NPTEL ONLINE CERTIFICATION COURSES

Course Name: Ethical Hacking

Faculty Name: Prof. Indranil Sen Gupta

Department : Computer Science and Engineering

Topic

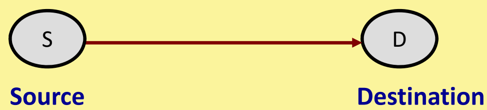
Lecture 26: Basic Concepts of Cryptography

CONCEPTS COVERED

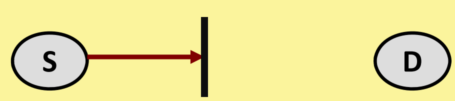
- Security attacks
- Security services
- Cryptographic primitives

Security Attacks

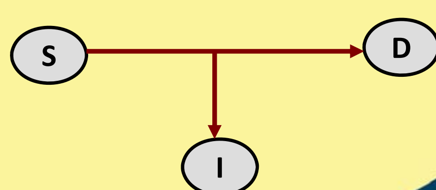
- Any action that compromises the security of information.
- Four types of attack:
    a) Interruption
    b) Interception
    c) Modification
    d) Fabrication
- Basic model:



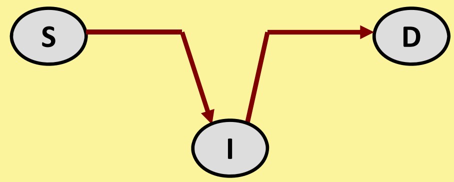
- Interruption:
    - Attack on availability



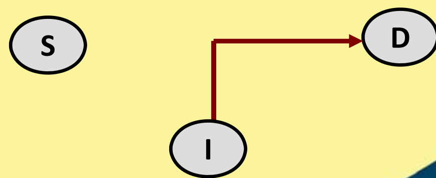
- Interception:
    - Attack on confidentiality



- Modification:
  - Attack on integrity



- Fabrication:
  - Attack on authenticity



Passive and Active Attacks

- **Passive attacks**
  - Obtain information that is being transmitted (eavesdropping).
  - Two types:
    a) Release of message contents.
    b) Traffic analysis.
  - Very difficult to detect.

- **Active attacks**
  - Involve some modification of the data stream or the creation of a false stream.
  - Four categories:
    - a) **Masquerade**:- One entity pretends to be a different entity.
    - b) **Replay**:- Passive capture of a transaction and subsequent replay.
    - c) **Modification**:- Some portion of a message is altered on its way.
    - d) **Denial of service**:- Prevents access to resources.

Security Services

- Confidentiality (privacy)
- Authentication (who created or sent the data)
- Integrity (has not been altered)
- Non-repudiation (parties cannot later deny)
- Access control (prevent misuse of resources)
- Availability (permanence, non-erasure)
  - Denial of Service Attacks
  - Virus that deletes files

Network Access Security Model

Opponent:
- Human
- Virus
- Worm

ACCESS CHANNEL →

GATEWAY

Internal Network
- Computers
- Software resources
- Databases

Security Control

Cryptography Primitives

Encryption

- Most important concept behind network security is *encryption*.
- Two forms of encryption:
  1. Private (or Symmetric)
     - Single key shared by sender and receiver.
  2. Public-key (or Asymmetric)
     - Separate keys for sender and receiver.

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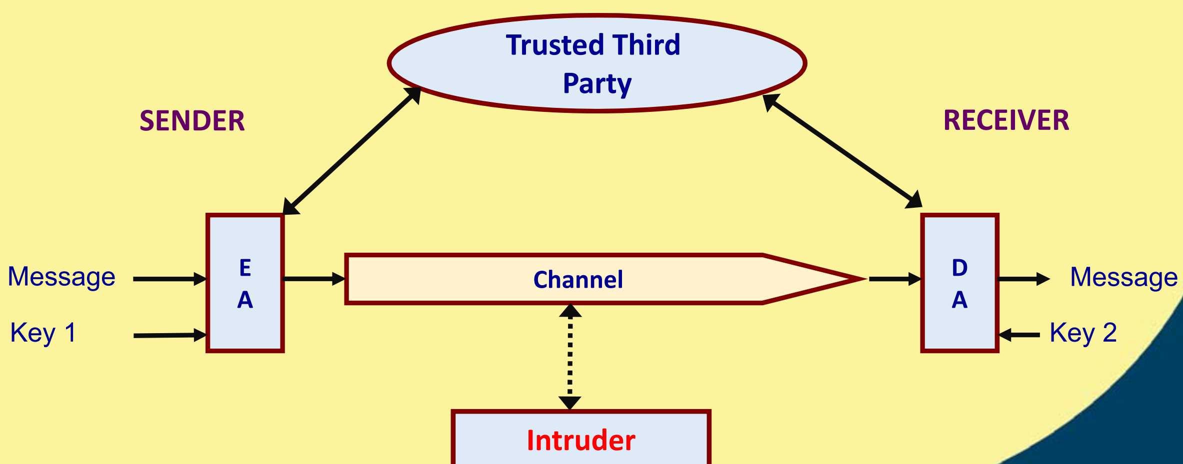

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Authentication

- Techniques to uniquely identify the sender of a message.
- Various approaches:
  - Encryption techniques
  - Cryptographic hash functions
  - Digital signature → a combination of various cryptographic primitives.

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Department : Computer Science and Engineering

Topic

Lecture 27: Private-Key Cryptography (Part I)

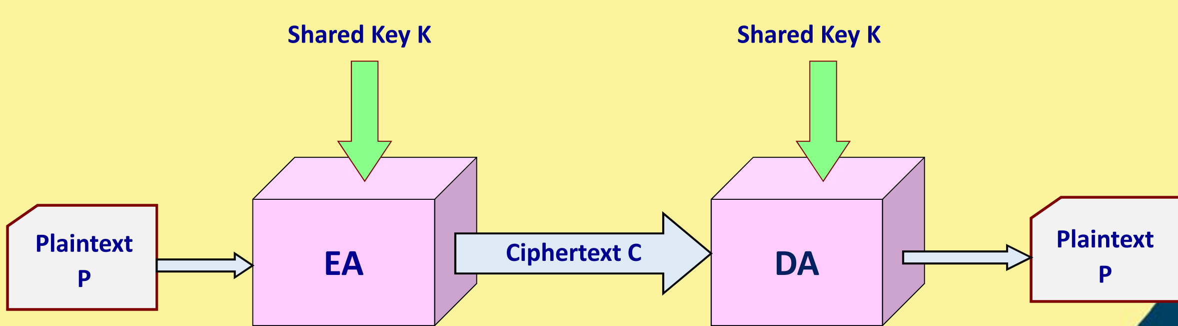
CONCEPTS COVERED

- Private/symmetric key cryptography
- Classical encryption techniques

Introduction

- Private or Symmetric Key Cryptography
  - A common secret value *K* (called ***key***) is shared between sender and receiver.
  - Sender encrypts a message *P* (called ***plaintext***) using *K* to generate a ***ciphertext*** *C*.
    - ❖ **C = EA (P, K)**
  - Receiver decrypts the ciphertext *C* using *K* to get back the plaintext *P*.
    - ❖ **P = DA (C, K)**

Illustration

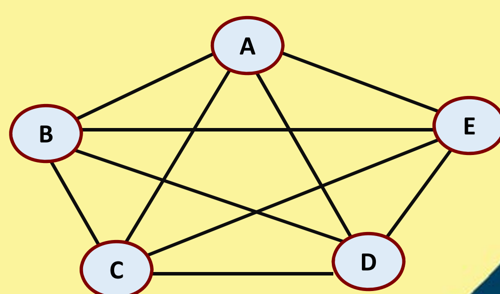


Point to Note

- Security of the scheme
  - Should depend only on the secrecy of the key.
  - Should not depend on the secrecy of the algorithm.
- Assumptions that we make:
  - Algorithms for encryption/decryption are known to the public.
  - Keys used for encryption/decryption are kept secret.

Some Points to Observe

- *Key distribution* problem of secret key systems:
  - Establish key before communication.
  - Need ***n(n-1)/2*** keys with ***n*** different parties.
- Overall, very large number of keys are required.
  - Difficult to maintain secrecy.



Classical Private-Key Encryption Techniques

- Broadly falls under two categories:
  1. **Substitution ciphers**
     - Each letter or group of letters of the plaintext are replaced by some other letter or group of letters, to obtain the ciphertext.
  2. **Transposition ciphers**
     - Letters of the plaintext are permuted in some form.

A Simple Example

Caesar Cipher (a substitution cipher):

- Earliest known substitution cipher.
- Replace each letter of the alphabet with the letter ***three places after*** that alphabet.
- Alphabets are assumed to be wrapped around (Z is followed by A, etc.).

P: H A P P Y N E W Y E A R

C: K D S S B Q H Z B H D U

- We can generalize the idea by replacing each letter by the k^{th} following letter.
  - "k" becomes the secret key.
- If we assign a number to each letter (A=1, B=2, etc), then

  C = E (P) = (P + k – 1) % 26 + 1

  P = D (C) = (C – k + 25) % 26 + 1

- **Drawback**:
  - Brute force attack is easy
  - Number of possibilities are rather small (i.e. 25)

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Mono-alphabetic Cipher:

- Allow any arbitrary substitution.
- There can be 26! or 4 x 10^{26} possible keys.
- A typical key may be: (Z A Q W S X C D E R F V B G T Y H N M J U I K L O P)
  - "A" replaced by "Z", "B" replaced by "A", "C" replaced by "Q", and so on.
- Drawbacks:
  - We can make guesses by observing the relative frequency of letters, digrams, and trigrams in the text.
  - Easy to break in general.

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Transposition Ciphers

- Many techniques have been proposed under this category.
- A simple scheme:
  - Write out the plaintext in a rectangle, row by row, and read the message column by column, by permuting the order of the columns.
  - Order of the column becomes the ***key***.

P: welcome to the nptel course on ethical hacking

Key:	4	3	1	2	5	6	7
	w	e	l	c	o	m	e
	-	t	o	-	t	h	e
	-	n	p	t	e	l	-
	c	o	u	r	s	e	-
	o	n	-	e	t	h	i
	c	a	l	-	h	a	c
	k	i	n	g	-	-	-

**C: lopu-ln c-tre-g etnonai w--cock otesth- mhleha-
ee--ic-**

Transposition Cipher … Drawbacks

- The ciphertext has the same letter frequency as the original plaintext.
- Guessing the number of columns and some probable words in the plaintext holds the key.

Practical Ciphers

- They are much more complicated.
  - Require computers to perform encryption and decryption.
  - Almost impossible to carry out by hand.
  - Can encrypt any kind of data, not necessarily only text.

Stream Ciphers vs. Block Ciphers

- A stream cipher encrypts the plaintext bit by bit (in streams).
- A block cipher encrypts n-bit blocks at a time.
  - For example, a 256-bit cipher encrypts 256-bit blocks at a time.
  - Shorter blocks have to be suitably padded.

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Course Name: Ethical Hacking

Faculty Name: Prof. Indranil Sen Gupta

Department : Computer Science and Engineering

Topic

Lecture 28: Private-Key Cryptography (Part II)

CONCEPTS COVERED

- Practical private-key algorithms
- DES and Triple-DES
- Advanced Encryption Standard (AES)

Practical Private-Key Algorithms

a) Data Encryption Standard (DES)
  - Block size is 64 bits.
  - Key is 56 bits.

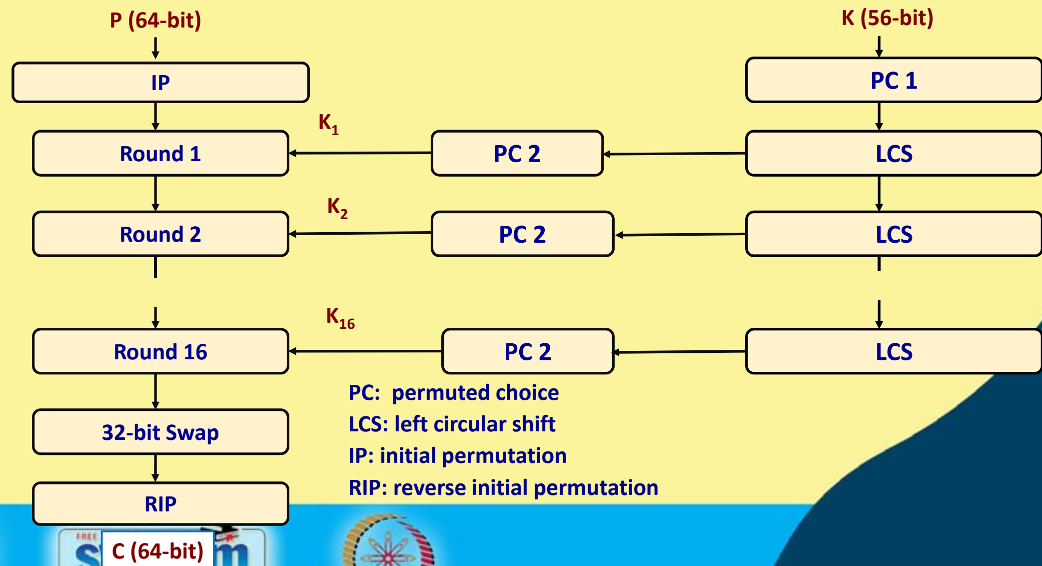
b) IDEA
  - Block size is 64 bits.
  - Key size is 128 bits.

c) Advanced Encryption Standard (AES)
  - Also known as Rijndael cryptosystem.
  - Block size is 128 bits.
  - Key size can be 128, 192, or 256 bits.

Data Encryption Standard (DES)

- The most widely used encryption scheme at one time.
  - Also known as the Data Encryption Algorithm (DEA).
  - It is a block cipher.
- Some of the features:
  - The plaintext is 64-bits in length.
  - The key is 56-bits in length.
  - Longer plaintexts are processed in 64-bit blocks.

General Schematic of DES



PC: permuted choice
LCS: left circular shift
IP: initial permutation
RIP: reverse initial permutation

DES

- The overall processing at each iteration:

$$\left.\begin{aligned} L_i &= R_{i-1} \\ R_i &= L_{i-1} \oplus F(R_{i-1}, K_i) \end{aligned}\right\} \textbf{Fiestel Structure}$$

- Concerns about:
  - The algorithm and the key length (56-bits).
  - Longer key lengths are essential for critical applications.

Triple DES

- Use three keys and three executions of the DES algorithm (encrypt-decrypt - encrypt).

$$C = E_{K3}\,[D_{K2}\,[E_{K1}\,[P]]]$$

C = ciphertext

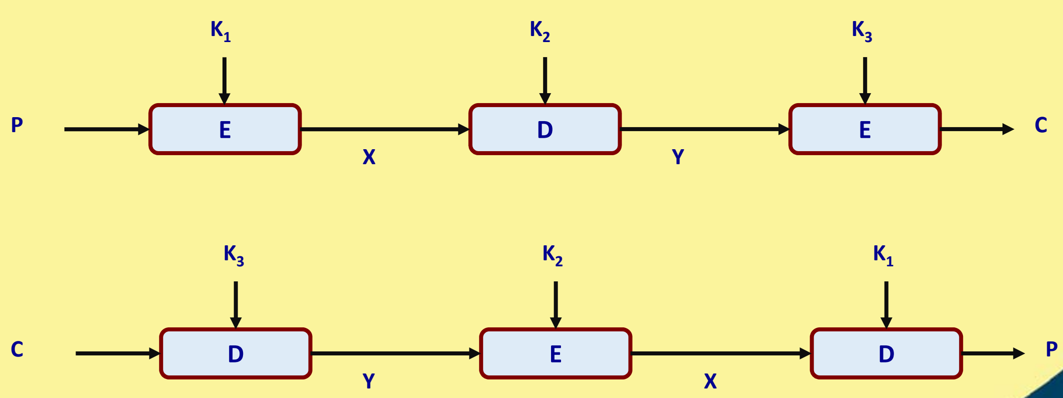
P = Plaintext

$E_K[X]$ = encryption of X using key K

$D_K[Y]$ = decryption of Y using key K

- Effective key length is 168 bits.

Triple DES: Illustration



Need for a new standard

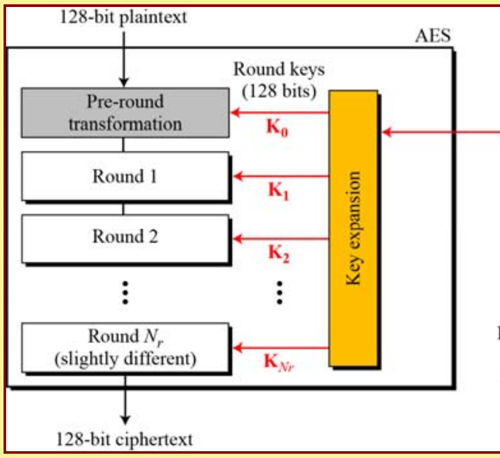
- DES had been in use for a long time.
  - A replacement for DES was needed.
  - Theoretical attacks can break it.
- Can use Triple-DES – but slow with small blocks.
- US NIST issued call for ciphers in 1997.
  - 15 candidates accepted in June 1998.
  - 5 were short-listed in August 1999.
- Rijndael was selected as the ***Advanced Encryption Standard*** in October 2000.

The AES Cryptosystem

- In the Rijndael proposal, the block length and the key length can be independently specified to be 128, 192, or 256 bits.
- The AES standard limits the block length to 128 bits.
  - Key length can be 128, 192, or 256 bits.
- Easy to implement, both in hardware and software.
- Resistant against all known attacks.

AES Rounds

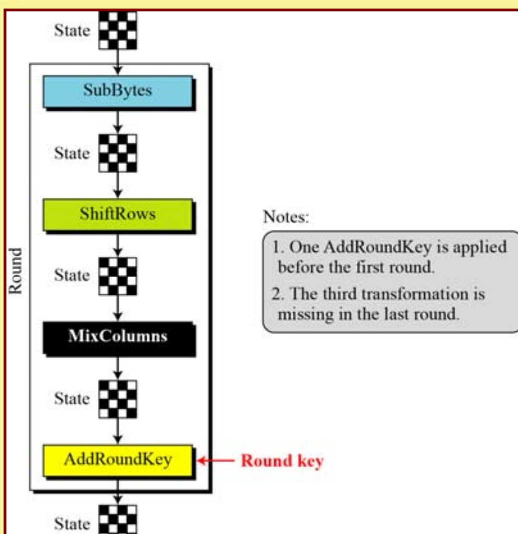
- AES has 10, 12 or 14 rounds.
  - All rounds are identical, except the first and last one.
- Various steps in each round:
  - **SubBytes** – Non-linear substitution
  - **ShiftRows** – Transposition
  - **MixColumn** – Mixing operations of each column
  - **AddRoundKey** – Round key added to state.

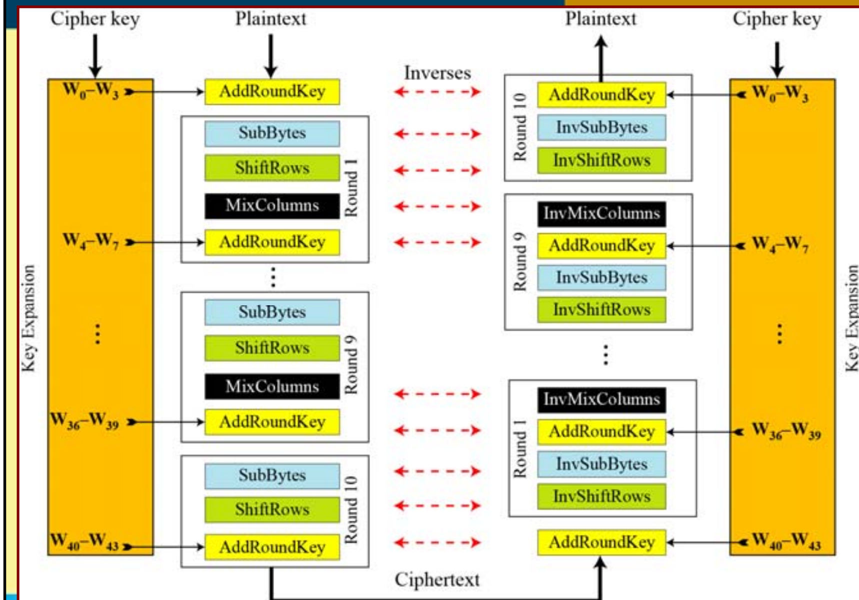


Nr	Key size
10	128
12	192
14	256

Relationship between number of rounds and cipher key size

Details of Each Round





Overall Structure

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Course Name: Ethical Hacking

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Department : Computer Science and Engineering

Topic

Lecture 29: Public-Key Cryptography (Part I)

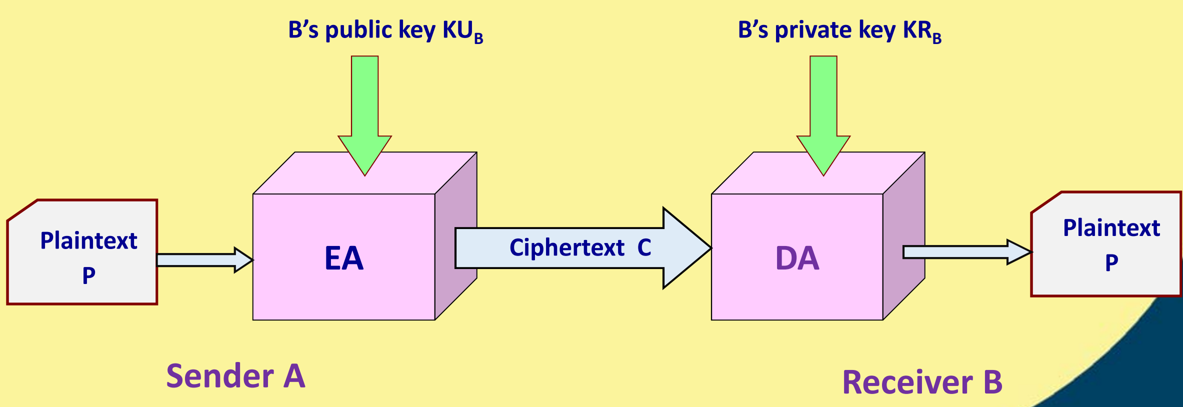
CONCEPTS COVERED

- Public-key cryptography
- Encryption and authentication
- RSA algorithm

Public Key Cryptography

- Uses two keys for every simplex logical communication link.
  a) Public key
  b) Private key
- The use of two keys has profound consequences in the areas of
  - Confidentiality
  - Key distribution
  - Authentication

Illustration :: Encryption



Key Usage for Encryption

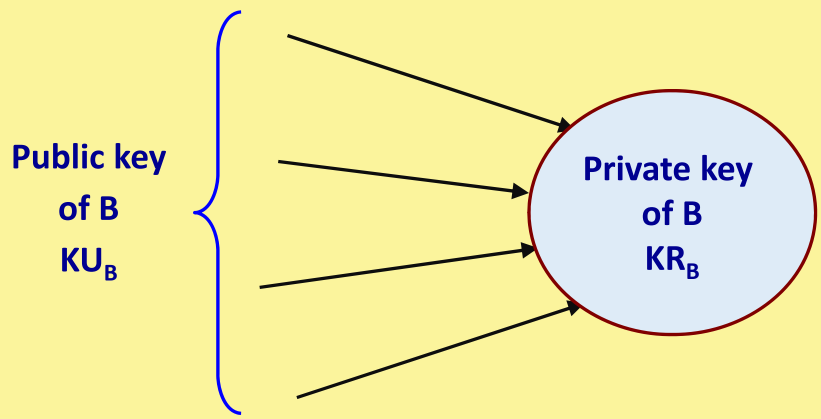
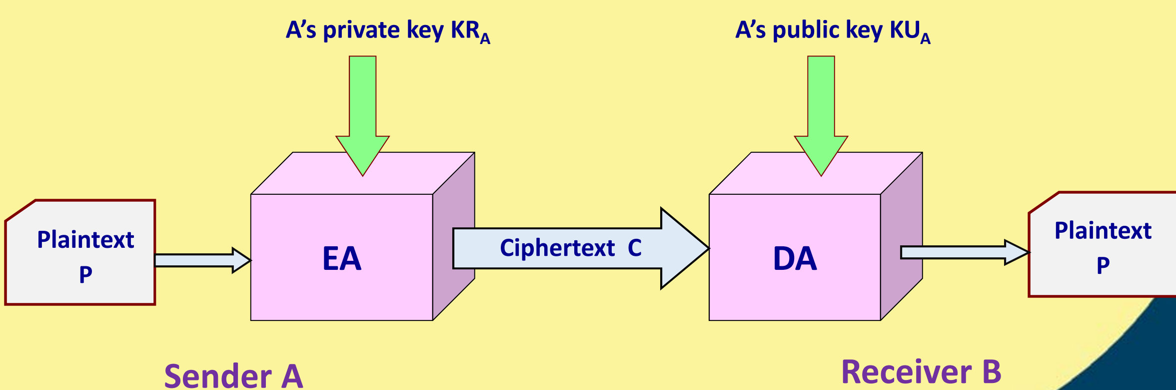
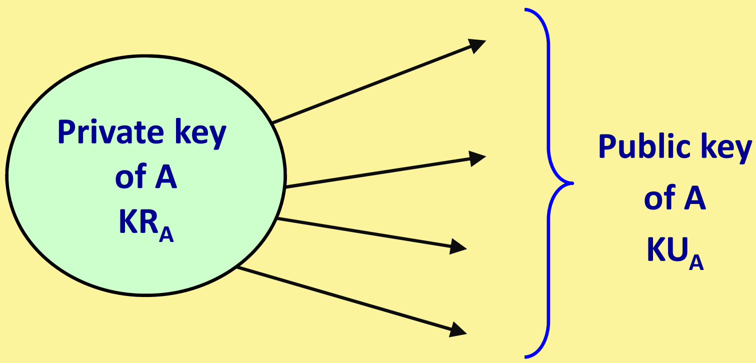


Illustration :: Authentication



Key Usage for Authentication



Applications

- Three categories:
  a) **Encryption/decryption:**
     - The sender encrypts a message with the recipient's public key.
  b) **Digital signature / authentication:**
     - The sender signs a message with its private key.
  c) **Key exchange:**
     - Two sides cooperate to exhange a session key.

Requirements

- Computationally easy for a party B to generate a key pair
  a) Public key KU_B
  b) Private key KR_B
- Easy for sender to generate ciphertext:

  $C = E(M, KU_B)$
- Easy for the receiver to decrypt ciphertext using private key:

  $M = D(C, KR_B) = D(E(M, KU_B), KR_B)$

- Computationally infeasible to determine **KR_B** knowing **KU_B**.
- Computationally infeasible to recover message **M**, knowing **KU_B** and ciphertext **C**.
- Either of the two keys can be used for encryption, with the other used for decryption:

  $M = D(E(M, KU_B), KR_B) = D(E(M, KR_B), KU_B)$

The RSA Public Key Algorithm

- RSA Algorithm
  - Developed by Ron Rivest, Adi Shamir and Len Adleman at MIT, in 1977.
  - A block cipher.
  - The most widely implemented.

RSA : Key Generation

1.	Select *p,q*	***p* and *q* both prime**
2.	Calculate $n = p \times q$	
3.	Calculate	$\Phi(n) = (p-1)(q-1)$
4.	Select integer *e*	$\gcd(\Phi(n),e)=1;\ 1<e<\Phi(n)$
5.	Calculate *d*	$d = e^{-1} \bmod \Phi(n)$
6.	Public Key	KU = {e,n}
7.	Private key	KR = {d,n}

$\phi(n)$ is the number of positive numbers less than *n* and relatively prime to *n* (called ***Euler totient***).

RSA : Encryption

- Plaintext: $M < n$
- Ciphertext: $C = M^e \pmod n$

RSA : Decryption

- Ciphertext: C
- Plaintext: $M = C^d \pmod n$

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Example

- Select two prime numbers, p=7 and q=17.
- Calculate $n = pq = 7 \times 17 = 119$.
- Calculate $\phi(n) = (p-1)(q-1) = 96$.
- Select e such that e is relatively prime to $\phi(n)=96$, and less than $\phi(n)$.
  - In this case, e=5.
- Determine d such that $de = 1 \pmod{96}$ and $d<96$.
  - $d=77$, because $77 \times 5 = 385 = 4 \times 96+1$.

Public key KU = {5,119}
Private key KR = {77,119}

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- **Encryption process:**
  - Say, plaintext M = 19.
  - Ciphertext C = 19^5 (mod 119)
    = 2476099 (mod 119) = 66
- **Decryption process:**
  - M = 66^{77} (mod 119) = 19.

The Security of RSA

- RSA is secure since
  - We use large number of bits in *e* and *d*.
  - The problem of factoring n into two prime factors is computationally very difficult.
    - ❖ Knowing *p* and *q* will allow us to know *Φ(n)*.
    - ❖ This will help an intruder to know the values of *e* and *d*.
  - Key sizes in the range of 1024 to 2048 bits seems safe.

Points to Note

- The RSA algorithm in conjunction with some private key algorithm (like AES) can be used for secure data transfer over insecure channel.
  - Private key K transmitted using public key algorithms (i.e. RSA).
  - K is used for encryption using private key algorithm.
- Prime factorization problem is solvable in polynomial time using quantum computers.
  - Resulted in research on post-quantum cryptographic algorithms.
  - Resistant against quantum attacks.

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Faculty Name: Prof. Indranil Sen Gupta

Department : Computer Science and Engineering

Topic

Lecture 30: Public-Key Cryptography (Part II)

CONCEPTS COVERED

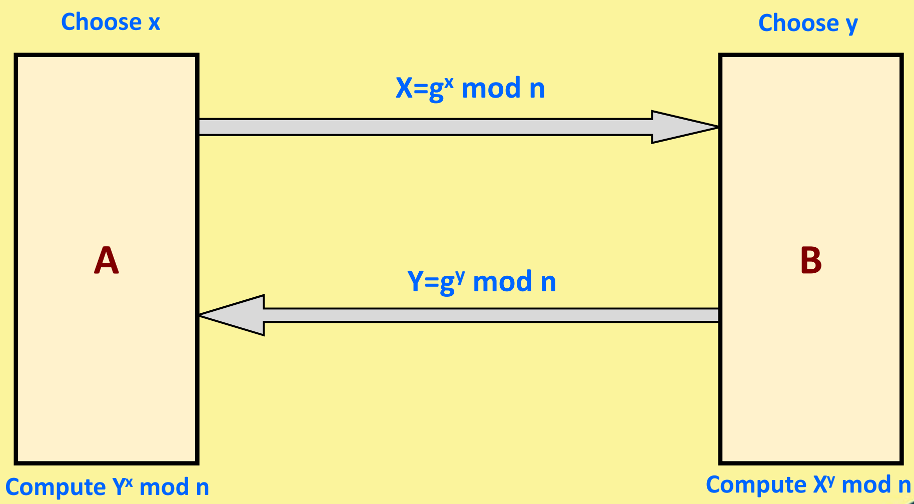
- ❑ Diffie Hellman key exchange
- ❑ Message authentication

Diffie-Hellman Key Exchange

- Proposed in 1976.
- Allows group of users to agree on secret key ***over insecure channel***.
- Cannot be used to encrypt and decrypt messages.
- Depends for its effectiveness on the difficulty of computing discrete logarithms.

D-H Algorithm

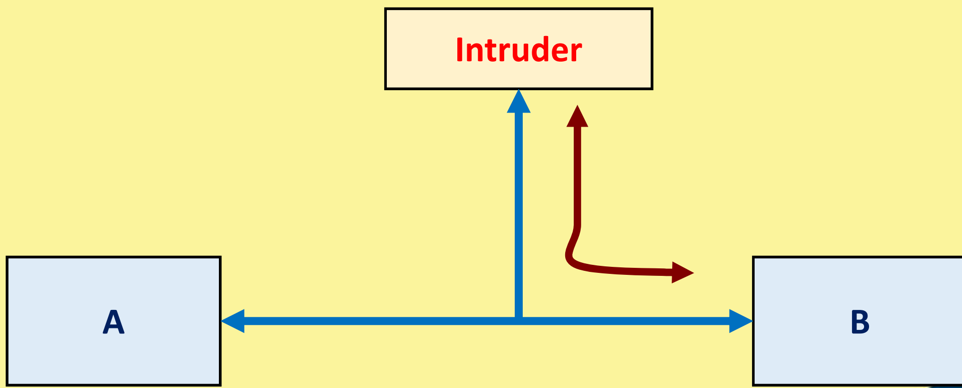
- A and B want to agree on secret key.
  - **a)** **A** and **B** agree on two large numbers **n** and **g**, such that $1<g<n$.
  - **b)** **A** choose random **x**, computes $X = g^x \bmod n$, and sends **X** to **B**.
  - **c)** **B** chooses random **y**, computes $Y = g^y \bmod n$, and sends **Y** to **A**.
  - **d)** **A** computes $k_1 = Y^x \bmod n$.
  - **e)** **B** computes $k_2 = X^y \bmod n$.
- Note: $k_1 = k_2 = g^{yx} \bmod n$.



D-H Algorithm (contd.)

- Requires no prior communication between ***A*** and ***B***.
- Security depends on difficulty of computing ***x***, given $X = g^x \bmod n$.
- Choices for ***g*** and ***n*** are critical.
  - Both ***n*** and ***(n-1)/2*** should be prime.
  - The value of ***n*** should be large.
- Susceptible to intruder-in-the-middle (man-in-the-middle) attack.
  - Active intruder.

Man-in-the-Middle Attack



A Comparison

- Symmetric encryption/decryption is much faster than asymmetric encryption/ decryption:

RSA: kilobits/second

DES: megabits/second

⇓

DES is about 100 times faster than RSA

- Key size:
  - a) **RSA**: selected by user
  - b) **DES**: 56 bits
  - c) **AES**: 128, 192 or 256 bits

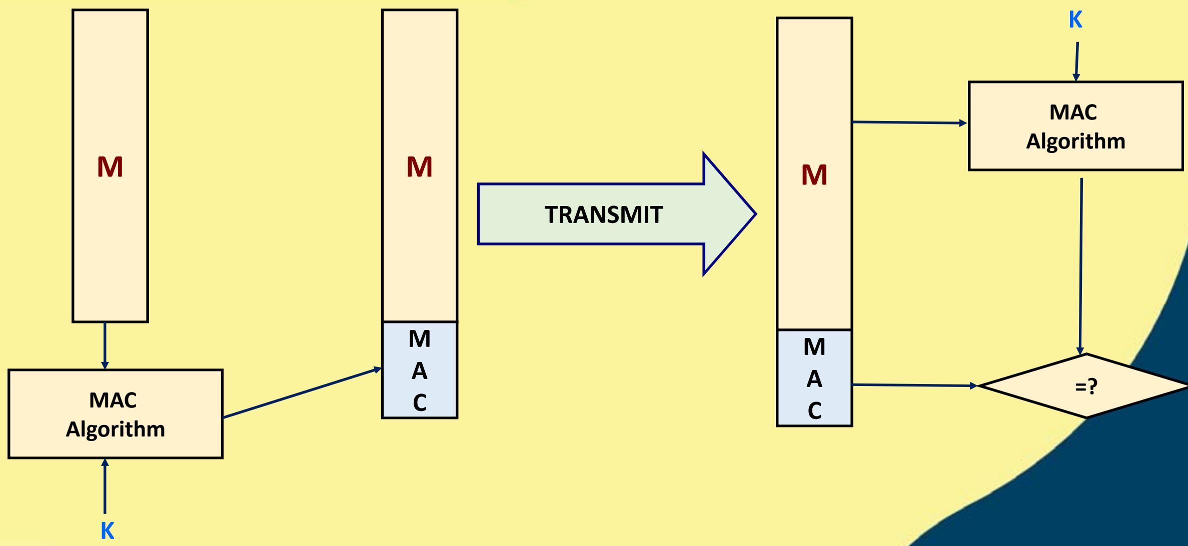
Message Authentication

Various Approaches

a) Authentication using conventional encryption.
   - Only the sender and receiver should share a key.

b) Message authentication without message encryption.
   - An authentication tag is generated and appended to each message.

c) Message authentication code.
   - Calculate the MAC as a function of the message and the key: ***MAC = F (K, M)***



Commonly Used Schemes

- The MD family
  - MD2, MD4 and MD5 (128-bit hash).
- The SHA family
  - SHA-1 (160-bit), SHA-256 (256-bit), SHA-384 (384-bit) and SHA-512 (512-bit).
- RIPEMD-128 (128-bit), RIPEMD-160 (160-bit).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