

MODULE - I

INTRODUCTION

Computer data often travels from one computer to another, leaving the safety of its protected physical surroundings. Once the data is out of hand, people with bad intention could modify or forge your data, either for amusement or for their own benefit.

Cryptography can reformat and transform our data, making it safer on its trip between computers. The technology is based on the essentials of secret codes, augmented by modern mathematics that protects our data in powerful ways.

- **Computer Security** - generic name for the collection of tools designed to protect data and to thwart hackers
- **Network Security** - measures to protect data during their transmission
- **Internet Security** - measures to protect data during their transmission over a collection of interconnected networks

Security Attacks, Services and Mechanisms

To assess the security needs of an organization effectively, the manager responsible for security needs some systematic way of defining the requirements for security and characterization of approaches to satisfy those requirements. One approach is to consider three aspects of information security:

Security attack – Any action that compromises the security of information owned by an organization.

Security mechanism – A mechanism that is designed to detect, prevent or recover from a security attack.

Security service – A service that enhances the security of the data processing systems and the information transfers of an organization. The services are intended to counter security attacks and they make use of one or more security mechanisms to provide the service.

Basic Concepts

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

Plaintext The original intelligible message

Cipher text The transformed message

Cipher An algorithm for transforming an intelligible message into one that is unintelligible by transposition and/or substitution methods

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

Encipher (encode) The process of converting plaintext to cipher text using a cipher and a key

Decipher (decode) the process of converting cipher text back into plaintext using a cipher and a key

Cryptanalysis The study of principles and methods of transforming an unintelligible message back into an intelligible message *without* knowledge of the key. Also called **code breaking**

Cryptology Both cryptography and cryptanalysis

Code An algorithm for transforming an intelligible message into an unintelligible one using a code-book

Cryptography

Cryptographic systems are generally classified along 3 independent dimensions:

Type of operations used for transforming plain text to cipher text

All the encryption algorithms are based on two general principles: **substitution**, in which each element in the plaintext is mapped into another element, and **transposition**, in which elements in the plaintext are rearranged.

The number of keys used

If the sender and receiver uses same key then it is said to be **symmetric key (or) single key (or) conventional encryption**.

If the sender and receiver use different keys then it is said to be **public key encryption**.

The way in which the plain text is processed

A **block cipher** processes the input and block of elements at a time, producing output block for each input block.

A **stream cipher** processes the input elements continuously, producing output element one at a time, as it goes along.

Cryptanalysis

The process of attempting to discover X or K or both is known as cryptanalysis. The strategy used by the cryptanalysis depends on the nature of the encryption scheme and the information available to the cryptanalyst.

There are various types of cryptanalytic attacks based on the amount of information known to the cryptanalyst.

Cipher text only – A copy of cipher text alone is known to the cryptanalyst.

Known plaintext – The cryptanalyst has a copy of the cipher text and the corresponding plaintext.

Chosen plaintext – The cryptanalysts gains temporary access to the encryption machine. They cannot open it to find the key, however; they can encrypt a large number of suitably chosen plaintexts and try to use the resulting cipher texts to deduce the key.

Chosen cipher text – The cryptanalyst obtains temporary access to the decryption machine, uses it to decrypt several string of symbols, and tries to use the results to deduce the key.

STEGANOGRAPHY

A plaintext message may be hidden in any one of the two ways. The methods of steganography conceal the existence of the message, whereas the methods of cryptography render the message unintelligible to outsiders by various transformations of the text.

A simple form of steganography, but one that is time consuming to construct is one in which an arrangement of words or letters within an apparently innocuous text spells out the real message.

e.g., (i) the sequence of first letters of each word of the overall message spells out the real (Hidden) message.

(ii) Subset of the words of the overall message is used to convey the hidden message.

Various other techniques have been used historically, some of them are

Character marking – selected letters of printed or typewritten text are overwritten in pencil. The

marks are ordinarily not visible unless the paper is held to an angle to bright light.

Invisible ink – a number of substances can be used for writing but leave no visible trace until heat or some chemical is applied to the paper.

Pin punctures – small pin punctures on selected letters are ordinarily not visible unless the paper is held in front of the light. Typewritten correction ribbon – used between the lines typed with a black ribbon, the results of typing with the correction tape are visible only under a strong light.

Drawbacks of steganography

Requires a lot of overhead to hide a relatively few bits of information.

Once the system is discovered, it becomes virtually worthless.

SECURITY SERVICES

The classification of security services are as follows:

Confidentiality: Ensures that the information in a computer system and transmitted information are accessible only for reading by authorized parties.

E.g. Printing, displaying and other forms of disclosure.

Authentication: Ensures that the origin of a message or electronic document is correctly identified, with an assurance that the identity is not false.

Integrity: Ensures that only authorized parties are able to modify computer system assets and transmitted information. Modification includes writing, changing status, deleting, creating and delaying or replaying of transmitted messages.

Non repudiation: Requires that neither the sender nor the receiver of a message be able to deny the transmission.

Access control: Requires that access to information resources may be controlled by or the target system.

Availability: Requires that computer system assets be available to authorized parties when needed.

SECURITY MECHANISMS

One of the most specific security mechanisms in use is cryptographic techniques. Encryption or encryption-like transformations of information are the most common means of providing security. Some of the mechanisms are

1 Encipherment

2 Digital Signature

3 Access Control

SECURITY ATTACKS

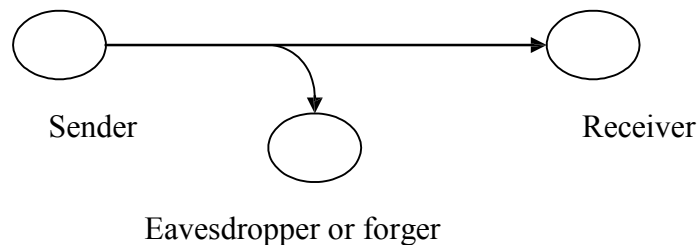
There are four general categories of attack which are listed below.

Interruption

An asset of the system is destroyed or becomes unavailable or unusable. This is an attack on availability e.g., destruction of piece of hardware, cutting of a communication line or Disabling of file management system.

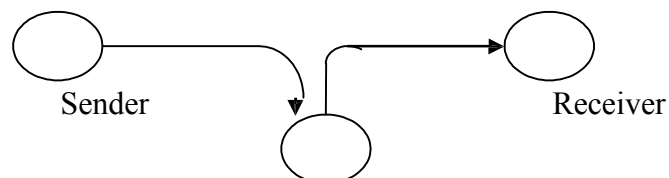
Interception

An unauthorized party gains access to an asset. This is an attack on confidentiality. Unauthorized party could be a person, a program or a computer.e.g., wire tapping to capture data in the network, illicit copying of files



Modification

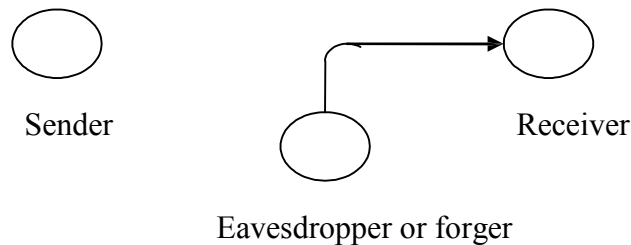
An unauthorized party not only gains access to but tampers with an asset. This is an attack on integrity. e.g., changing values in data file, altering a program, modifying the contents of messages being transmitted in a network.



Eavesdropper or forger

Fabrication

An unauthorized party inserts counterfeit objects into the system. This is an attack on authenticity. e.g., insertion of spurious message in a network or addition of records to a file.



Cryptographic Attacks

Passive Attacks

Passive attacks are in the nature of eavesdropping on, or monitoring of, transmissions. The goal of the opponent is to obtain information that is being transmitted. Passive attacks are of two types:

Release of message contents: A telephone conversation, an e-mail message and a transferred file may contain sensitive or confidential information. We would like to prevent the opponent from learning the contents of these transmissions.

Traffic analysis: If we had encryption protection in place, an opponent might still be able to observe the pattern of the message. The opponent could determine the location and identity of communication hosts and could observe the frequency and length of messages being exchanged. This information might be useful in guessing the nature of communication that was taking place.

Passive attacks are very difficult to detect because they do not involve any alteration of data. However, it is feasible to prevent the success of these attacks.

Active attacks

These attacks involve some modification of the data stream or the creation of a false stream. These attacks can be classified into four categories:

Masquerade – One entity pretends to be a different entity.

Replay – involves passive capture of a data unit and its subsequent transmission to produce an unauthorized effect.

Modification of messages – Some portion of message is altered or the messages are delayed or recorded, to produce an unauthorized effect.

Denial of service – Prevents or inhibits the normal use or management of communication facilities. Another form of service denial is the disruption of an entire network, either by disabling the network or overloading it with messages so as to degrade performance.

It is quite difficult to prevent active attacks absolutely, because to do so would require physical protection of all communication facilities and paths at all times. Instead, the goal is to detect them and to recover from any disruption or delays caused by them.

Symmetric and public key algorithms

Encryption/Decryption methods fall into two categories.

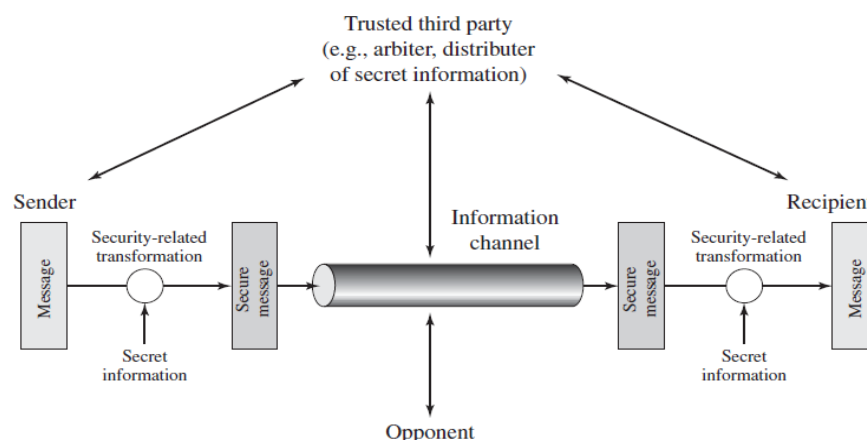
Symmetric key

Public key

In symmetric key algorithms, the encryption and decryption keys are known both to sender and receiver. The encryption key is shared and the decryption key is easily calculated from it. In many cases, the encryption and decryption keys are the same.

In public key cryptography, encryption key is made public, but it is computationally infeasible to find the decryption key without the information known to the receiver.

A MODEL FOR NETWORK SECURITY

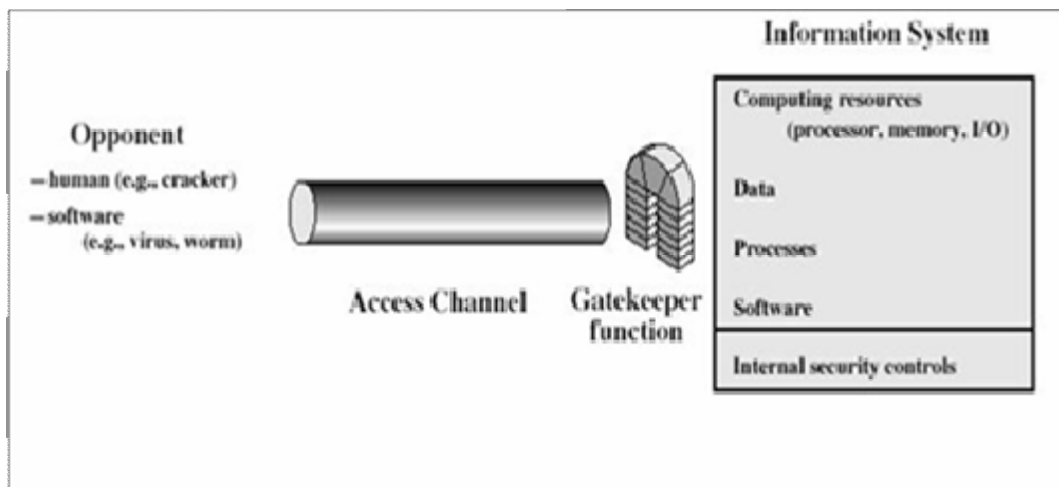


A message is to be transferred from one party to another across some sort of internet. The two parties, who are the principals in this transaction, must cooperate for the exchange to take place. A logical information channel is established by defining a route through the internet from source to destination and by the cooperative use of communication protocols (e.g., TCP/IP) by the two principals.

Using this model requires us to:

- design a suitable algorithm for the security transformation
- generate the secret information (keys) used by the algorithm
- develop methods to distribute and share the secret information
- specify a protocol enabling the principals to use the transformation and secret information for a security service

MODEL FOR NETWORK ACCESS SECURITY



Using this model requires us to:

- select appropriate gatekeeper functions to identify users
- implement security controls to ensure only authorized users access designated information or resources
- **Trusted computer systems can be used to implement this model**

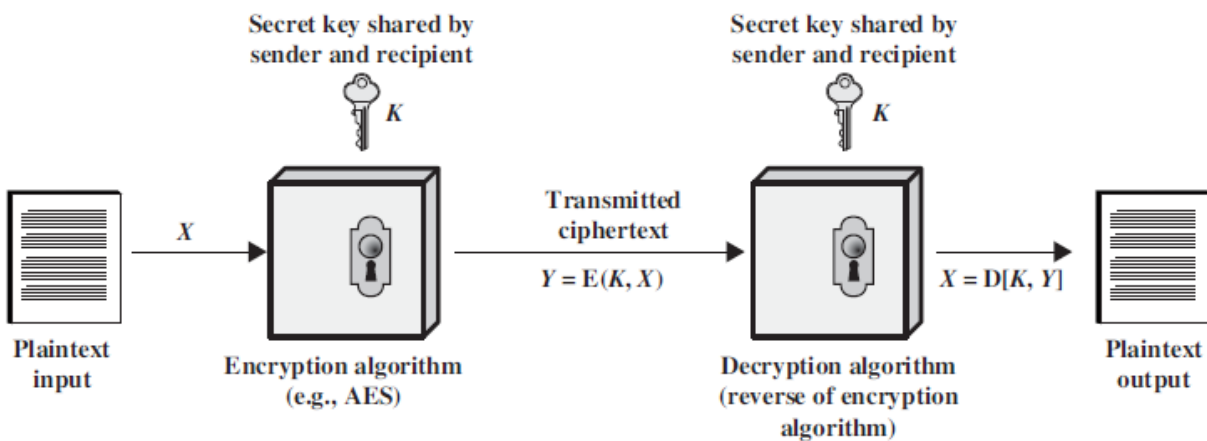
CONVENTIONAL ENCRYPTION

- Referred conventional / private-key / single-key
- Sender and recipient share a common key

All classical encryption algorithms are private-key was only type prior to invention of public-key in 1970“**plaintext** - the original message

Some basic terminologies used:

- **cipher text** - the coded message
- **Cipher** - algorithm for transforming plaintext to cipher text
- **Key** - info used in cipher known only to sender/receiver
- **encipher (encrypt)** - converting plaintext to cipher text
- **decipher (decrypt)** - recovering cipher text from plaintext
- **Cryptography** - study of encryption principles/methods
- **Cryptanalysis (code breaking)** - the study of principles/ methods of deciphering cipher text *without* knowing key
- **Cryptology** - the field of both cryptography and cryptanalysis



Here the original message, referred to as plaintext, is converted into apparently random nonsense, referred to as cipher text. The encryption process consists of an algorithm and a key. The key is a value independent of the plaintext. Changing the key changes the output of the algorithm. Once the cipher text is produced, it may be transmitted. Upon reception, the cipher text can be transformed back to the original plaintext by using a decryption algorithm and the same key that was used for encryption. The security depends on several factors. First, the encryption algorithm must be powerful enough that it is impractical to decrypt a message on the basis of cipher text alone. Beyond that, the security depends on the secrecy of the key, not the secrecy of the algorithm.

- **Two requirements for secure use of symmetric encryption:**

- A strong encryption algorithm
- A secret key known only to sender / receiver

$$Y = EK(X)$$

$$X = DK(Y)$$

- **assume encryption algorithm is known**
- **implies a secure channel to distribute key**

A source produces a message in plaintext, $X = [X_1, X_2 \dots X_M]$ where M are the number of letters in the message. A key of the form $K = [K_1, K_2 \dots K_J]$ is generated. If the key is generated at the source, then it must be provided to the destination by means of some secure channel.

With the message X and the encryption key K as input, the encryption algorithm forms the cipher text $Y = [Y_1, Y_2, Y_N]$. This can be expressed as

$$Y = E_K(X)$$

The intended receiver, in possession of the key, is able to invert the transformation:

$$X = D_K(Y)$$

An opponent, observing Y but not having access to K or X , may attempt to recover X or K or both. It is assumed that the opponent knows the encryption and decryption algorithms.

If the opponent is interested in only this particular message, then the focus of effort is to recover X by generating a plaintext estimate. Often if the opponent is interested in being able to read future messages as well, in which case an attempt is made to recover K by generating an estimate.

CLASSICAL ENCRYPTION TECHNIQUES

There are two basic building blocks of all encryption techniques: substitution and transposition.

SUBSTITUTION TECHNIQUES

A substitution technique is one in which the letters of plaintext are replaced by other letters or by numbers or symbols. If the plaintext is viewed as a sequence of bits, then substitution involves replacing plaintext bit patterns with cipher text bit patterns.

Caesar cipher (or) shift cipher

The earliest known use of a substitution cipher and the simplest was by Julius Caesar. The Caesar cipher involves replacing each letter of the alphabet with the letter standing 3 places further down the alphabet.

e.g., plain text : pay more money

Cipher text: SDB PRUH PRQHB

Note that the alphabet is wrapped around, so that letter following „z“ is „a“.

For each plaintext letter p, substitute the cipher text letter c such that

$$C = E(p) = (p+3) \bmod 26$$

A shift may be any amount, so that general Caesar algorithm is

$$C = E(p) = (p+k) \bmod 26$$

Where k takes on a value in the range 1 to 25. The decryption algorithm is simply

$$P = D(C) = (C-k) \bmod 26$$

Playfair cipher

The best known multiple letter encryption cipher is the playfair, which treats digrams in the plaintext as single units and translates these units into cipher text digrams. The playfair

algorithm is based on the use of 5x5 matrix of letters constructed using a keyword. Let the keyword be „monarchy“. The matrix is constructed by filling in the letters of the keyword (minus duplicates) from left to right and from top to bottom, and then filling in the remainder of the matrix with the remaining letters in alphabetical order.

The letter „i“ and „j“ count as one letter. Plaintext is encrypted two letters at a time According to the following rules:

Repeating plaintext letters that would fall in the same pair are separated with a Filler letter such as „x“.

Plaintext letters that fall in the same row of the matrix are each replaced by the letter to the right, with the first element of the row following the last.

Plaintext letters that fall in the same column are replaced by the letter beneath, with the top element of the column following the last.

Otherwise, each plaintext letter is replaced by the letter that lies in its own row And the column occupied by the other plaintext letter.

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

Plaintext = meet me at the school house

Splitting two letters as a unit => me et me at the school house

Corresponding cipher text => CL KL CL RS PD IL HY AV MP HF XL IU

Strength of playfair cipher

Playfair cipher is a great advance over simple mono alphabetic ciphers.

Since there are 26 letters, $26 \times 26 = 676$ diagrams are possible, so identification of individual diagram is more difficult.

1.15.1.3 Polyalphabetic ciphers

Another way to improve on the simple monoalphabetic technique is to use different monoalphabetic substitutions as one proceeds through the plaintext message. The general name for this approach is polyalphabetic cipher. All the techniques have the following features in common.

A set of related monoalphabetic substitution rules are used

A key determines which particular rule is chosen for a given transformation.

Vigenere cipher

In this scheme, the set of related monoalphabetic substitution rules consisting of 26 caesar ciphers with shifts of 0 through 25. Each cipher is denoted by a key letter. e.g., Caesar cipher with a shift of 3 is denoted by the key value 'd' (since a=0, b=1, c=2 and so on). To aid in understanding the scheme, a matrix known as vigenere tableau is Constructed

Each of the 26 ciphers is laid out horizontally, with the key letter for each cipher to its left. A normal alphabet for the plaintext runs across the top. The process of

	PLAIN TEXT															
K		a	b	c	d	e	f	g	h	i	j	k	...	x	y	z
E	a	A	B	C	D	E	F	G	H	I	J	K	...	X	Y	Z
Y	b	B	C	D	E	F	G	H	I	J	K	L	...	Y	Z	A
	c	C	D	E	F	G	H	I	J	K	L	M	...	Z	A	B
L	d	D	E	F	G	H	I	J	K	L	M	N	...	A	B	C
E	e	E	F	G	H	I	J	K	L	M	N	O	...	B	C	D
T	f	F	G	H	I	J	K	L	M	N	O	P	...	C	D	E
T	g	G	H	I	J	K	L	M	N	O	P	Q	...	D	E	F
E	:	:	:	:	:	:	:	:	:	:	:	:	...	:	:	:
R	:	:	:	:	:	:	:	:	:	:	:	:	...	:	:	:
S	x	X	Y	Z	A	B	C	D	E	F	G	H	...			W
	y	Y	Z	A	B	C	D	E	F	G	H	I	...			X
	z	Z	A	B	C	D	E	F	G	H	I	J	...			Y

Encryption is simple: Given a key letter X and a plaintext letter y, the cipher text is at the intersection of the row labeled x and the column labeled y; in this case, the ciphertext is V.

To encrypt a message, a key is needed that is as long as the message. Usually, the key is a repeating keyword.

e.g., key = `deceptivedeceptivedeceptive` PT = `wearediscoveredsa`
`veyourself` CT = `ZICVTWQNGRZGVTWAVZHCQYGLMGJ`

Decryption is equally simple. The key letter again identifies the row. The position of the cipher text letter in that row determines the column, and the plaintext letter is at the top of that column.

Strength of Vigenere cipher

- o There are multiple cipher text letters for each plaintext letter.
- o Letter frequency information is obscured.

One Time Pad Cipher

It is an unbreakable cryptosystem. It represents the message as a sequence of 0s and 1s. this can be accomplished by writing all numbers in binary, for example, or by using ASCII. The key is a random sequence of 0's and 1's of same length as the message. Once a key is used, it is discarded and never used again. The system can be expressed as

Follows:

$C_i = P_i \oplus K_i$ C_i - i^{th} binary digit of cipher text P_i - i^{th} binary digit of plaintext K_i - i^{th} binary digit of key

Exclusive OR operation

Thus the cipher text is generated by performing the bitwise XOR of the plaintext and the key. Decryption uses the same key. Because of the properties of XOR, decryption simply involves the same bitwise operation:

$$P_i = C_i \oplus K_i$$

e.g., plaintext = `0 0 1 0 1 0 0 1`

Key = `1 0 1 0 1 1 0 0`

----- ciphertext = 1 0 0 0 0 1 0 1

Advantage:

Encryption method is completely unbreakable for a ciphertext only attack.

Disadvantages

It requires a very long key which is expensive to produce and expensive to transmit.

Once a key is used, it is dangerous to reuse it for a second message; any knowledge on the first message would give knowledge of the second.

TRANSPOSITION TECHNIQUES

All the techniques examined so far involve the substitution of a cipher text symbol for a plaintext symbol. A very different kind of mapping is achieved by performing some sort of permutation on the plaintext letters. This technique is referred to as a transposition cipher.

Rail fence

is simplest of such cipher, in which the plaintext is written down as a sequence of diagonals and then read off as a sequence of rows.

Plaintext = meet at the school house

To encipher this message with a rail fence of depth 2, we write the message as follows:

m e a t e c o l o s
e t t h s h o h u e

The encrypted message is

MEATECOLOSETTHSHOHUE

Row Transposition Ciphers-

A more complex scheme is to write the message in a rectangle, row by row, and read the message off, column by column, but permute the order of the columns. The order of columns then becomes the key of the algorithm.

e.g., plaintext = meet at the school house

Key = 4 3 1 2 5 6 7
PT = m e e t a t t

h	e	s	c	h	o	o
l	h	o	u	s	e	

CT = ESOTCUEEHMHLAHSTOETO

A pure transposition cipher is easily recognized because it has the same letter frequencies as the original plaintext. The transposition cipher can be made significantly more secure by performing more than one stage of transposition. The result is more complex permutation that is not easily reconstructed.

Feistel cipher structure

The input to the encryption algorithm are a plaintext block of length $2w$ bits and a key K . the plaintext block is divided into two halves L_0 and R_0 . The two halves of the data pass through „ n “ rounds of processing and then combine to produce the ciphertext block. Each round „ i “ has inputs L_{i-1} and R_{i-1} , derived from the previous round, as well as the subkey K_i , derived from the overall key K . in general, the subkeys K_i are different from K and from each other.

All rounds have the same structure. A substitution is performed on the left half of the data (as similar to S-DES). This is done by applying a round function F to the right half of the data and then taking the XOR of the output of that function and the left half of the data. The round function has the same general structure for each round but is parameterized by the round sub key k_i . Following this substitution, a permutation is performed that consists of the interchange of the two halves of the data. This structure is a particular form of the substitution-permutation network. The exact realization of a Feistel network depends on the choice of the following parameters and design features:

Block size - Increasing size improves security, but slows cipher

Key size - Increasing size improves security, makes exhaustive key searching harder, but may slow cipher

Number of rounds - Increasing number improves security, but slows cipher

Subkey generation - Greater complexity can make analysis harder, but slows cipher

Round function - Greater complexity can make analysis harder, but slows cipher

Fast software en/decryption & ease of analysis - are more recent concerns for practical use and testing.

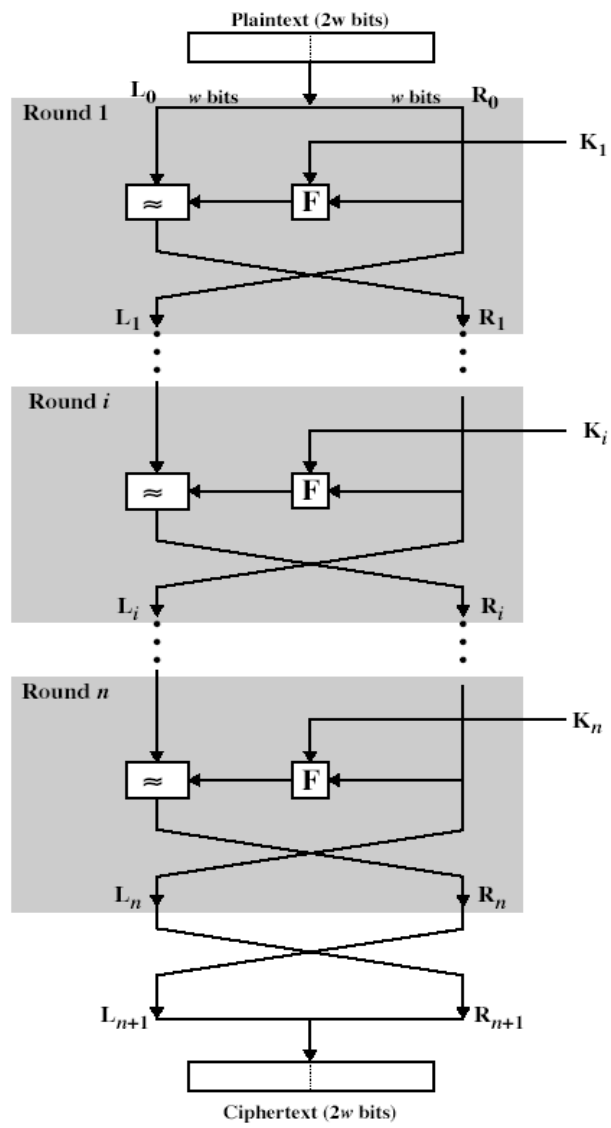


Fig: Classical Feistel Network

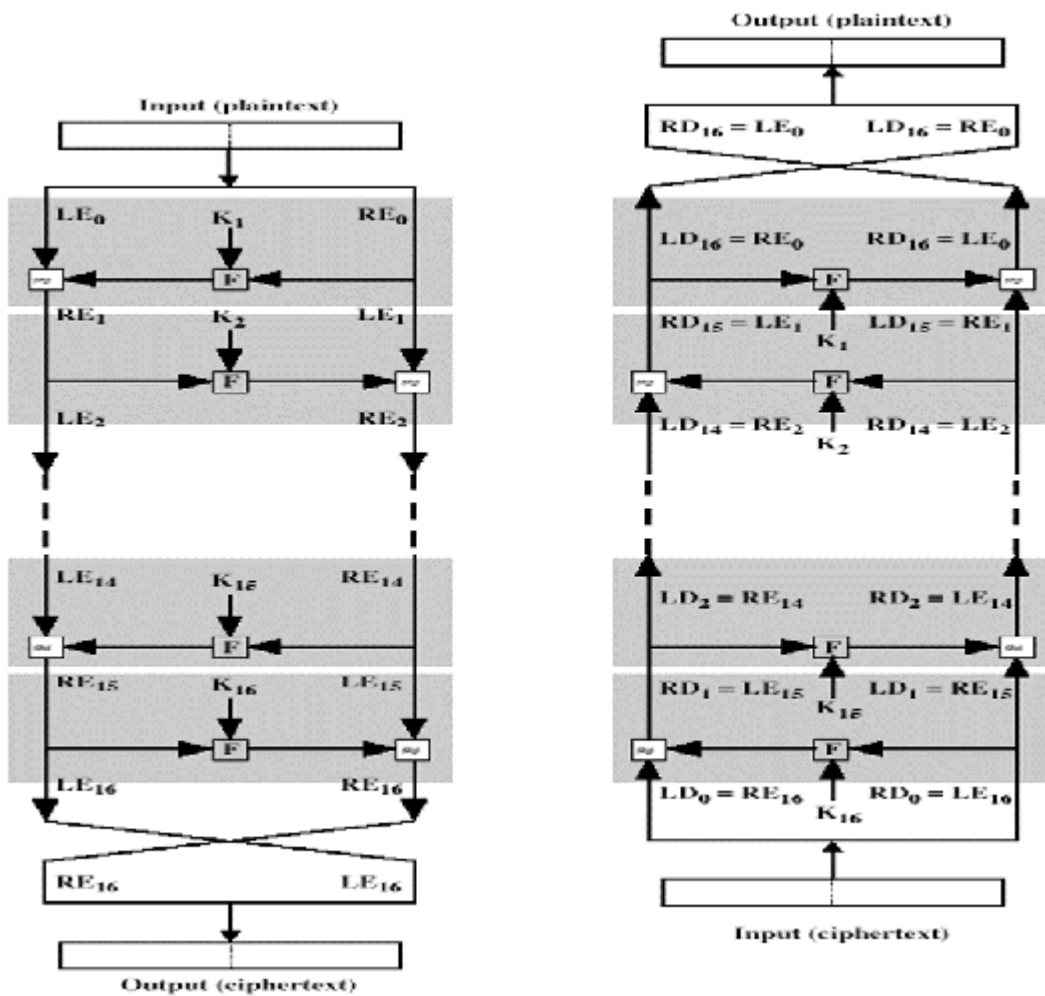


Fig: Feistel encryption and decryption

The process of decryption is essentially the same as the encryption process. The rule is as follows: use the cipher text as input to the algorithm, but use the subkey k_i in reverse order. i.e., k_n in the first round, k_{n-1} in second round and so on. For clarity, we use the notation LE_i and RE_i for data traveling through the decryption algorithm. The diagram below indicates that, at each round, the intermediate value of the decryption process is same (equal) to the corresponding value of the encryption process with two halves of the value swapped.

i.e., $RE_i \parallel LE_i$ (or) equivalently $RD_{16-i} \parallel LD_{16-i}$

After the last iteration of the encryption process, the two halves of the output are swapped, so that the cipher text is $RE_{16} \parallel LE_{16}$. The output of that round is the cipher text. Now take the cipher text and use it as input to the same algorithm. The input to the first round is $RE_{16} \parallel LE_{16}$, which is equal to the 32-bit swap of the output of the sixteenth round of the encryption process.

Now we will see how the output of the first round of the decryption process is equal to a 32-bit swap of the input to the sixteenth round of the encryption process. First consider the encryption process,

$$LE_{16} = RE_{15}$$

$$RE_{16} = LE_{15} \oplus F(RE_{15}, K_{16}) \text{ On the decryption side,}$$

$$LD_1 = RD_0 = LE_{16} = RE_{15}$$

$$RD_1 = LD_0 \oplus F(RD_0, K_{16})$$

$$= RE_{16} \oplus F(RE_{15}, K_{16})$$

$$= [LE_{15} \oplus F(RE_{15}, K_{16})] \oplus F(RE_{15}, K_{16})$$

$$= LE_{15}$$

$$\text{Therefore, } LD_1 = RE_{15}$$

$RD_1 = LE_{15}$ In general, for the i^{th} iteration of the encryption algorithm, $LE_i = RE_{i-1}$

$$RE_i = LE_{i-1} \oplus F(RE_{i-1}, K_i)$$

Finally, the output of the last round of the decryption process is $RE_0 \parallel LE_0$. A 32-bit swap recovers the original plaintext.

MODULE - II

BLOCK CIPHER PRINCIPLES

Virtually, all symmetric block encryption algorithms in current use are based on a structure referred to as Feistel block cipher. For that reason, it is important to examine the design principles of the Feistel cipher. We begin with a **comparison of stream cipher with block cipher**.

- A **stream cipher** is one that encrypts a digital data stream one bit or one byte at a time. E.g, vigenere cipher. A **block cipher** is one in which a block of plaintext is treated as a whole and used to produce a cipher text block of equal length. Typically a block size of 64 or 128 bits is used.

Block cipher principles

- most symmetric block ciphers are based on a **Feistel Cipher Structure** needed since must be able to **decrypt** ciphertext to recover messages efficiently. block ciphers look like an extremely large substitution
- would need table of 264 entries for a 64-bit block
- Instead create from smaller building blocks
- using idea of a product cipher in 1949 Claude Shannon introduced idea of substitution-permutation (S-P) networks called modern substitution-transposition product cipher these form the basis of modern block ciphers
- S-P networks are based on the two primitive cryptographic operations we have seen before:
 - *substitution* (S-box)
 - *permutation* (P-box)
 - provide *confusion* and *diffusion* of message
 - **diffusion** – dissipates statistical structure of plaintext over bulk of ciphertext
- **confusion** – makes relationship between ciphertext and key as complex as possible

DATA ENCRYPTION STANDARD (DES)

In May 1973, and again in Aug 1974 the NBS (now NIST) called for possible encryption algorithms for use in unclassified government applications response was mostly disappointing, however IBM submitted their Lucifer design following a period of redesign and comment it became the Data Encryption Standard (DES)

it was adopted as a (US) federal standard in Nov 76, published by NBS as a hardware only scheme in Jan 77 and by ANSI for both hardware and software standards in ANSI X3.92-1981 (also X3.106-1983 modes of use) subsequently it has been widely adopted and is now published in many standards around the world cf Australian Standard AS2805.5-1985

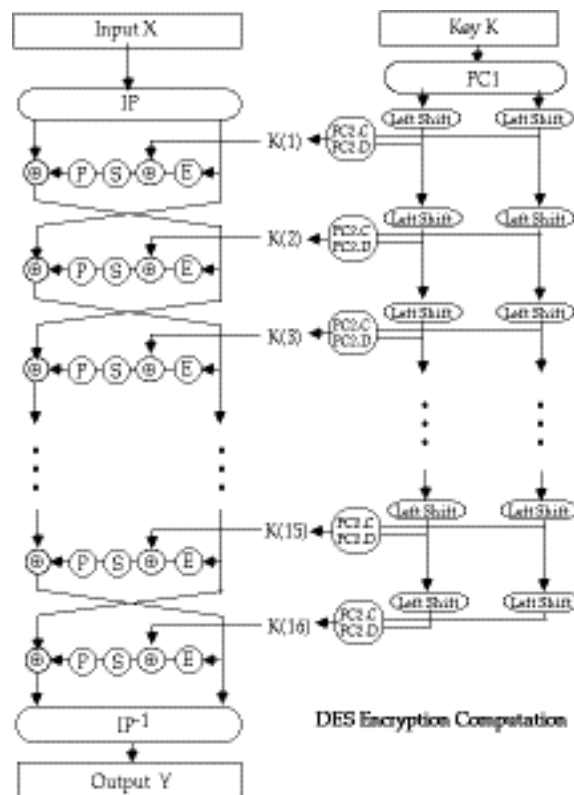
one of the largest users of the DES is the banking industry, particularly with EFT, and EFTPOS

it is for this use that the DES has primarily been standardized, with ANSI having twice reconfirmed its recommended use for 5 year periods - a further extension is not expected however although the standard is public, the design criteria used are classified and have yet to be released there has been considerable controversy over the design, particularly in the choice of a 56-bit key

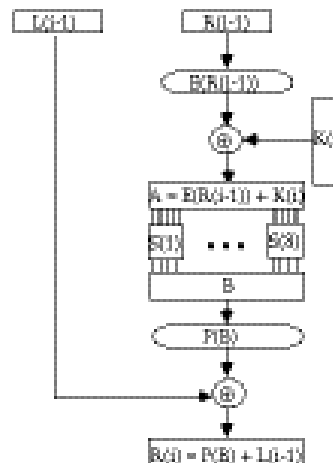
- recent analysis has shown despite this that the choice was appropriate, and that DES is well designed
- rapid advances in computing speed though have rendered the 56 bit key susceptible to exhaustive key search, as predicted by Diffie & Hellman

- the DES has also been theoretically broken using a method called Differential Cryptanalysis, however in practice this is unlikely to be a problem (yet)

Overview of the DES Encryption Algorithm



- the basic process in enciphering a 64-bit data block using the DES consists of:
 - an initial permutation (IP)
 - 16 rounds of a complex key dependent calculation f
 - a final permutation, being the inverse of IP
- in more detail the 16 rounds of f consist of:



- this can be described functionally as