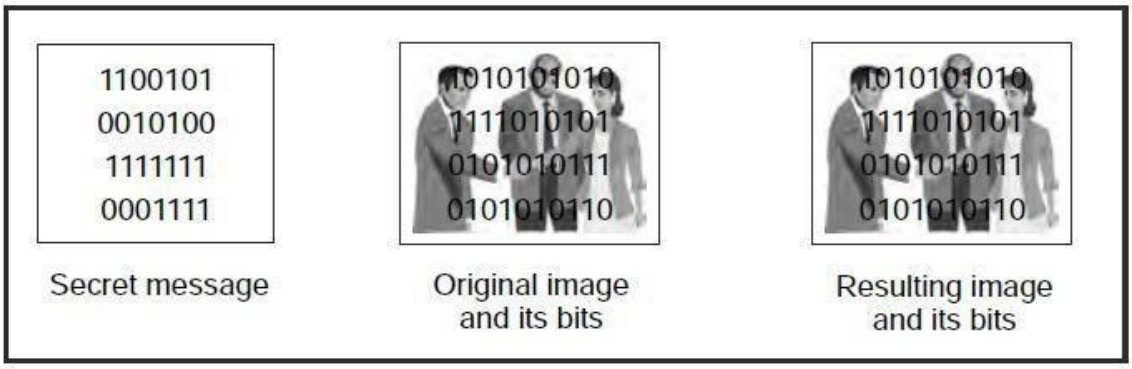
An interesting property of this scheme is that B possesses a different but related key (K2), which isobtained by B from T along with the lock and key K1, only which can open the lock. It is guaranteed thatno other key and of course, including the one used by A (i.e. K1) for locking, can open the lock. Sinceone key (K1) is used for locking and another, different key (K2) is used for unlocking; we will call thisscheme as asymmetric key operation. Also, T is clearly defined here as a **trusted third party.** T iscertified as a highly trustworthy and efficient agency by the government.



STEGANOGRAPHY

Steganography is a technique that facilitates hiding of a message that is to be kept secret inside othermessages.

The sender usedmethods such as invisible ink, tiny pin punctures on specific characters, minute variations betweenhandwritten characters, pencil marks on handwritten characters, etc.

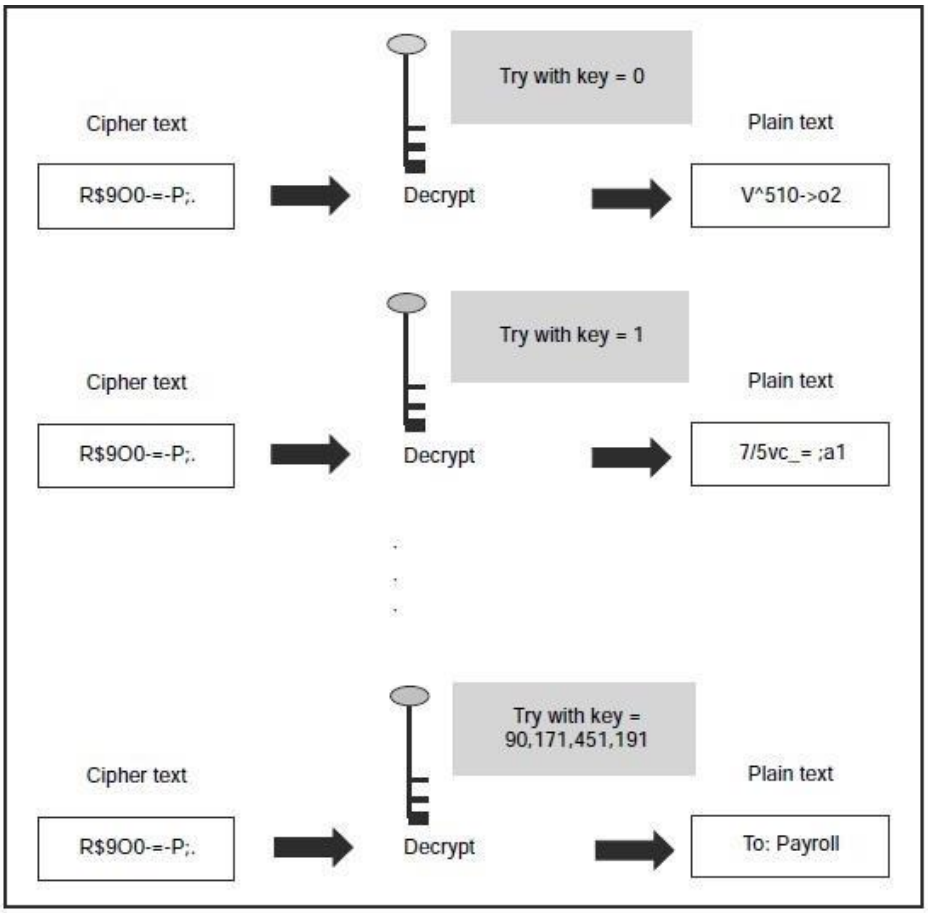


KEY RANGE AND KEY SIZE

The cryptanalystis armed with the following information:

- The encryption/decryption algorithm
- The encrypted message
- Knowledge about the key size (e.g. the value of the key is a number between 0 and 100 billion).

For example consider the **brute force attack** here, which works onthe principle of trying every possible key in the key range, until you get the right key.



Brute forceattack

A 2-bit binary number has four possible states:

00
01
10
11

If we have one more bit to make it a 3-bit binary number, the number of possible states also doubles to eight, as follows:

000
001
010
011
100
101
110
111

In general, if an *n bit* binary number has *k* possible states, an *n+1 bit* binary number will have *2k* possible states.

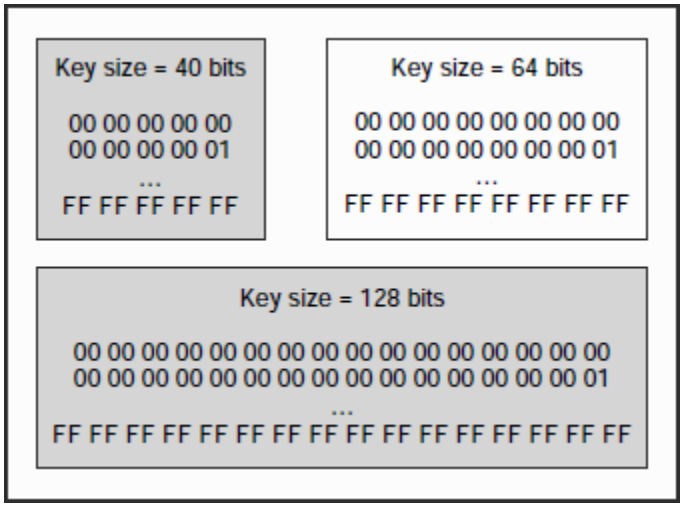
Understanding key range

With every incremental bit, the attacker has to perform double the number of operations ascompared to the previous key size. It is found that for a 56-bit key,

it takes 1 second to search 1 percentof the key range. Taking this argument further, it takes about 1 minute to search about half of the keyrange (which is what is required, on an average, to crack a key). Using this as the basis, let us have a lookat the similar values (time required for a search of 1 percent and 50 percent of the key space) for variouskey sizes. This is shown in Table

Key size on bits	*Time required to search 1 percent of the key space*	*Time required to search 50 percent of the key space*
56	1 second	1 minute
57	2 seconds	2 minutes
58	4 seconds	4 minutes
64	4.2 minutes	4.2 hours
72	17.9 hours	44.8 days
80	190.9 days	31.4 years
90	535 years	321 centuries
128	146 billion millennia	8 trillion millennia

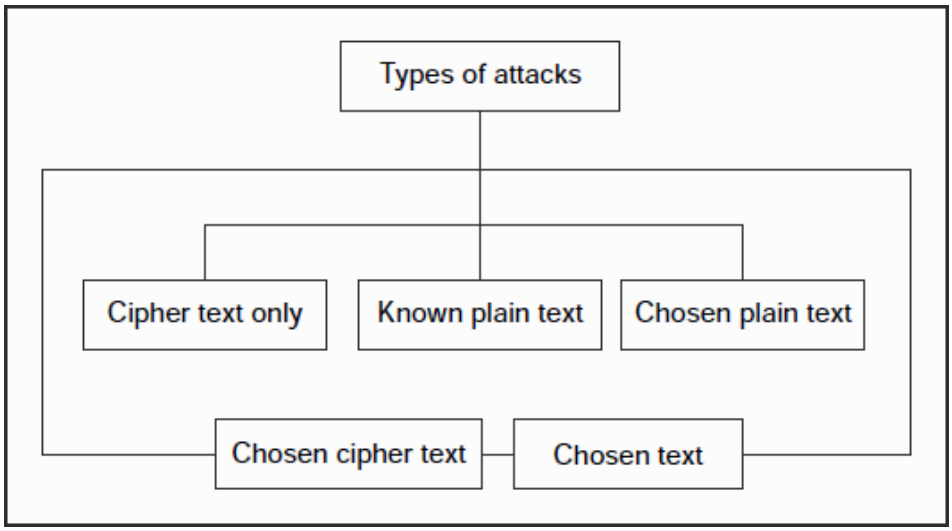
We can represent the possible values in the key range using hexadecimal notation and see visuallyhow an increase in the key size increases the key range and therefore, the complexity for an attacker.



Key sizes and ranges

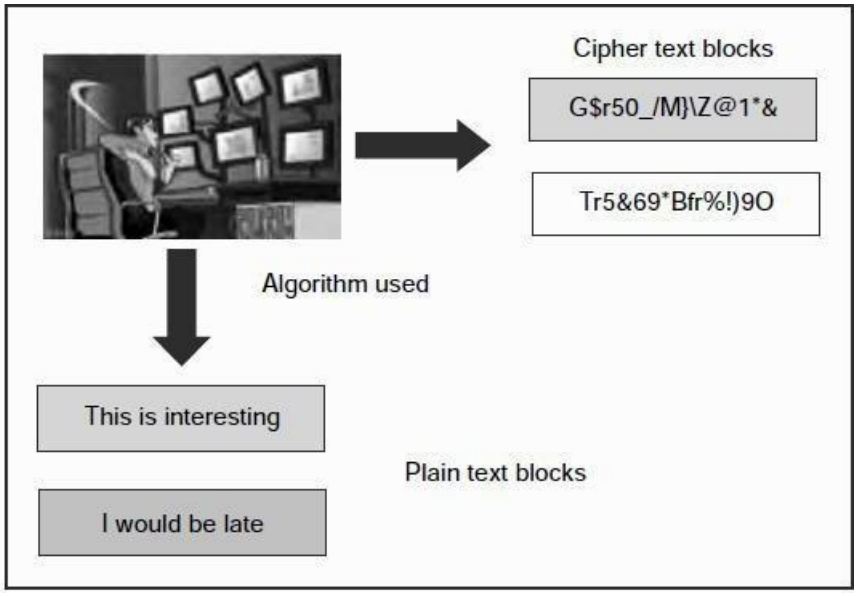
POSSIBLE TYPES OF ATTACKS

When the sender of a message encrypts a plain text message into itscorresponding cipher text, there are five possibilities for an attack on this message.



Cipher text only attack: In this type of attack, the attacker does not have any clue about the plaintext and has some or all of the cipher text.The attacker analyzes the cipher text at leisure to try andfigure out the original plain text.

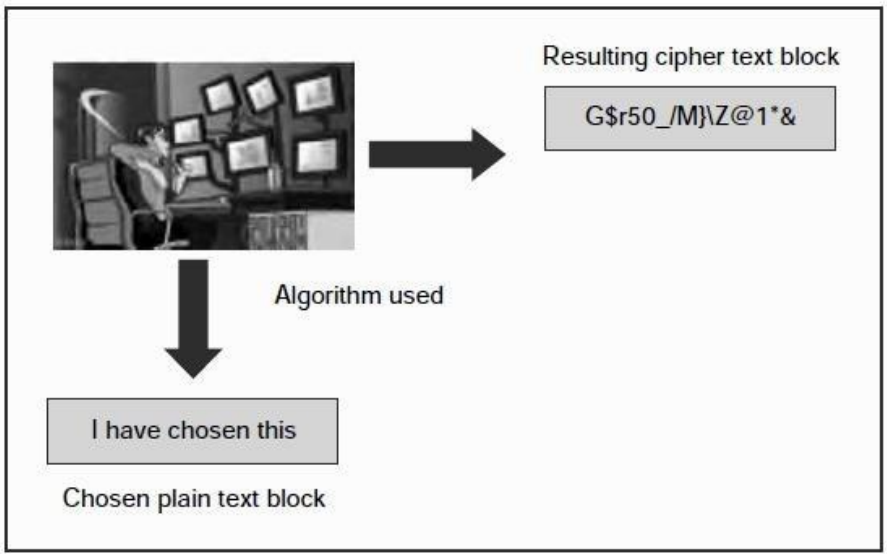
Known plain text attack: In this case, the attacker knows about some pairs of plain text andcorresponding cipher text for those pairs. Using this information, the attacker tries to find otherpairs and therefore, know more and more of the plain text. Examples of such known plain texts arecompany banners, file headers, etc. which are found commonly in all the documents of a particularcompany.



Known plain text attack

Chosen plain text attack: Here, the attacker selects a plain text block and tries to look for theencryption of the same in the cipher text. Here, the attacker is able to choose the messages toencrypt. Based on this, the attacker intentionally

picks patterns of cipher text that result inobtaining more information about the key.



Chosen plain text attack

Chosen cipher text attack: In the chosen cipher text attack, the attacker knows the cipher text tobe decrypted, the encryption algorithm that was used to produce this cipher text and thecorresponding plain text block. The attacker's job is to discover the key used for encryption.

Chosen text attack: The chosen text attack is essentially a combination of chosen plain textattack and chosen cipher text attack.

SYMMETRIC KEY CIPHERS

BLOCK CIPHER PRICNIPLLES

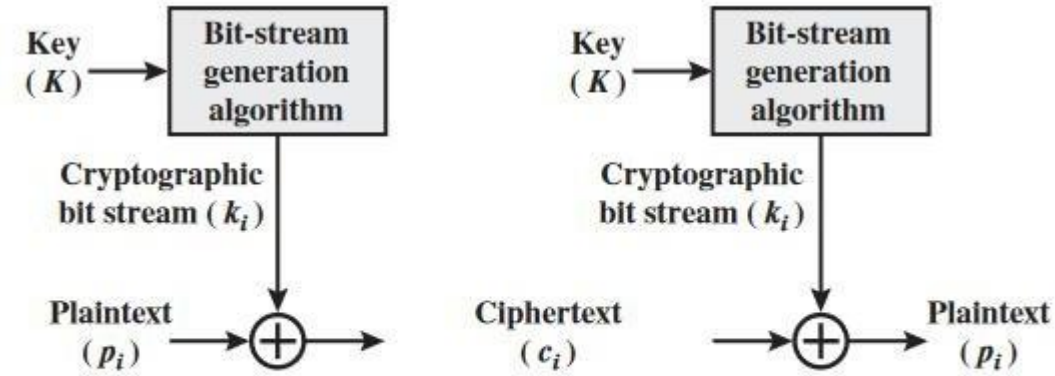
Stream Ciphers and Block Ciphers

A stream cipher is one that encrypts a digital data stream one bit or one byte at a time.

Examples of classical stream ciphers are the autokeyed Vigenère cipher and the Vernam cipher.

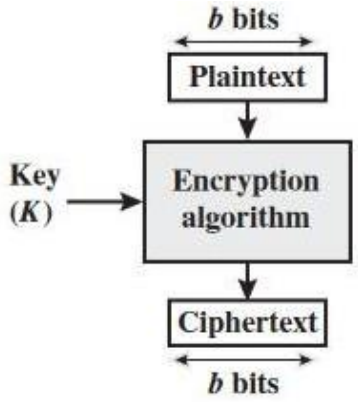
In the ideal case, a one-time pad version of the Vernam cipher wouldbe used, in which the keystream (K_i) is as long as the plaintext bit stream (P_i). If the cryptographic keystream is random, then this cipher is unbreakable by anymeans other than acquiring the keystream.

The bit-stream generator is akey-controlled algorithm and must produce a bit stream that is cryptographicallystrong.



(a) Stream cipher using algorithmic bit-stream generator

A block cipher is one in which a block of plaintext is treated as a whole andused to produce a ciphertext block of equal length. Typically, a block size of 64 or128 bits is used. As with a stream cipher, the two users share a symmetric encryptionkey.



(b) Block cipher

Motivation for the Feistel Cipher Structure

A block cipher operates on a plaintext block of n bits to produce a ciphertextblock of n bits. There are 2^npossible different plaintext blocks and, forthe encryption to be reversible (i.e., for decryption to be possible), each mustproduce a unique ciphertext block.

Reversible Mapping

Plaintext	Ciphertext
00	11
01	10
10	00
11	01

Irreversible Mapping

Plaintext	Ciphertext
00	11
01	10
10	01
11	01

The logic of a general substitution cipher for A 4-bit input produces one of 16 possible input states, which is mapped by thesubstitution cipher into a unique one of 16 possible output states, each of which isrepresented by 4 ciphertext bits.

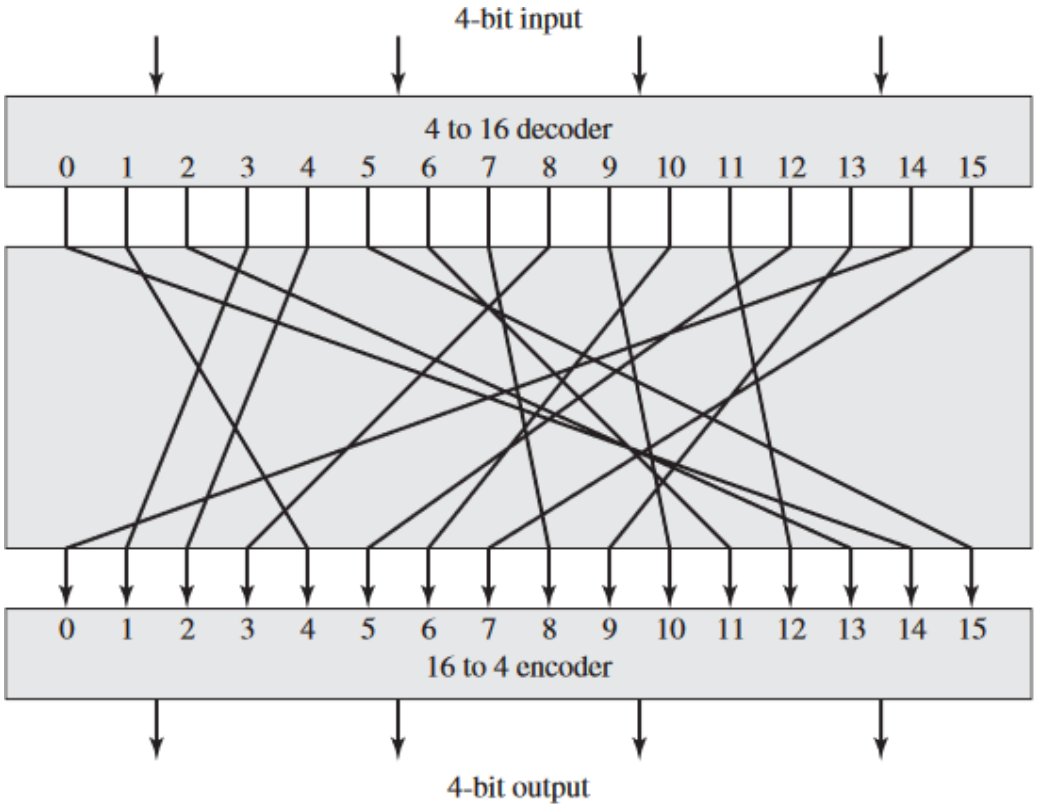


Figure 3.2 General n-bit-n-bit Block Substitution (shown with $n = 4$)

Table 3.1 Encryption and Decryption Tables for Substitution Cipher of Figure 3.2

Plaintext	Ciphertext
0000	1110
0001	0100
0010	1101
0011	0001
0100	0010
0101	1111
0110	1011
0111	1000
1000	0011
1001	1010
1010	0110
1011	1100
1100	0101
1101	1001
1110	0000
1111	0111

Ciphertext	Plaintext
0000	1110
0001	0011
0010	0100
0011	1000
0100	0001
0101	1100
0110	1010
0111	1111
1000	0111
1001	1101
1010	1001
1011	0110
1100	1011
1101	0010
1110	0000
1111	0101

Block Cipher Principles

A block cipher is designed by considering its three critical aspects which are listed as below:

1. Number of Rounds
2. Design of Function F
3. Key Schedule Algorithm

1. Number of Rounds

The number of rounds judges the strength of the block cipher algorithm. It is considered that more is the number of rounds, difficult is for cryptanalysis to break the algorithm.

It is considered that even if the function F is relatively weak, the number of rounds would make the algorithm tough to break.

2. Design of Function F

The function F of the block cipher must be designed such that it must be impossible for any cryptanalysis to unscramble the substitution. The criterion that strengthens the function F is it non-linearity.

More the function F is nonlinear, more it would be difficult to crack it. Well, while designing the function F it should be confirmed that it has a good avalanche property which states that a change in one-bit of input must reflect the change in many bits of output.

The Function F should be designed such that it possesses a bit independence criterion which states that the output bits must change independently if there is any change in the input bit.

3. Key Schedule Algorithm

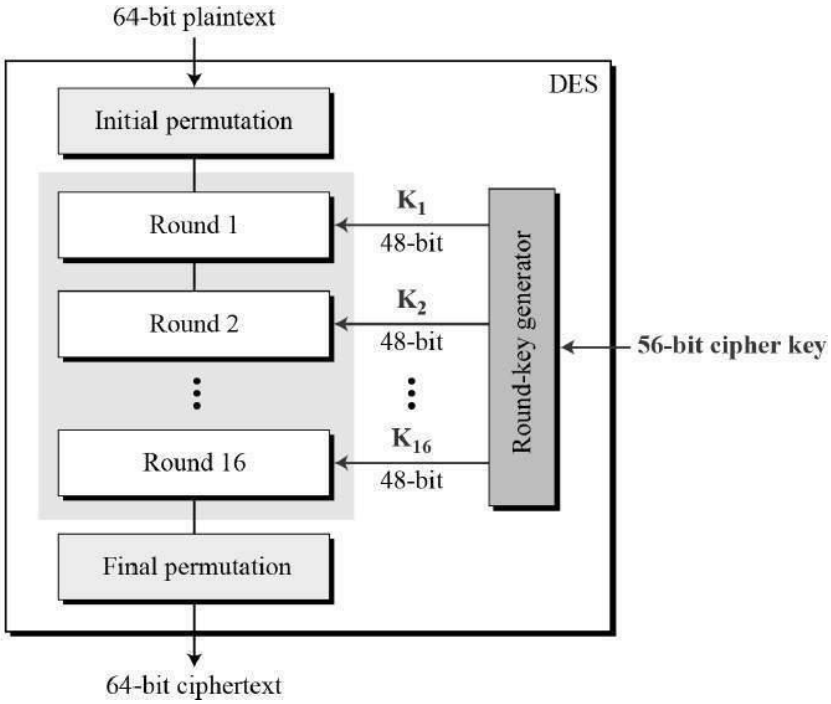
It is suggested that the key schedule should confirm the strict avalanche effect and bit independence criterion.

DATA ENCRYPTION STANDARD

The Data Encryption Standard (DES) is a symmetric-key block cipher published by the National Institute of Standards and Technology (NIST).

DES is an implementation of a Feistel Cipher. It uses 16 round Feistel structure. The block size is 64-bit. Though, key length is 64-bit, DES has an effective key

length of 56 bits, since 8 of the 64 bits of the key are not used by the encryption algorithm (function as check bits only). General Structure of DES is depicted in the following illustration –

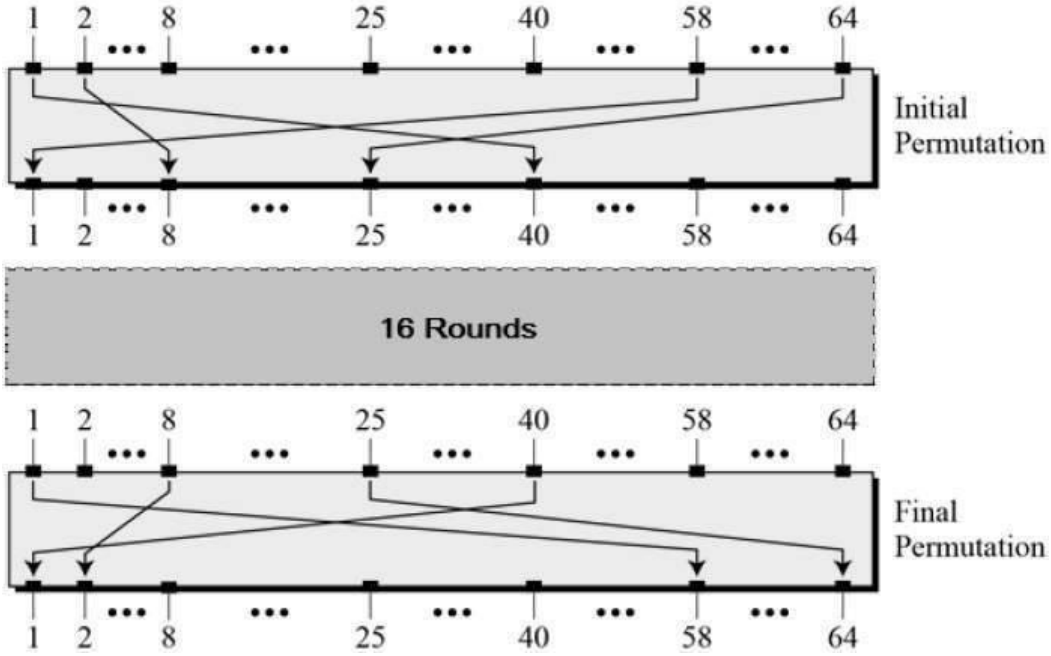


Since DES is based on the Feistel Cipher, all that is required to specify DES is –

- Round function
- Key schedule
- Any additional processing – Initial and final permutation

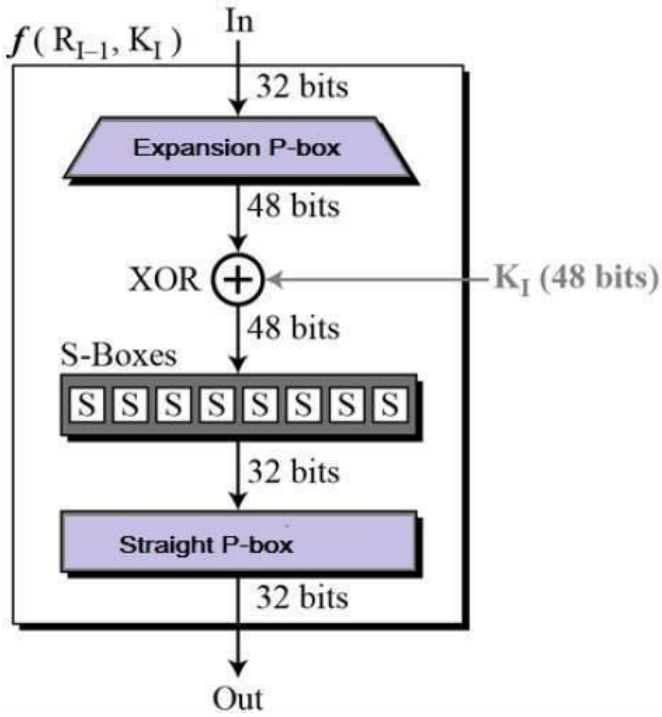
Initial and Final Permutation

The initial and final permutations are straight Permutation boxes (P-boxes) that are inverses of each other. They have no cryptography significance in DES. The initial and final permutations are shown as follows –

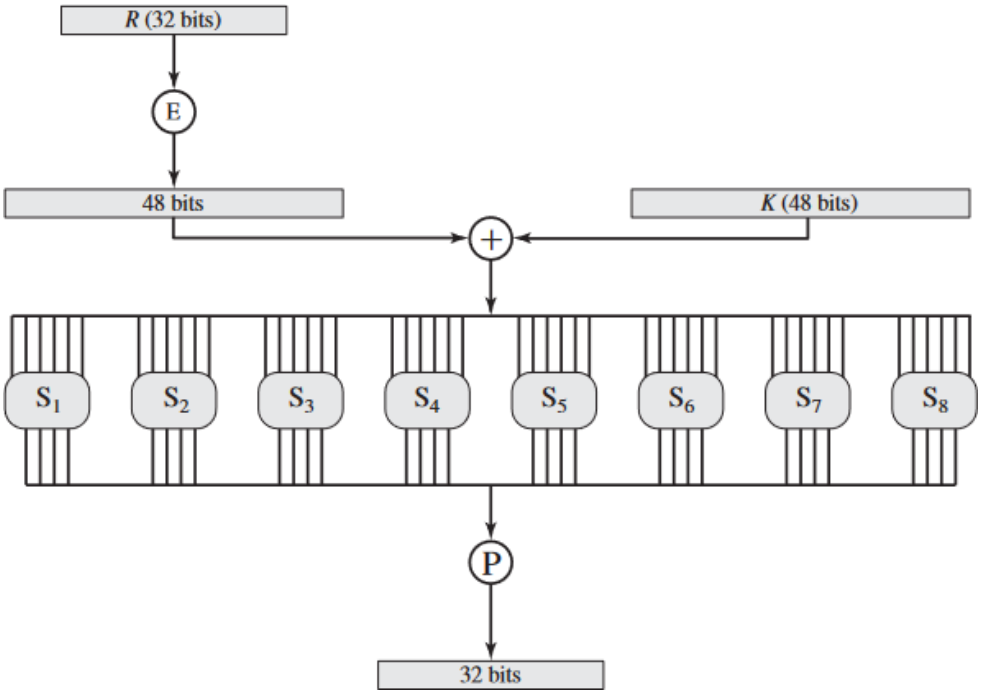


Round Function

The heart of this cipher is the DES function, f. The DES function applies a 48-bit key to the rightmost 32 bits to produce a 32-bit output.



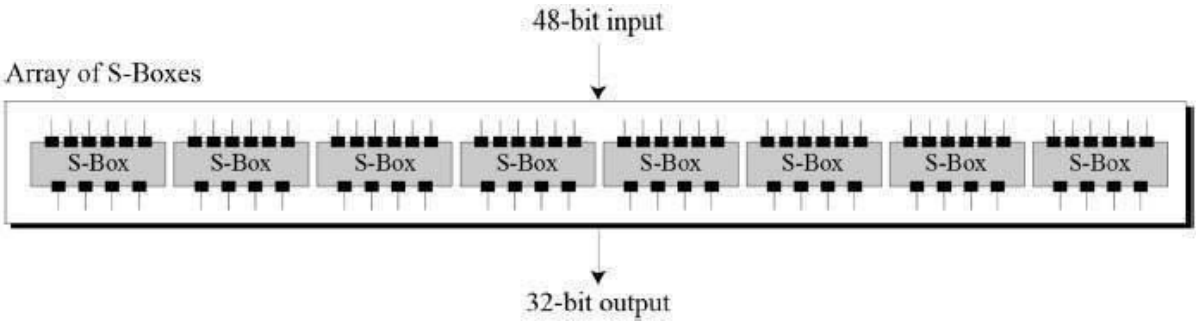
Expansion Permutation Box –Since right input is 32-bit and round key is a 48-bit, we first need to expand right input to 48 bits. Permutation logic is graphically depicted in the following illustration



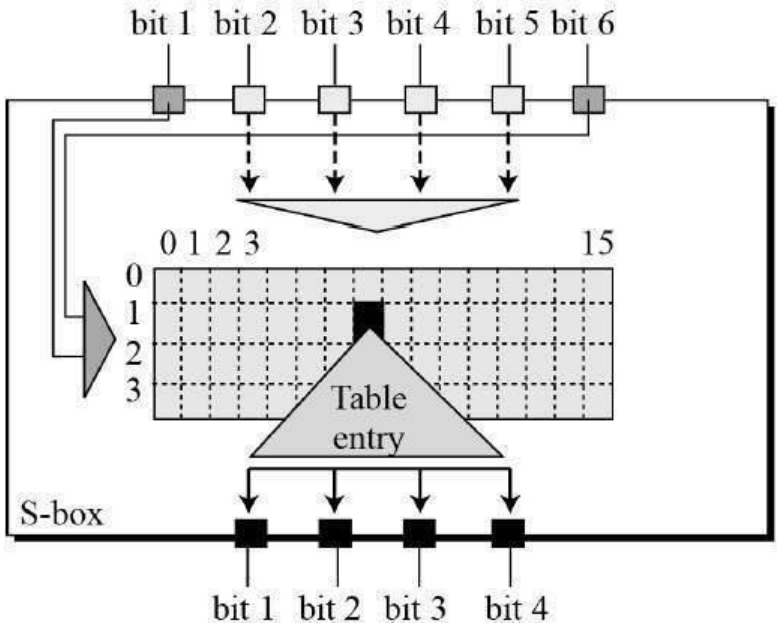
The graphically depicted permutation logic is generally described as table in DES specification illustrated as shown

32	01	02	03	04	05
04	05	06	07	08	09
08	09	10	11	12	13
12	13	14	15	16	17
16	17	18	19	20	21
20	21	22	23	24	25
24	25	26	27	28	29
28	29	31	31	32	01

- **XOR (Whitener).** – After the expansion permutation, DES does XOR operation on the expanded right section and the round key. The round key is used only in this operation.
- **Substitution Boxes.** – The S-boxes carry out the real mixing (confusion). DES uses 8 S-boxes, each with a 6-bit input and a 4-bit output. Refer the following illustration –



The S-box rule is illustrated below

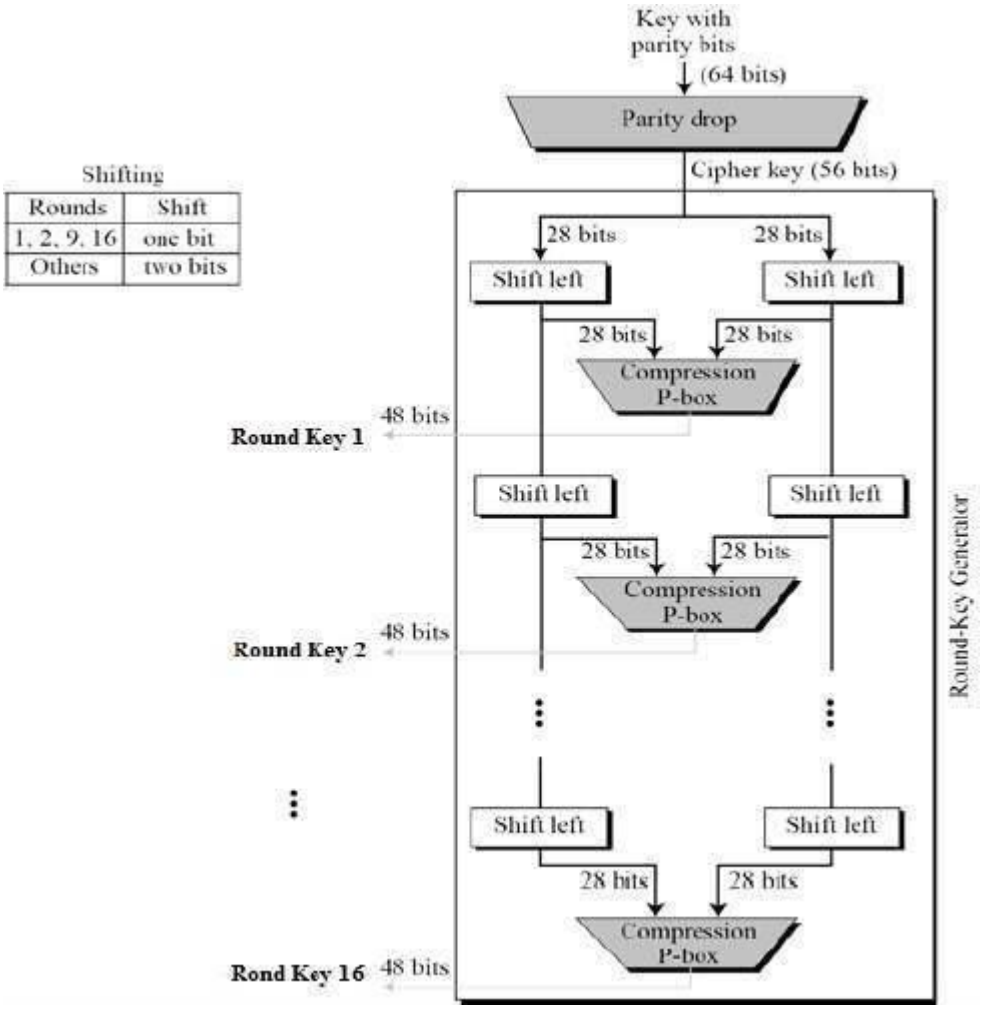


 There are a total of eight S-box tables. The output of all eight s-boxes is then combined in to 32 bit section.

 Straight Permutation – The 32 bit output of S-boxes is then subjected to the straight permutation with rule shown in the following illustration:

Key Generation

The round-key generator creates sixteen 48-bit keys out of a 56-bit cipher key. The process of key generation is depicted in the following illustration



Shifting

Rounds	Shift
1, 2, 9, 16	one bit
Others	two bits

ADVANCED ENCRYPTION STANDARD

The Advanced Encryption Standard (AES) was published by the National Institute ofStandards and Technology (NIST) in 2001. AES is a symmetric block cipher that isintended to replace DES as the approved standard for a wide range of applications.

AES is a block cipher intended to replace DES for commercial applications. It uses a 128-bit block size and a key size of 128, 192, or 256 bits.

AES does not use a Feistel structure. Instead, each full round consists offour separate functions: byte substitution, permutation, arithmetic operations over a finite field, and XOR with a key.

General Structure

Figure shows the overall structure of the AES encryption process. The cipher takes a plaintext block size of 128 bits, or 16 bytes. The key length can be 16, 24, or 32bytes (128, 192, or 256 bits). The algorithm is referred to as AES-128, AES-192, orAES-256, depending on the key length.

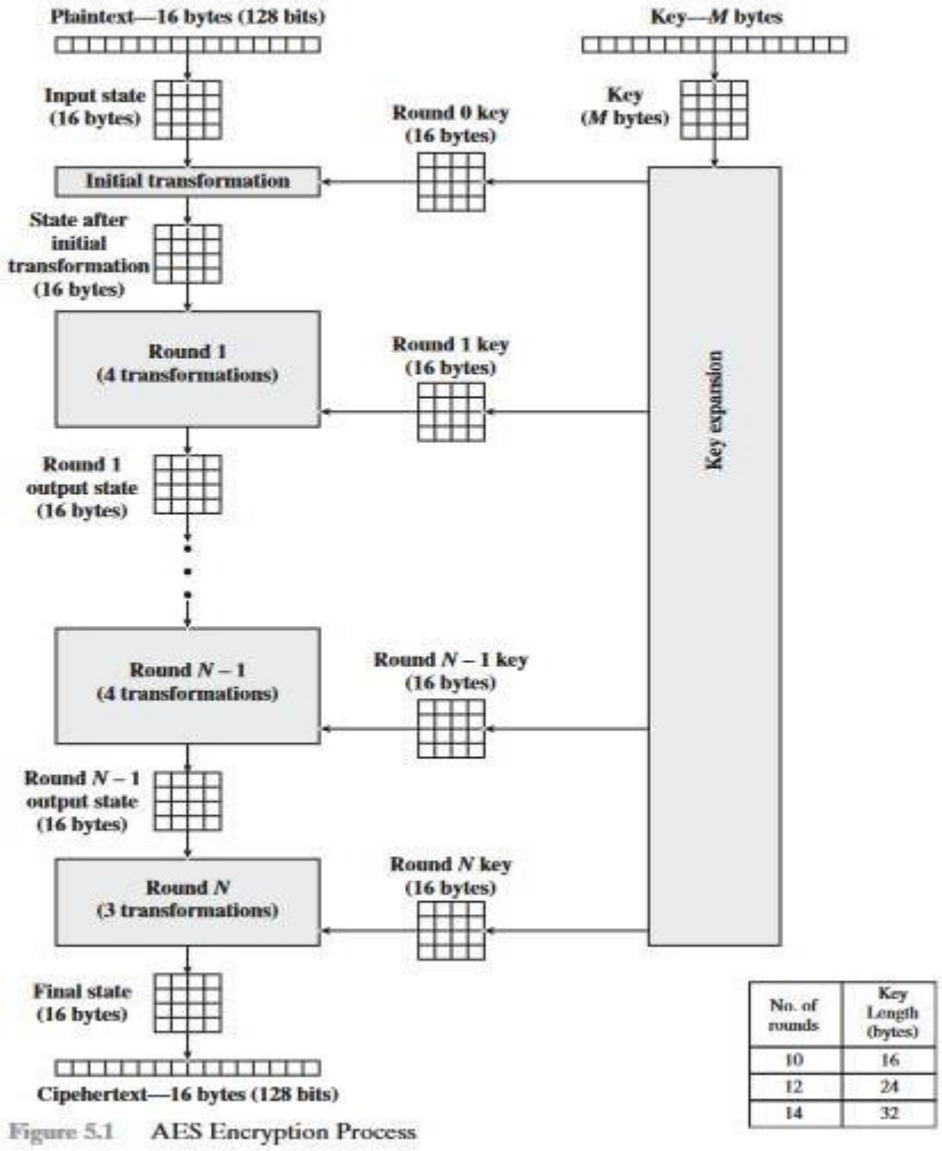


Figure 5.1 AES Encryption Process

Advanced Encryption Standard is found at least six time faster than triple DES. A replacement for DES was needed as its key size was too small. With increasing computing power, it was considered vulnerable against exhaustive key search attack. Triple DES was designed to overcome this drawback but it was found slow.

The features of AES are as follows –

- Symmetric key symmetric block cipher
- 128-bit data, 128/192/256-bit keys
- Stronger and faster than Triple-DES
- Provide full specification and design details
- Software implementable in C and Java

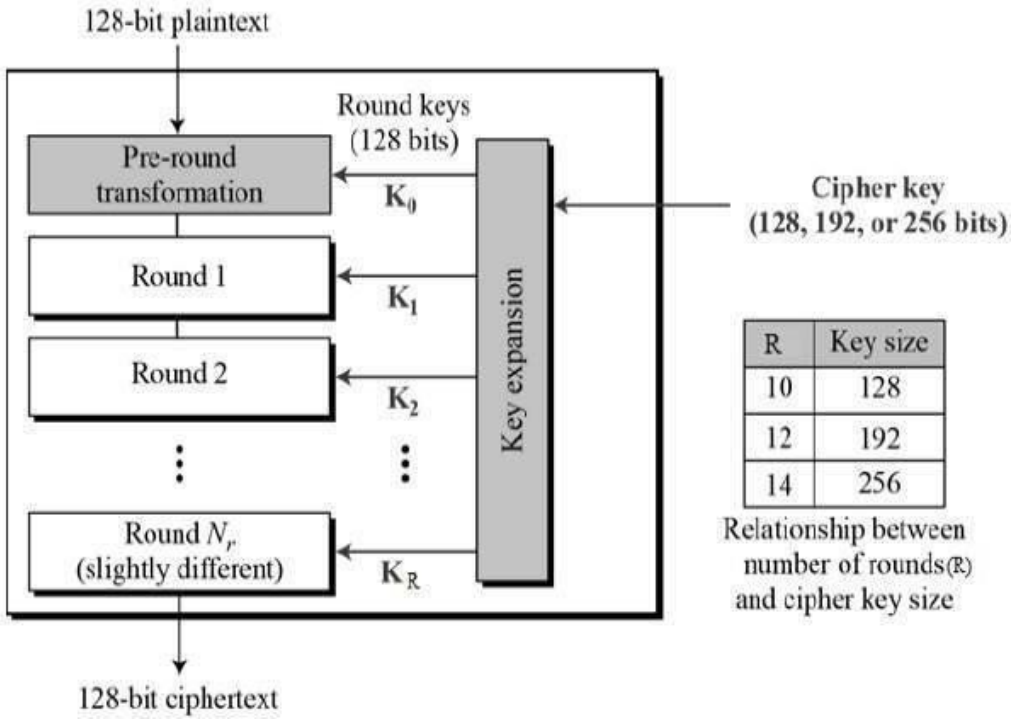
Operation of AES

AES is an iterative rather than Feistel cipher. It is based on 'substitution-permutation network'. It comprises of a series of linked operations, some of which involve replacing inputs by specific outputs (substitutions) and others involve shuffling bits around (permutations).

Interestingly, AES performs all its computations on bytes rather than bits. Hence, AES treats the 128 bits of a plaintext block as 16 bytes. These 16 bytes are arranged in four columns and four rows for processing as a matrix –

Unlike DES, the number of rounds in AES is variable and depends on the length of the key. AES uses 10 rounds for 128-bit keys, 12 rounds for 192-bit keys and 14 rounds for 256-bit keys. Each of these rounds uses a different 128-bit round key, which is calculated from the original AES key.

The schematic of AES structure is given in the following illustration

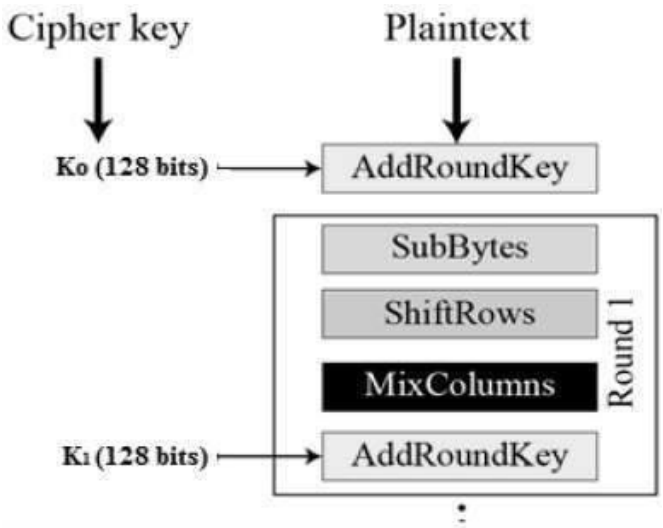


R	Key size
10	128
12	192
14	256

Relationship between number of rounds(R) and cipher key size

Encryption Process

Here, we restrict to description of a typical round of AES encryption. Each round comprise of four sub-processes. The first round process is depicted below –



Byte Substitution (SubBytes)

The 16 input bytes are substituted by looking up a fixed table (S-box) given in design. The result is in a matrix of four rows and four columns.

Shiftrows

Each of the four rows of the matrix is shifted to the left. Any entries that 'fall off' are re-inserted on the right side of row. Shift is carried out as follows –

- First row is not shifted.
- Second row is shifted one (byte) position to the left.
- Third row is shifted two positions to the left.
- Fourth row is shifted three positions to the left.
- The result is a new matrix consisting of the same 16 bytes but shifted with respect to each other.

```
[ b0  | b1  | b2  | b3  ]          [ b0  | b1  | b2  | b3  ]
| b4  | b5  | b6  | b7  |    ->    | b5  | b6  | b7  | b4  |
| b8  | b9  | b10 | b11 |          | b10 | b11 | b8  | b9  |
[ b12 | b13 | b14 | b15 ]          [ b15 | b12 | b13 | b14 ]
```

MixColumns

Each column of four bytes is now transformed using a special mathematical function. This function takes as input the four bytes of one column and outputs four completely new bytes, which replace the original column. The result is another new matrix consisting of 16 new bytes. It should be noted that this step is not performed in the last round.

```
[ c0 ]          [ 2  3  1  1 ] [ b0 ]
| c1 |  =       | 1  2  3  1 || b1 |
| c2 |          | 1  1  2  3 || b2 |
[ c3 ]          [ 3  1  1  2 ][ b3 ]
```

Addroundkey

The 16 bytes of the matrix are now considered as 128 bits and are XORed to the 128 bits of the round key. If this is the last round then the output is the ciphertext. Otherwise, the resulting 128 bits are interpreted as 16 bytes and we begin another similar round.

Decryption Process

The process of decryption of an AES ciphertext is similar to the encryption process in the reverse order. Each round consists of the four processes conducted in the reverse order –

- Add round key
- Mix columns
- Shift rows
- Byte substitution

Since sub-processes in each round are in reverse manner, unlike for a Feistel Cipher, the encryption and decryption algorithms needs to be separately implemented, although they are very closely related.

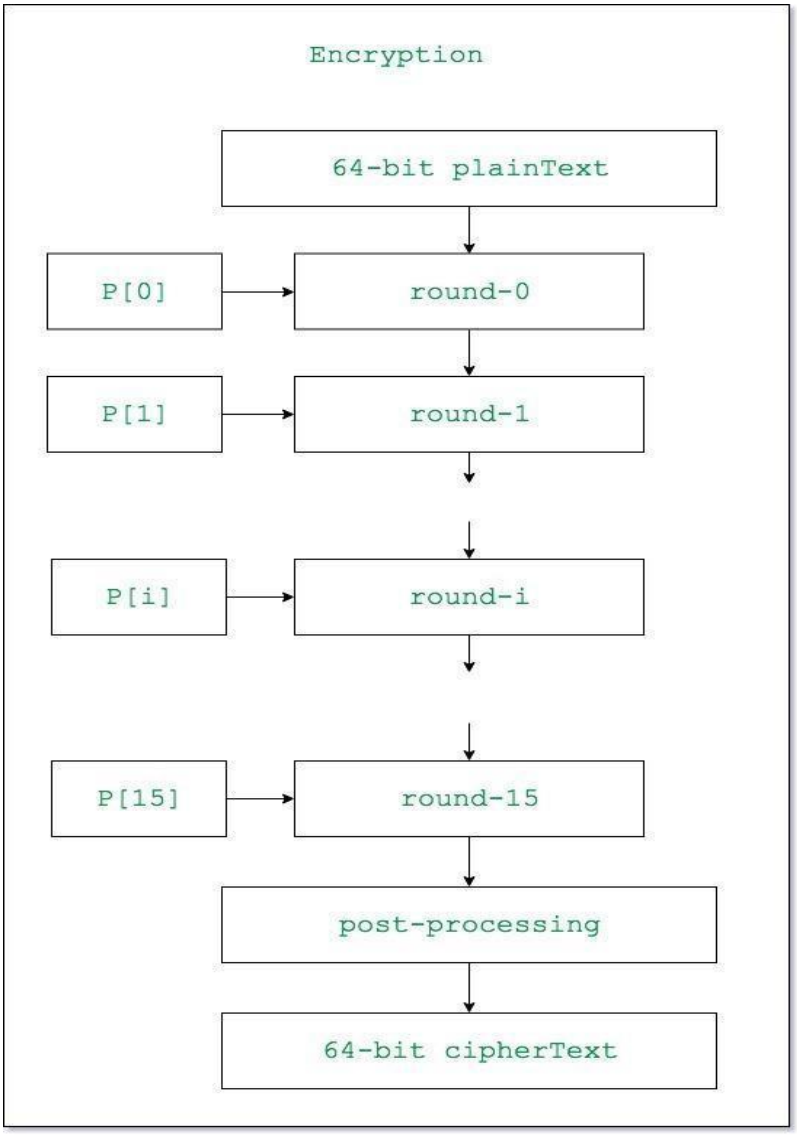
BLOWFISH ALGORITHM

Blowfish is an encryption technique designed by Bruce Schneier in 1993 as an alternative to DES Encryption Technique. It is significantly faster than DES and provides a good encryption rate with no effective cryptanalysis technique found to date. It is one of the first, secure block cyphers not subject to any patents and hence freely available for anyone to use.

1. blockSize: 64-bits
2. keySize: 32-bits to 448-bits variable size
3. number of subkeys: 18 [P-array]
4. number of rounds: 16
5. number of substitution boxes: 4 [each having 512 entries of 32-bits each]

Blowfish Encryption Algorithm

The entire encryption process can be elaborated as:



Lets see each step one by one:

Step1: Generation of subkeys:

- 18 subkeys{P[0]…P[17]} are needed in both encryption as well as decryption process and the same subkeys are used for both the processes.
- These 18 subkeys are stored in a P-array with each array element being a 32-bit entry.
- It is initialized with the digits of pi(?).
- The hexadecimal representation of each of the subkeys is given by:

32-bit hexadecimal representation of initial values of sub-keys

P[0]	243f6a88	P[9]	38d01377
P[1]	85a308d3	P[10]	be5466cf
P[2]	13198a2e	P[11]	34e90c6c
P[3]	03707344	P[12]	c0ac29b7
P[4]	a4093822	P[13]	c97c50dd
P[5]	299f31d0	P[14]	3f84d5b5
P[6]	082efa98	P[15]	b5470917
P[7]	ec4e6c89	P[16]	9216d5d9
P[8]	452821e6	P[17]	8979fb1b

Now each of the subkey is changed with respect to the input key as:

P[0] = P[0] xor 1st 32-bits of input key
P[1] = P[1] xor 2nd 32-bits of input key
.
.
.
P[i] = P[i] xor (i+1)th 32-bits of input key
(roll over to 1st 32-bits depending on the key length)
.
.
.
P[17] = P[17] xor 18th 32-bits of input key
(roll over to 1st 32-bits depending on key length)

The resultant P-array holds 18 subkeys that is used during the entire encryption process

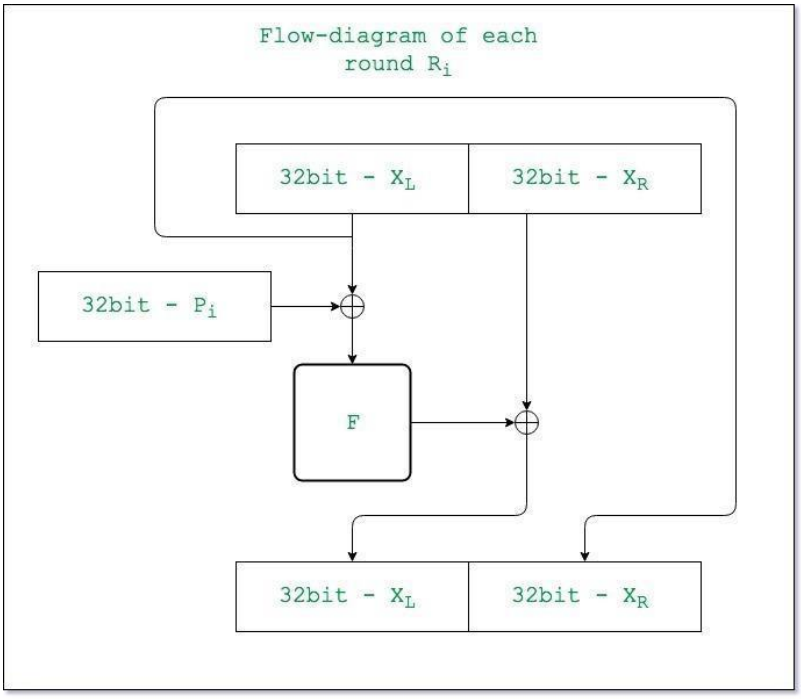
Step2: initialise Substitution Boxes:

- 4 Substitution boxes(S-boxes) are needed{S[0]…S[4]} in both encryption aswell as decryption process with each S-box having 256 entries{S[i][0]…S[i][255], 0&lei&le4} where each entry is 32-bit.
- It is initialized with the digits of pi(?) after initializing the P-array.

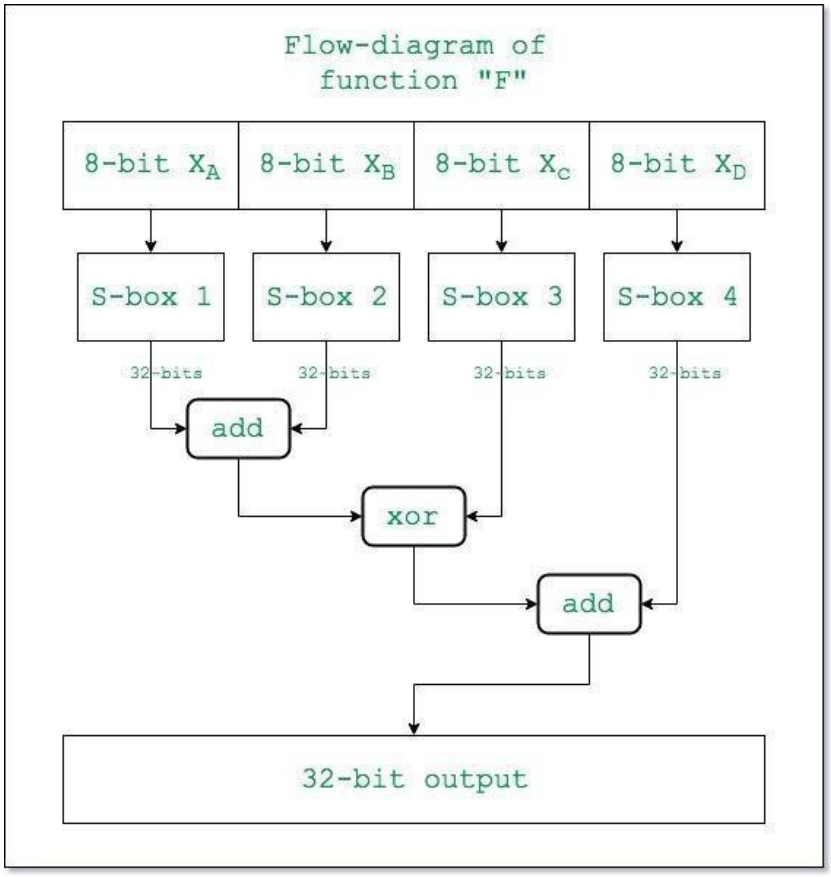
Step3: Encryption:

- The encryption function consists of two parts:
  a. Rounds: The encryption consists of 16 rounds with each round(Ri)

taking inputs the plainText(P.T.) from previous round and corresponding subkey(Pi). The description of each round is as follows:

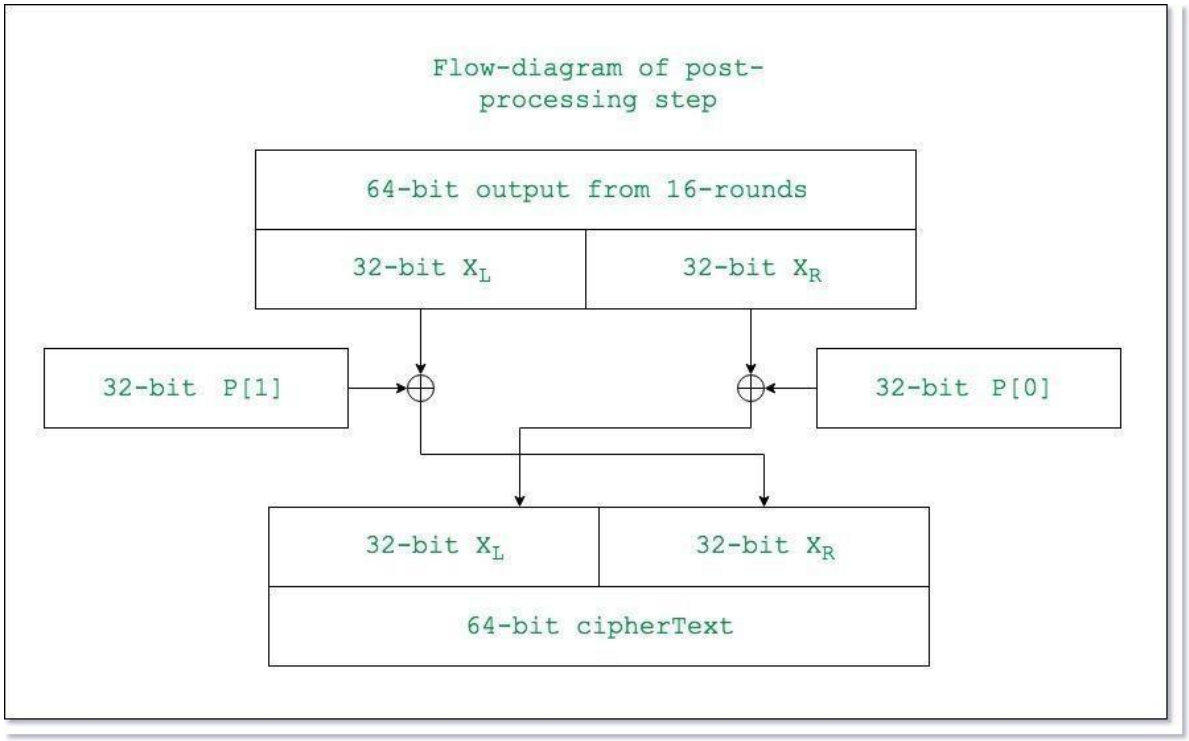


The description of the function " F " is as follows:



Here the function "add" is addition modulo 2^32.

b. Post-processing: The output after the 16 rounds is processed as follows:



DIFFERENTIAL AND LINEAR CRYPTANALYSIS

One of the most significant advances in cryptanalysis in recent years is differentialcryptanalysis.

DIFFERENTIAL CRYPTANALYSIS ATTACK The differential cryptanalysis attack is complex, provides a complete description. The rationale behind differentialcryptanalysis is to observe the behaviour of pairs of text blocks evolving along eachround of the cipher, instead of observing the evolution of a single text block.

We begin with a change in notation for DES. Consider the original plaintext block m to consist of two halves m_0, m_1. Each round of DES maps the right-hand input into the left-hand output and sets the right-hand output to be a function of the left-hand input and the subkey for this round. So, at each round, only one new 32-bit block is created. If we label each new block $m_i (2 \leq i \leq 17)$, then the intermediate message halves are related as follows:

$$m_{i+1} = m_{i-1} \oplus \mathrm{f}(m_i, K_i), \qquad i = 1, 2, \ldots, 16$$

In differential cryptanalysis, we start with two messages, m and m', with a known XOR difference $\Delta m = m \oplus m'$, and consider the difference between the intermediate message halves: $\Delta m_i = m_i \oplus m'_i$. Then we have

$$\begin{aligned} \Delta m_{i+1} &= m_{i+1} \oplus m'_{i+1} \\ &= [m_{i-1} \oplus \mathrm{f}(m_i, K_i)] \oplus [m'_{i-1} \oplus \mathrm{f}(m'_i, K_i)] \\ &= \Delta m_{i-1} \oplus [\mathrm{f}(m_i, K_i) \oplus \mathrm{f}(m'_i, K_i)] \end{aligned}$$

Linear Cryptanalysis

This attackis based on finding linear approximations to describe the transformations performed inDES. This method can find a DES key given 2^{43}known plaintexts, as compared to 2^{47}chosen plaintexts for differential cryptanalysis. Although this is a minor improvement,because it may be easier to acquire known plaintext rather than chosen plaintext, it stillleaves linear cryptanalysis infeasible as an attack on DES.

We now give a brief summary of the principle on which linear cryptanalysis is based. For a cipher with n-bit plaintext and ciphertext blocks and an m-bit key, let the plaintext block be labeled P[1], ... P[n], the cipher text block C[1], ... C[n], and the key K[1], ..., K[m]. Then define

$$A[i, j, \ldots, k] = A[i] \oplus A[j] \oplus \ldots \oplus A[k]$$

The objective of linear cryptanalysis is to find an effective *linear* equation of the form:

$$P[\alpha_1, \alpha_2, \ldots, \alpha_a] \oplus C[\beta_1, \beta_2, \ldots, \beta_b] = K[\gamma_1, \gamma_2, \ldots, \gamma_c]$$

(where $x = 0$ or 1; $1 \leq a$; $b \leq n$; $c \leq m$; and where the α, β, and γ terms represent fixed, unique bit locations) that holds with probability $p \neq 0.5$. The further p is from 0.5, the more effective the equation. Once a proposed relation is determined, the procedure is to compute the results of the left-hand side of the preceding equation for a large number of plaintext–ciphertext pairs. If the result is 0 more than half the time, assume $K[\gamma_1, \gamma_2, \ldots, \gamma_c] = 0$. If it is 1 most of the time, assume $K[\gamma_1, \gamma_2, \ldots, \gamma_c] = 1$.

BLOCK CIPHER MODES OF OPERATION

A block cipher processes the data blocks of fixed size. Usually, the size of a message is larger than the block size. Hence, the long message is divided into a series of sequential message blocks, and the cipher operates on these blocks one at a time.

Electronic Code Book (ECB) Mode

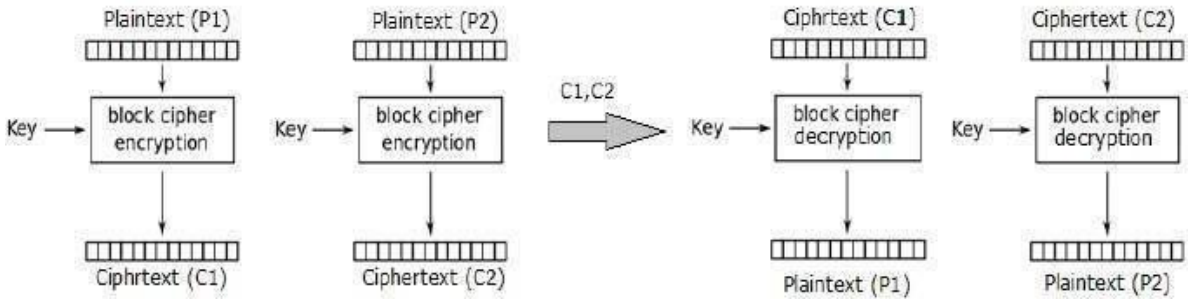
This mode is a most straightforward way of processing a series of sequentially listed message blocks.

Operation

- The user takes the first block of plaintext and encrypts it with the key to produce the first block of ciphertext.
- He then takes the second block of plaintext and follows the same process with same key and so on so forth.

The ECB mode is **deterministic**, that is, if plaintext block P1, P2,…, Pm are encrypted twice under the same key, the output ciphertext blocks will be the same.

In fact, for a given key technically we can create a codebook of ciphertexts for all possible plaintext blocks. Encryption would then entail only looking up for required plaintext and select the corresponding ciphertext. Thus, the operation is analogous to the assignment of code words in a codebook, and hence gets an official name – Electronic Codebook mode of operation (ECB). It is illustrated as follows



Analysis of ECB Mode

In reality, any application data usually have partial information which can be guessed. For example, the range of salary can be guessed. A ciphertext from ECB can allow an attacker to guess the plaintext by trial-and-error if the plaintext message is within predictable.

For example, if a ciphertext from the ECB mode is known to encrypt a salary figure, then a small number of trials will allow an attacker to recover the figure. In general, we do not wish to use a deterministic cipher, and hence the ECB mode should not be used in most applications.

Cipher Block Chaining (CBC) Mode

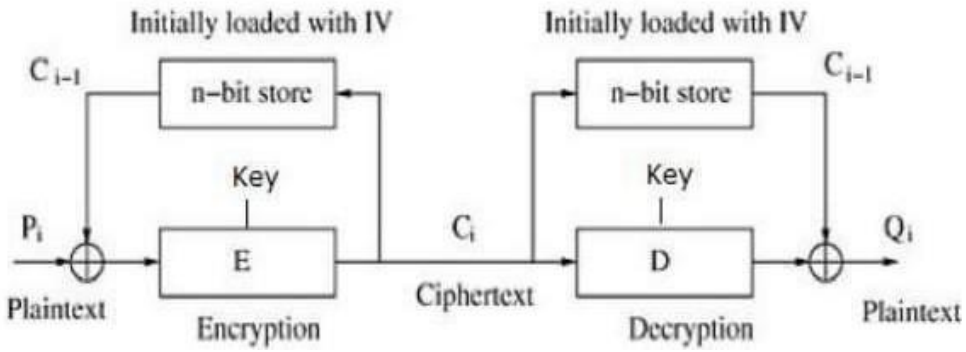
CBC mode of operation provides message dependence for generating ciphertext and makes the system non-deterministic.

Operation

The operation of CBC mode is depicted in the following illustration. The steps are as follows –

- Load the n-bit Initialization Vector (IV) in the top register.
- XOR the n-bit plaintext block with data value in top register.
- Encrypt the result of XOR operation with underlying block cipher with key K.

- Feed ciphertext block into top register and continue the operation till all plaintext blocks are processed.
- For decryption, IV data is XORed with first ciphertext block decrypted. The first ciphertext block is also fed into to register replacing IV for decrypting next ciphertext block.



Analysis of CBC Mode

In CBC mode, the current plaintext block is added to the previous ciphertext block, and then the result is encrypted with the key. Decryption is thus the reverse process, which involves decrypting the current ciphertext and then adding the previous ciphertext block to the result.

Advantage of CBC over ECB is that changing IV results in different ciphertext for identical message. On the drawback side, the error in transmission gets propagated to few further block during decryption due to chaining effect.

It is worth mentioning that CBC mode forms the basis for a well-known data origin authentication mechanism. Thus, it has an advantage for those applications that require both symmetric encryption and data origin authentication.

Cipher Feedback (CFB) Mode

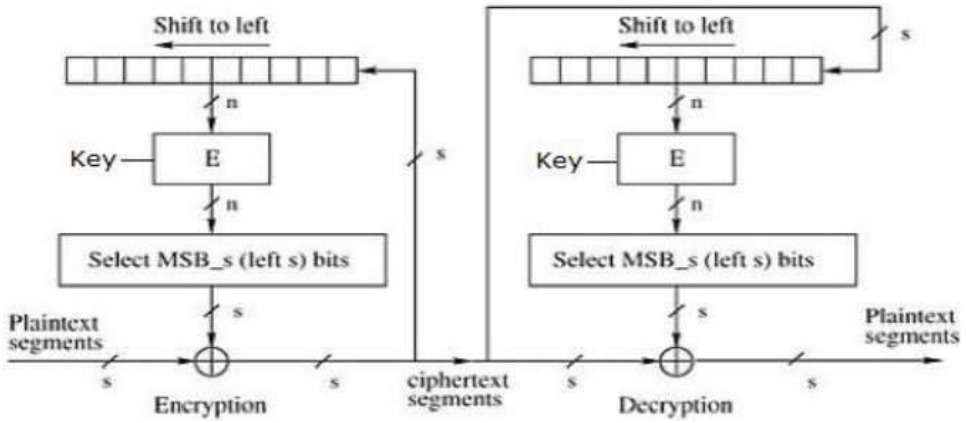
In this mode, each ciphertext block gets 'fed back' into the encryption process in order to encrypt the next plaintext block.

Operation

The operation of CFB mode is depicted in the following illustration. For example, in the present system, a message block has a size 's' bits where 1 < s < n. The CFB mode requires an initialization vector (IV) as the initial random n-bit input block. The IV need not be secret. Steps of operation are –

- Load the IV in the top register.

- Encrypt the data value in top register with underlying block cipher with key K.
- Take only 's' number of most significant bits (left bits) of output of encryption process and XOR them with 's' bit plaintext message block to generate ciphertext block.
- Feed ciphertext block into top register by shifting already present data to the left and continue the operation till all plaintext blocks are processed.
- Essentially, the previous ciphertext block is encrypted with the key, and then the result is XORed to the current plaintext block.
- Similar steps are followed for decryption. Pre-decided IV is initially loaded at the start of decryption.



Analysis of CFB Mode

CFB mode differs significantly from ECB mode, the ciphertext corresponding to a given plaintext block depends not just on that plaintext block and the key, but also on the previous ciphertext block. In other words, the ciphertext block is dependent of message.

CFB has a very strange feature. In this mode, user decrypts the ciphertext using only the encryption process of the block cipher. The decryption algorithm of the underlying block cipher is never used.

Apparently, CFB mode is converting a block cipher into a type of stream cipher. The encryption algorithm is used as a key-stream generator to produce key-stream that is placed in the bottom register. This key stream is then XORed with the plaintext as in case of stream cipher.

By converting a block cipher into a stream cipher, CFB mode provides some of the advantageous properties of a stream cipher while retaining the advantageous properties of a block cipher.

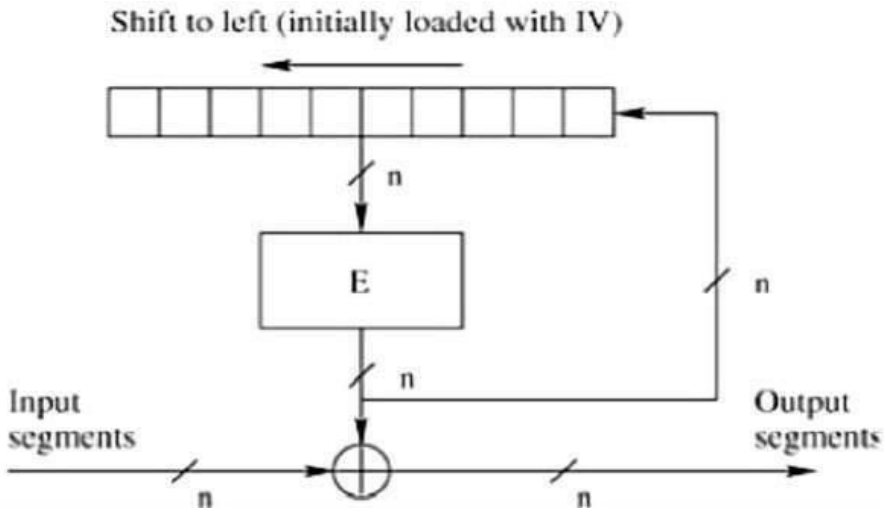
On the flip side, the error of transmission gets propagated due to changing of blocks.

Output Feedback (OFB) Mode

It involves feeding the successive output blocks from the underlying block cipher back to it. These feedback blocks provide string of bits to feed the encryption algorithm which act as the key-stream generator as in case of CFB mode.

The key stream generated is XOR-ed with the plaintext blocks. The OFB mode requires an IV as the initial random n-bit input block. The IV need not be secret.

The operation is depicted in the following illustration –



Counter (CTR) Mode

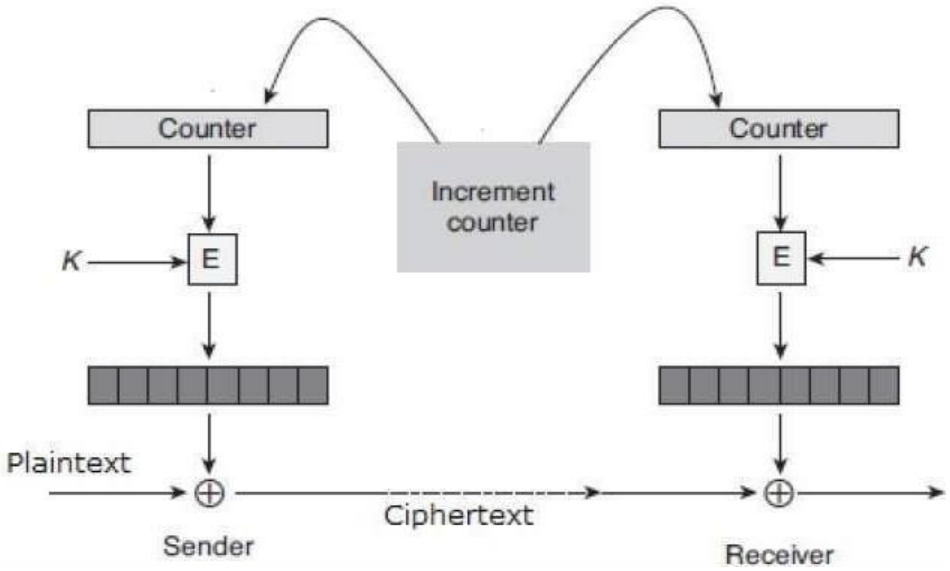
It can be considered as a counter-based version of CFB mode without the feedback. In this mode, both the sender and receiver need to access to a reliable counter, which computes a new shared value each time a ciphertext block is exchanged. This shared counter is not necessarily a secret value, but challenge is that both sides must keep the counter synchronized.

Operation

Both encryption and decryption in CTR mode are depicted in the following illustration. Steps in operation are –

- Load the initial counter value in the top register is the same for both the sender and the receiver. It plays the same role as the IV in CFB (and CBC) mode.
- Encrypt the contents of the counter with the key and place the result in the bottom register.

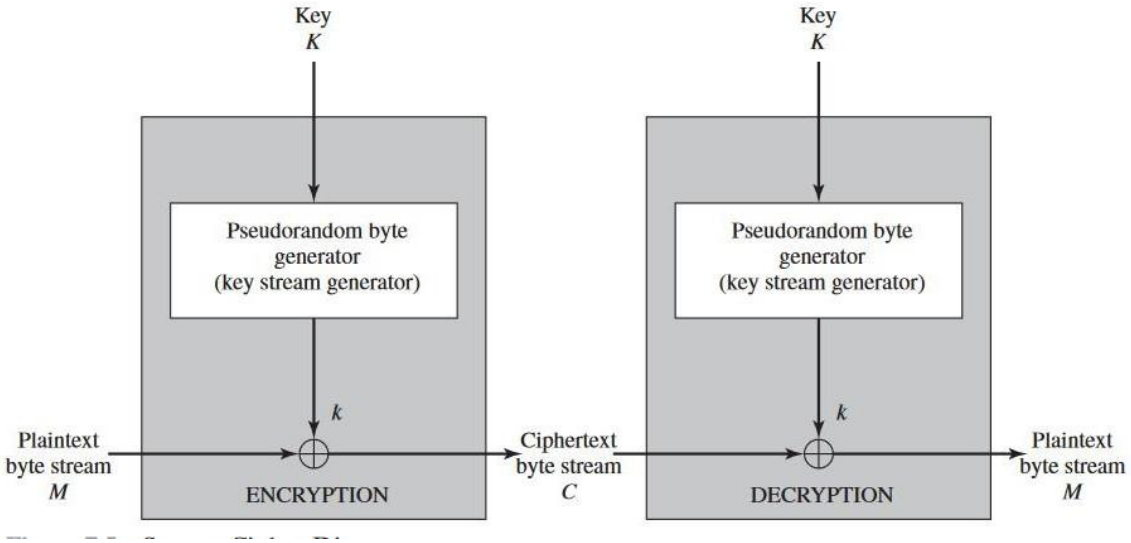
- Take the first plaintext block P1 and XOR this to the contents of the bottom register. The result of this is C1. Send C1 to the receiver and update the counter. The counter update replaces the ciphertext feedback in CFB mode.
- Continue in this manner until the last plaintext block has been encrypted.
- The decryption is the reverse process. The ciphertext block is XORed with the output of encrypted contents of counter value. After decryption of each ciphertext block counter is updated as in case of encryption.



STREAM CIPHERS

A typical stream cipher encrypts plaintext one byte at a time, although a stream cipher may be designed to operate on one bit at a time or on units larger than a byteat a time. A key is input to a pseudorandom bit generator that produces a stream of8-bit numbers that are apparently random. The output of the generator, called akeystream, is combined one byte at a time with the plaintext stream using the bit-wise exclusive-OR (XOR) operation. For example, if the next byte generated by thegenerator is 01101100 and the next plaintext byte is 11001100, then the resultingciphertext byte is

```
  11001100  plaintext
⊕ 01101100  key stream
  10100000  ciphertext
```



STREAM CIPHERS

Decryption requires the use of the same pseudorandom sequence

```
  10100000  ciphertext
⊕ 01101100  key stream
  11001100  plaintext
```

RC4

RC4 is a stream cipher designed in 1987 by Ron Rivest for RSA Security. It is a variable key size stream cipher with byte-oriented operations. The algorithm is based onthe use of a random permutation. Analysis shows that the period of the cipher is overwhelmingly likely to be greater than 10^{100}. Eight to sixteen machine operations are required per output byte, and the cipher can be expected to run veryquickly in software. RC4 is used in the Secure Sockets Layer/Transport Layer Security(SSL/TLS) standards that have been defined for communication between Webbrowsers and servers.

The RC4 algorithm is remarkably simple and quite easy to explain. A variable length key of from 1 to 256 bytes (8 to 2048 bits) is used to initialize a 256-bytestate vector S, with elementsS[0],S[1],S[2], S[255].

Initialization of S

To begin, the entries are set equal to the values from 0 through 255 in ascendingorder; that is, S[0],S[1],S[2], S[255]=255.

A temporary vector, T, is alsocreated. If the length of the key K is 256 bytes, then T is transferred to T. Otherwise,for a key of length keylen bytes, the first keylen elements of T are copied from K,and then K is repeated as many times as necessary to fill out T. These preliminaryoperations can be summarized as

```
/* Initialization */
for i = 0 to 255 do
S[i] = i;
T[i] = K[i mod keylen];
```

Next we use T to produce the initial permutation of S. This involves starting with S[0] and going through to S[255], and for each S[i], swapping S[i] with another byte in S according to a scheme dictated by T[i]:

```
/* Initial Permutation of S */
j = 0;
for i = 0 to 255 do
    j = (j + S[i] + T[i]) mod 256;
Swap (S[i], S[j]);
```

Stream Generation

Once the S vector is initialized, the input key is no longer used. Stream generationinvolves cycling through all the elements of S[i] , and for each S[i], swapping S[i] withanother byte in S according to a scheme dictated by the current configuration of S.After S[255]is reached, the process continues, starting over again at S[0].

```
/* Stream Generation */
i, j = 0;
while (true)
i = (i + 1) mod 256;
j = (j + S[i]) mod 256;
Swap (S[i], S[j]);
t = (S[i] + S[j]) mod 256;
k = S[t];
```

LOCATION AND PLACEMENT OF ENCRYPTION FUNCTION

If encryption is to be used to counter attacks on confidentiality, we need to decide what to encrypt and where the encryption function should be located. To begin, this section examines the potential locations of security attacks and then looks at the two major approaches to encryption placement: link and end to end.

Potential Locations for Confidentiality Attacks

As an example, consider a user workstation in a typical business organization. Figure 7.1 suggests the types of communications facilities that might be employed by such a workstation and therefore gives an indication of the points of vulnerability.

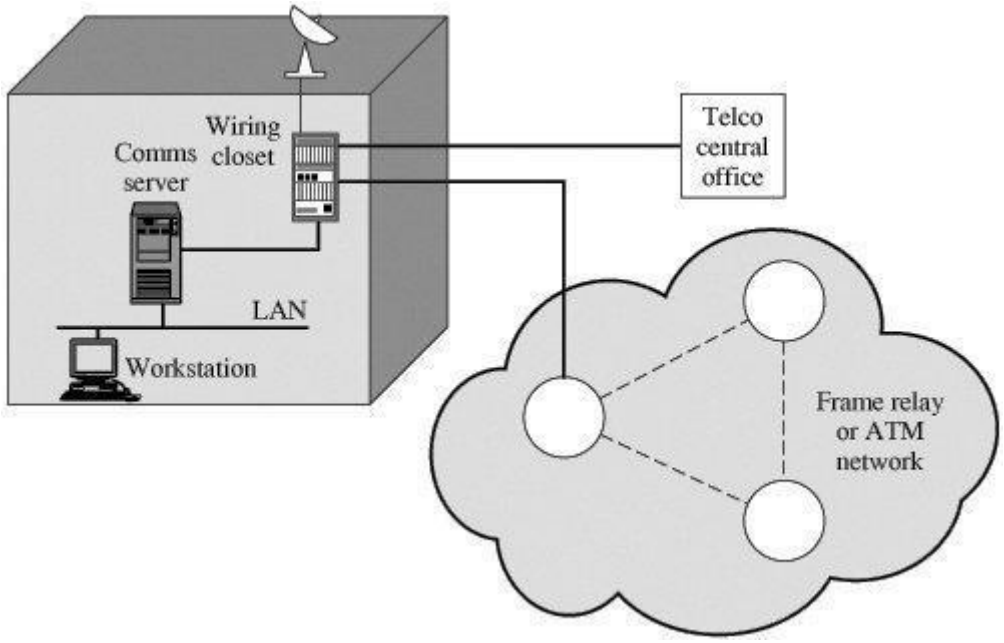


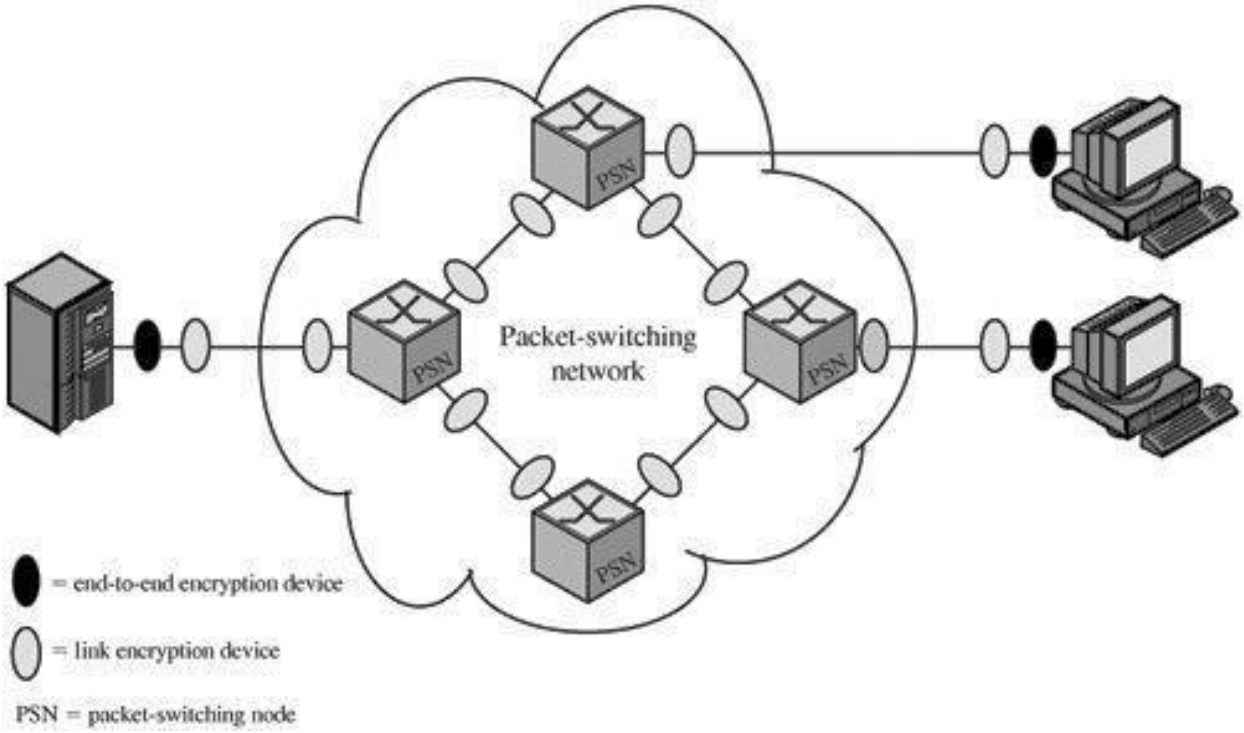
Figure 7.1. Points of Vulnerability

In most organizations, workstations are attached to local area networks (LANs). Typically, the user can reach other workstations, hosts, and servers directly on the LAN or on other LANs in the same building that are interconnected with bridges and routers. Here, then, is the first point of vulnerability. In this case, the main concern is eavesdropping by another employee. Typically, a LAN is a broadcast network: Transmission from any station to any other station is visible on the LAN medium to all stations. Data are transmitted in the form of frames, with each frame containing the source and destination address. An eavesdropper can monitor the traffic on the LAN and capture any traffic desired on the basis of source and destination addresses. If part or all of the LAN is wireless, then the potential for eavesdropping is greater.

Link versus End-to-End Encryption

The most powerful and most common approach to securing the points of vulnerability highlighted in the preceding section is encryption. If encryption is to be used to counter these attacks, then we need to decide what to encrypt and

where the encryption gear should be located. As Figure indicates, there are two fundamental alternatives: link encryption and end-to-end encryption.



Encryption Across a Packet-Switching Network

Table 7.1. Characteristics of Link and End-to-End Encryption [PFLE02]

Link Encryption	End-to-End Encryption
Security within End Systems and Intermediate Systems	
Message exposed in sending host	Message encrypted in sending host
Message exposed in intermediate nodes	Message encrypted in intermediate nodes
Role of User	
Applied by sending host	Applied by sending process
Transparent to user	User applies encryption
Host maintains encryption facility	User must determine algorithm
One facility for all users	Users selects encryption scheme
Can be done in hardware	Software implementation
All or no messages encrypted	User chooses to encrypt, or not, for each message
Implementation Concerns	
Requires one key per (host-intermediate node) pair and (intermediate node-intermediate node) pair	Requires one key per user pair
Provides host authentication	Provides user authentication

PRINCIPLES OF PUBLIC KEY CRYPTOSYSTEMS

The concept of public-key cryptography evolved from an attempt to attack two ofthe most difficult problems associated with symmetric encryption. The first problem is that of key distribution.

The second problem that Diffie pondered, and one that was apparentlyunrelated to the first, was that of digital signatures.

Public key Cryptosystem – Asymmetric algorithms depends on one key for encryption and a distinct but related key for decryption. These algorithms have the following characteristics which are as follows –

- It is computationally infeasible to decide the decryption key given only information of the cryptographic algorithm and the encryption key.
- There are two related keys such as one can be used for encryption, with the other used for decryption.

A public key encryption scheme has the following ingredients which are as follows

- **Plaintext** – This is the readable message or information that is informer into the algorithm as input.
- **Encryption algorithm** – The encryption algorithm performs several conversion on the plaintext.
- **Public and Private keys** – This is a set of keys that have been selected so that if one can be used for encryption, and the other can be used for decryption.
- **Ciphertext** – This is scrambled message generated as output. It based on the plaintext and the key. For a given message, there are two specific keys will create two different ciphertexts.
- **Decryption Algorithm** – This algorithm get the ciphertext and the matching key and create the original plaintext.

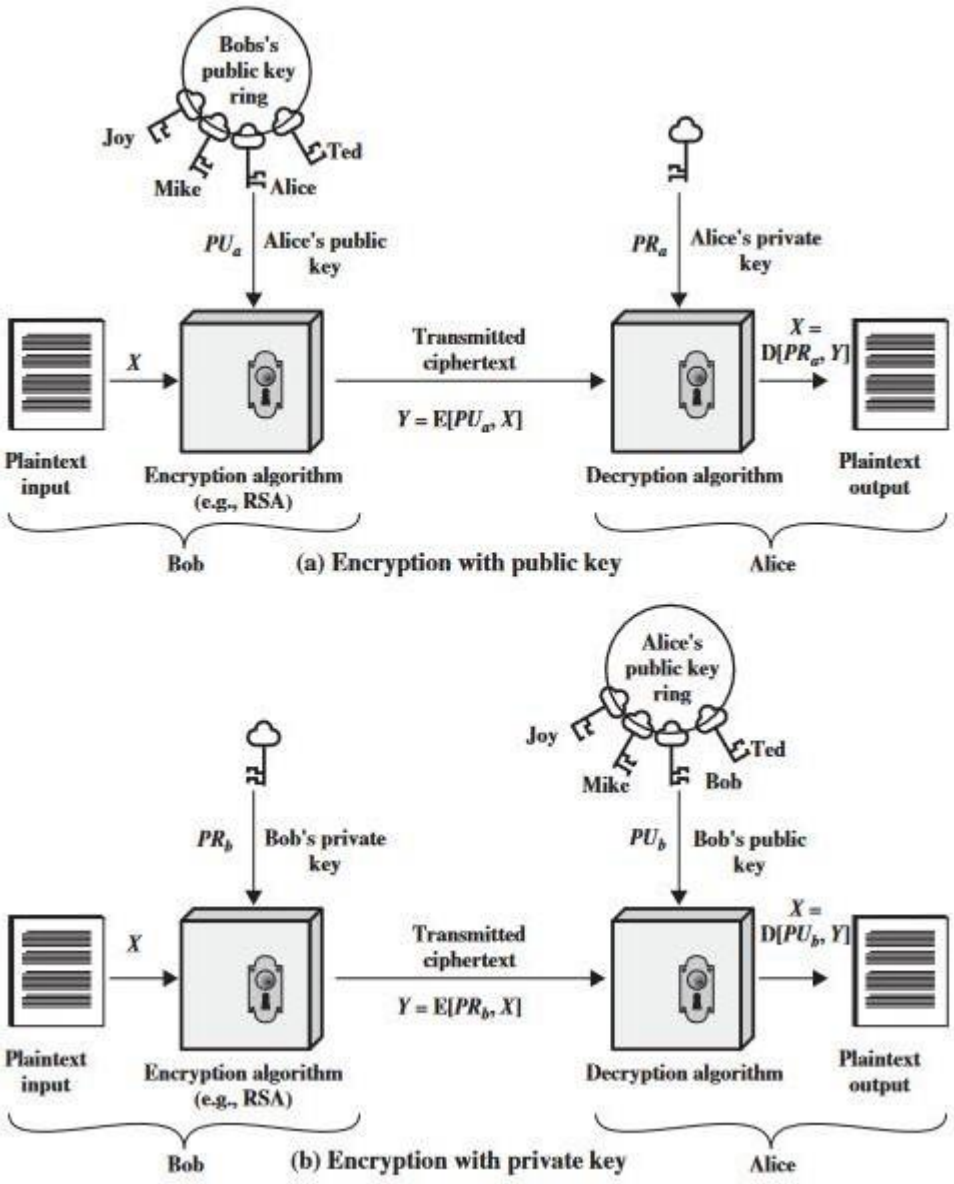
The essential steps are the following.

1. Each user generates a pair of keys to be used for the encryption and decryption of messages.

2. Each user places one of the two keys in a public register or other accessible file. This is the public key.The companion key is kept private. As in Figure suggests, each user maintains a collection of public keys obtained from others.

3. If Bob wishes to send a confidential message to Alice, Bob encrypts the message using Alice's public key.

4. When Alice receives the message, she decrypts it using her private key. No other recipient can decrypt the message because only Alice knows Alice'sprivate key.



Public Key Cryptography Requirements

To accomplish the public key cryptography there are following requirements as discussed below.

- The computation of the pair of keys i.e. private key and the public key must be easy.
- Knowing the encryption algorithm and public key of the intended receiver, computation of cipher text must be easy.
- For a receiver of the message, it should be computationally easy to decrypt the obtained cipher text using his private key.
- It is also required that any opponent in the network knowing the public key should be unable to determine its corresponding private key.
- Having the cipher text and public key an opponent should be unable to determine the original message.

- The two keys i.e. public and private key can be implemented in both orders D[PU, E(PR, M)] = D[PR, E(PU, M)]

RSA ALGORITHM

In this algorithm two keys were used. One is private key and another one is public key.

RSA Algorithm

- Ron Rivest, Adi Shamir and Len Adleman have developed this algorithm (Rivest-Shamir-Adleman). It is a block cipher which converts plain text into cipher text and vice versa at receiver side.

- **The algorithm works as follow:**
  1. Select two prime numbers p and q where $p \neq q$.
  2. Calculate $n = p * q$.
  3. Calculate $\Phi(n) = (p-1) * (q-1)$.
  4. Select e such that, e is relatively prime to $\Phi(n)$
     i.e. $(e, \Phi(n)) = 1$ and $1 < e < \Phi(n)$
  5. Calculate $d = e^{-1} \bmod \Phi(n)$ or $ed = 1 \bmod \Phi(n)$.
  6. Public key = {e, n}, private key = {d, n}.
  7. Find out cipher text using the formula,
     $C = P^e \bmod n$ where, $P < n$ and
     C = Cipher text, P = Plain text, e = Encryption key and n=block size.
  8. $P = C^d \bmod n$. Plain text P can be obtain using the given formula.
     where, d = decryption key.

RSA Algorithm step by step explanation

- **Step – 1:** Select two prime numbers p and q where $p \neq q$.
- **Step – 2:** Calculate $n = p * q$.
- **Step – 3:** Calculate $\Phi(n) = (p-1) * (q-1)$.
- **Step – 4:** Select e such that, e is relatively prime to $\Phi(n)$
  i.e. $(e, \Phi(n)) = 1$ and $1 < e < \Phi(n)$

❖**Explanation with example:**

1. Two prime numbers $p = 13$, $q = 11$.
2. $n = p * q = 13 * 11 = 143$.
3. $\Phi(n) = (13 - 1) * (12 - 1) = 12 * 10 = 120$.
4. Select $e = 13$, gcd $(13, 120) = 1$.

➢ **Step – 5:** Calculate $d = e^{-1} \bmod \Phi(n)$ or $ed = 1 \bmod \Phi(n)$.

❖**Explanation with example:**

5. Finding d:

➔ $e * d \bmod \Phi(n) = 1$

➔ $13 * d \bmod 120 = 1$

(How to find: $d * e = 1 \bmod \Phi(n)$ ➔ $d = ((\Phi(n) * i) + 1) / e$

$d = (120 + 1) / 13 = 9.30$ ($\because i = 1$)

$d = (240 + 1) / 13 = 18.53$ ($\because i = 2$)

$d = (360 + 1) / 13 = 27.76$ ($\because i = 3$)

$d = (480 + 1) / 13 = 37$ ($\because i = 4$))

➢ **Step – 6:** Public key = {e, n}, private key = {d, n}.

➢ **Step – 7:** Find out cipher text using the formula,

$C = P^e \bmod n$ where, $P < n$

C = Cipher text, P = Plain text, e = Encryption key and n=block size.

➢ **Step – 8:** $P = C^d \bmod n$. Plain text P can be obtain using the given formula.

where, d = decryption key.

❖**Explanation with example:**

6. Public key = {13, 143} and private key = {37, 143}.

7. **Encryption :** Plain text ***P = 13***. (where, $P < n$)

$C = P^e \bmod n = 13^{13} \bmod 143 = 52$. ***C = 52***

8. **Decryption:**

$P = C^d \bmod n = 52^{37} \bmod 143 = 13$. ***P = 13***

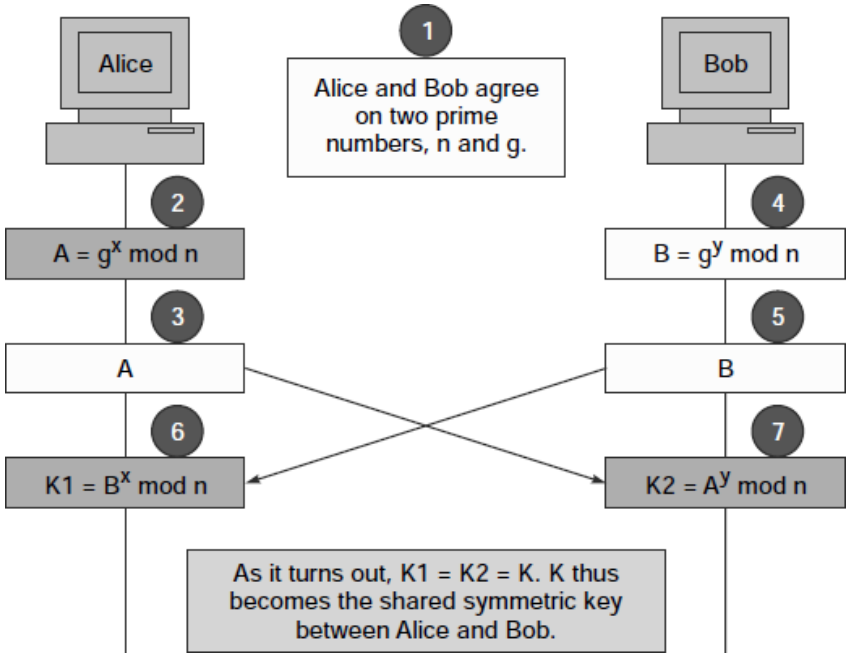
Diffie–Hellman Key Exchange/Agreement Algorithm

In this scheme the two parties, who want to communicatesecurely, can agree on a **symmetric key** using this technique. This key can then be used for encryption/ decryption. However, we must note that Diffie–Hellman key exchange algorithm can be used only forkey agreement, but not for encryption or decryption of messages. Once both the parties agree on the keyto be used, they need to use other symmetric key encryption algorithms for actual encryption or decryption of messages.

Description of the Algorithm

1. Firstly, Alice and Bob agree on two large prime numbers, n and g. These two integers need not be kept secret. Alice and Bob can use an insecure channel to agree on them.
2. Alice chooses another large random number x, and calculates A such that:
   $A = g^x \bmod n$
3. Alice sends the number A to Bob.
4. Bob independently chooses another large random integer y and calculates B such that:
   $B = g^y \bmod n$
5. Bob sends the number B to Alice.
6. A now computes the secret key K1 as follows:
   $K1 = B^x \bmod n$
7. B now computes the secret key K2 as follows:
   $K2 = A^y \bmod n$

Diffie–Hellman key exchange algorithm



Example of the Algorithm

1. Firstly, Alice and Bob agree on two large prime numbers, n and g. These two integers need not be kept secret. Alice and Bob can use an insecure channel to agree on them.

   Let n = 11, g = 7.

2. Alice chooses another large random number x, and calculates A such that:
   $A = g^x \bmod n$

   Let x = 3. Then, we have, $A = 7^3 \bmod 11 = 343 \bmod 11 = 2$.

3. Alice sends the number A to Bob.

   Alice sends 2 to Bob.

4. Bob independently chooses another large random integer y and calculates B such that:
   $B = g^y \bmod n$

   Let y = 6. Then, we have, $B = 7^6 \bmod 11 = 117649 \bmod 11 = 4$.

5. Bob sends the number B to Alice.

   Bob sends 4 to Alice.

6. A now computes the secret key K1 as follows:
   $K1 = B^x \bmod n$

   We have, $K1 = 4^3 \bmod 11 = 64 \bmod 11 = 9$.

7. B now computes the secret key K2 as follows:
   $K2 = A^y \bmod n$

   We have, $K2 = 2^6 \bmod 11 = 64 \bmod 11 = 9$.

ELAGAMAL CRYPTOGRAPHY (ECC)

In this ECC we have three phases

1. Key generation
2. Encryption
3. Decryption

1. Generate a random integer X_A, such that $1 < X_A < q - 1$.
2. Compute $Y^A = \alpha^{X_A} \bmod q$.
3. A's private key is X_A; A's pubic key is $\{q, \alpha, Y_A\}$.

Any user B that has access to A's public key can encrypt a message as follows:

1. Represent the message as an integer M in the range $0 \leq M \leq q - 1$. Longer messages are sent as a sequence of blocks, with each block being an integer less than q.
2. Choose a random integer k such that $1 \leq k \leq q - 1$.
3. Compute a one-time key $K = (Y_A)^k \bmod q$.
4. Encrypt M as the pair of integers (C_1, C_2) where

$$C_1 = \alpha^k \bmod q; \; C_2 = KM \bmod q$$

User A recovers the plaintext as follows:

1. Recover the key by computing $K = (C_1)^{X_A} \bmod q$.
2. Compute $M = (C_2 K^{-1}) \bmod q$.

ElGamal process as follows,

Global Public Elements	
q	prime number
α	$\alpha < q$ and α a primitive root of q

Key Generation by Alice	
Select private X_A	$X_A < q - 1$
Calculate Y_A	$Y_A = \alpha^{XA} \bmod q$
Public key	$PU = \{q, \alpha, Y_A\}$
Private key	X_A

Encryption by Bob with Alice's Public Key	
Plaintext:	$M < q$
Select random integer k	$k < q$
Calculate K	$K = (Y_A)^k \bmod q$
Calculate C_1	$C_1 = \alpha^k \bmod q$
Calculate C_2	$C_2 = KM \bmod q$
Ciphertext:	(C_1, C_2)

Decryption by Alice with Alice's Private Key	
Ciphertext:	(C_1, C_2)
Calculate K	$K = (C_1)^{XA} \bmod q$
Plaintext:	$M = (C_2 K^{-1}) \bmod q$

Thus, K functions as a one-time key, used to encrypt and decrypt the message.

For example, let us start with the prime field GF(19); that is, $q = 19$. It has primitive roots $\{2, 3, 10, 13, 14, 15\}$, as shown in Table 8.3. We choose $\alpha = 10$.

Alice generates a key pair as follows:

1. Alice chooses $X_A = 5$.
2. Then $Y_A = \alpha^{X_A} \bmod q = \alpha^5 \bmod 19 = 3$ (see Table 8.3).
3. Alice's private key is 5; Alice's pubic key is $\{q, \alpha, Y_A\} = \{19, 10, 3\}$.

Suppose Bob wants to send the message with the value $M = 17$. Then,

1. Bob chooses $k = 6$.
2. Then $K = (Y_A)^k \bmod q = 3^6 \bmod 19 = 729 \bmod 19 = 7$.
3. So
   $C_1 = \alpha^k \bmod q = \alpha^6 \bmod 19 = 11$
   $C_2 = KM \bmod q = 7 \times 17 \bmod 19 = 119 \bmod 19 = 5$
4. Bob sends the ciphertext $(11, 5)$.

For decryption:

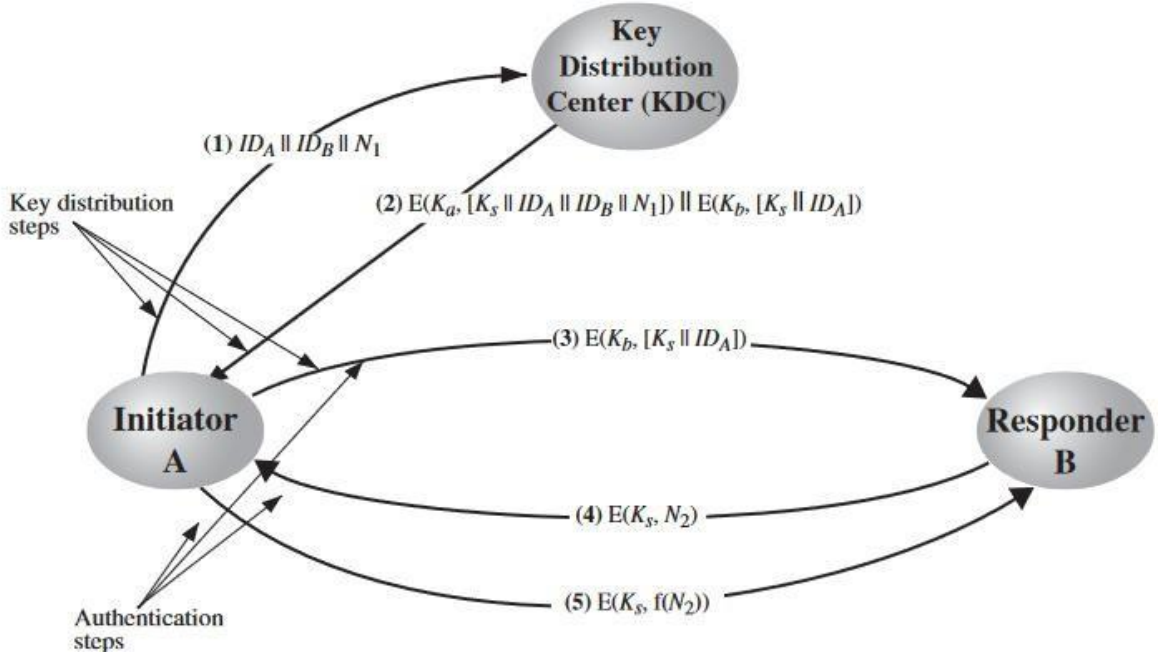
1. Alice calculates $K = (C_1)^{X_A} \bmod q = 11^5 \bmod 19 = 161051 \bmod 19 = 7$.
2. Then K^{-1} in GF(19) is $7^{-1} \bmod 19 = 11$.
3. Finally, $M = (C_2 K^{-1}) \bmod q = 5 \times 11 \bmod 19 = 55 \bmod 19 = 17$.

KEY DISTRIBUTION

- Key distribution is the function that delivers a key to two parties who wish to exchange secure encrypted data. Some sort of mechanism or protocol is needed to provide for the secure distribution of keys.
- Key distribution often involves the use of master keys, which are infrequently used and are long lasting, and session keys, which are generated and distributed for temporary use between two parties.
- Public-key encryption schemes are secure only if the authenticity of the public key is assured. A public-key certificate scheme provides the necessary security.
- 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 Key Distribution Scenario



User A wishes to establish a logical connection with B andrequires a one-time session key to protect the data transmitted over the connection.A has a master key, K_a, known only to itself and the KDC; similarly, B shares themaster key $K_b$with the KDC.

Hierarchical Key Control

It is not necessary to limit the key distribution function to a single KDC. Indeed, forvery large networks, it may not be practical to do so. As an alternative, a hierarchy ofKDCs can be established. For example, there can be local KDCs, each responsiblefor a small domain of the overall internetwork, such as a single LAN or a singlebuilding.

A hierarchical scheme minimizes the effort involved in master key distribution, because most master keys are those shared by a local KDC with its local entities. Furthermore, such a scheme limits the damage of a faulty or subverted KDC to its local area only.

Session Key Lifetime

The more frequently session keys are exchanged, the more secure they are, becausethe opponent has less ciphertext to work with for any given session key. On theother hand, the distribution of session keys delays the start of any exchange andplaces a burden on network capacity. A security manager must try to balance thesecompeting considerations in determining the lifetime of a particular session key.

Decentralized Key Control

The use of a key distribution center imposes the requirement that the KDC be trusted and be protected from subversion. This requirement can be avoided if keydistribution is fully decentralized. Although full decentralization is not practical forlarger networks using symmetric encryption only, it may be useful within a localcontext.

A decentralized approach requires that each end system be able to communicate in a secure manner with all potential partner end systems for purposes of session key distribution. Thus, there may need to be as many as n(n-1)/2 master keys for a configuration with n end systems.

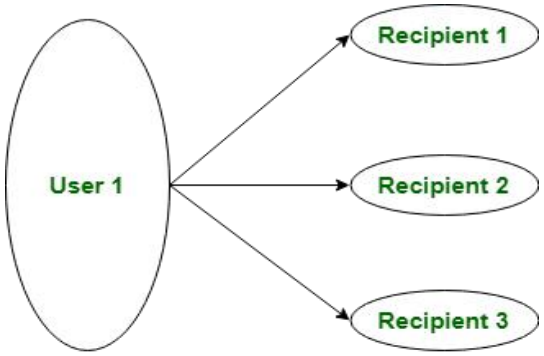
Distribution of Public Key:

The public key can be distributed in four ways:

1. Public announcement
2. Publicly available directory
3. Public-key authority
4. Public-key certificates.

These are explained as following below:

1. Public Announcement: Here the public key is broadcasted to everyone. The major weakness of this method is a forgery. Anyone can create a key claiming to be someone else and broadcast it. Until forgery is discovered can masquerade as claimed user.



Public Key Announcement

2. Publicly Available Directory: In this type, the public key is stored in a public directory. Directories are trusted here, with properties like Participant Registration, access and allow to modify values at any time, contains entries like {name, public-key}. Directories can be accessed electronically still vulnerable to forgery or tampering.

3. Public Key Authority: It is similar to the directory but, improves security by tightening control over the distribution of keys from the directory. It requires users to know the public key for the directory. Whenever the keys are needed, real-time access to the directory is made by the user to obtain any desired public key securely.

4. Public Certification: This time authority provides a certificate (which binds an identity to the public key) to allow key exchange without real-time access to the public authority each time. The certificate is accompanied by some other info such as period of validity, rights of use, etc. All of this content is signed by the private key of the certificate authority and it can be verified by anyone possessing the authority's public key.