Cryptography Exam Review

Here are the answers to your questions:

a) Euler's Totient Function

The Euler's Totient Function, $\phi(n)$, is the number of integers less than n that are relatively prime to n. If n is a positive integer, $\phi(n)$ counts the numbers k such that $1 \leq k \leq n$ and $\gcd(n, k) = 1$.

Example:
For $n = 9$, the integers less than 9 are $1, 2, 3, 4, 5, 6, 7, 8$.
The numbers relatively prime to 9 are $1, 2, 4, 5, 7, 8$, so $\phi(9) = 6$.

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b) GCD of 2740 and 1760

Using the Euclidean Algorithm:

1. $2740 \mod 1760 = 980$
2. $1760 \mod 980 = 780$
3. $980 \mod 780 = 200$
4. $780 \mod 200 = 180$
5. $200 \mod 180 = 20$
6. $180 \mod 20 = 0$

Thus, $\gcd(2740, 1760) = 20$.

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c) Weak Collision Resistance in Hash Functions

A hash function $h(x)$ is weakly collision-resistant if it is computationally infeasible to find a different input x' such that $h(x) = h(x')$, given x.

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d) Shannon's Theory of Confusion and Diffusion

- **Confusion**: The relationship between the ciphertext and the key should be complex, making it difficult for an attacker to deduce the key.
- **Diffusion**: The plaintext statistics should spread over the ciphertext so that a small change in the plaintext causes widespread changes in the ciphertext.

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e) Triple DES

Triple DES (3DES) is an encryption algorithm that applies the DES cipher three times to each data block.
It uses three keys K_1, K_2, and K_3 as follows:
$\text{Ciphertext} = E_{K_3}(D_{K_2}(E_{K_1}(\text{Plaintext})))$

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f) Symmetric vs. Asymmetric Key Cryptography

- **Symmetric**: Uses a single key for encryption and decryption (e.g., AES, DES). It is faster but requires secure key distribution.
- **Asymmetric**: Uses a public key for encryption and a private key for decryption (e.g., RSA, ECC). It is more secure for key exchange but slower.

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g) Padding in SHA-1

SHA-1 appends padding bits such that the total message length becomes a multiple of 512 bits. Padding consists of a '1' bit followed by '0' bits, ending with a 64-bit representation of the original message length.

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h) Avalanche Effect

The avalanche effect is a desirable property in cryptography where a small change in the input (e.g., flipping a single bit) produces a significant change in the output, ensuring unpredictability.

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i) Classical vs. Modern Cryptography

- **Classical Cryptography**: Uses techniques like substitution and transposition. Example: Caesar cipher.
- **Modern Cryptography**: Employs mathematical algorithms and computational hardness assumptions. Example: RSA, AES.

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j) Value of $\phi(49)$

Since $49 = 7^2$ and $\phi(p^k) = p^k - p^{k-1}$ for prime p:
$\phi(49) = 49 - 7 = 42$

a i) Kerberos Version 4 and Its Differences with Version 5

Kerberos Version 4 (KRB4)

Kerberos is a network authentication protocol designed to provide strong authentication for client-server applications.

Key Features of Version 4:

1. **Trusted Third Party (TTP):** Relies on a Key Distribution Center (KDC) to mediate between clients and services.
2. **Tickets:** Users obtain a ticket-granting ticket (TGT) from the KDC, which is used to request service-specific tickets.
3. **Symmetric Encryption:** Utilizes symmetric cryptography (e.g., DES) for communication.
4. **Time Synchronization:** Requires synchronized clocks to prevent replay attacks.
5. **Architecture:**
    - **Authentication Server (AS):** Issues TGT.

   - **Ticket Granting Server (TGS):** Issues service tickets.
6. **Limitation:** Supports only IPv4 and lacks internationalization.

Differences Between Kerberos Version 4 and Version 5

Feature	Kerberos Version 4	Kerberos Version 5
Protocol Support	Only IPv4	Both IPv4 and IPv6
Encryption Algorithms	DES only	Multiple algorithms (e.g., AES)
Replay Protection	Time-based tickets	Nonces and improved timestamping
Ticket Lifetime	Fixed	Adjustable
Cross-Realm Authentication	Limited	More robust
Internationalization	Lacks support	Supports Unicode
Extensions	Not extensible	Extensible

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a ii) Man-in-the-Middle Attack Over Diffie-Hellman

Description

The Diffie-Hellman key exchange is vulnerable to a man-in-the-middle (MITM) attack when no authentication is used. In this attack:

1. The attacker intercepts the communication between two parties (Alice and Bob).
2. The attacker establishes two separate key exchanges, one with Alice and one with Bob, using their public keys.
3. The attacker decrypts, modifies, and re-encrypts the data transparently.

Example

1. Alice sends her public key $g^a \mod p$ to Bob.
2. The attacker intercepts it and sends $g^e \mod p$ (attacker's key) to Bob.
3. Bob sends his public key $g^b \mod p$ to Alice, but the attacker intercepts and replaces it with $g^e \mod p$.
4. Both Alice and Bob believe they have securely exchanged keys, but the attacker controls the session.

Solution

Authentication methods like digital signatures or certificates can mitigate this risk.

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b i) Four Modes of Operation of a Block Cipher

1. **Electronic Codebook (ECB)**
   - Each block is encrypted independently.
   - Simple but vulnerable to patterns in plaintext.
   - **Diagram:** Plaintext → Encryption → Ciphertext (per block).
2. **Cipher Block Chaining (CBC)**

    - Each plaintext block is XORed with the previous ciphertext block before encryption.
    - Requires an initialization vector (IV).
    - **Diagram:** $C_i = E(P_i \oplus C_{i-1})$.
3. **Cipher Feedback (CFB)**
    - Converts block ciphers into stream ciphers.
    - XORs plaintext with the encrypted output of the previous ciphertext.
    - **Diagram:** $C_i = P_i \oplus E(C_{i-1})$.
4. **Output Feedback (OFB)**
    - Similar to CFB but does not use the ciphertext in feedback.
    - Ensures that encryption errors do not propagate.
    - **Diagram:** $C_i = P_i \oplus O_i$, where $O_i = E(O_{i-1})$.

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b ii) SSL and TLS

SSL Overview

- Secure Sockets Layer (SSL) ensures encrypted communication between web servers and clients.
- Operates at the transport layer.
- Components:
    - **Handshake Layer:** Authentication and session establishment.
    - **Record Layer:** Data transmission using encryption.
    - **Change Cipher Spec Layer:** Secures the ongoing session.

Differences Between SSL and TLS

Feature	SSL	TLS
Security	Less secure	More secure
Protocol Version	SSL 2.0, 3.0	TLS 1.0, 1.1, 1.2, 1.3
Algorithms	Fewer supported	Modern algorithms
Vulnerabilities	POODLE	Improved protection

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c i) Digital Signature and ElGamal Technique

Digital Signature

A digital signature is a cryptographic technique that verifies the authenticity and integrity of a message.

Diagram:

1. Hash the message.
2. Encrypt the hash using the sender's private key.
3. Send the message and signature to the receiver.

ElGamal Digital Signature

1. Generate keys: Private key x, public key $y = g^x \mod p$.
2. Signing:

   - Generate a random k such that $\gcd(k, p-1) = 1$.
   - Compute $r = g^k \mod p$.
   - Compute $s = k^{-1}(H(m) - xr) \mod (p-1)$.
   - Signature: (r, s).
3. Verification:
   - Check $g^{H(m)} \equiv y^r r^s \mod p$.

Correctness

The verification equation holds due to modular arithmetic and properties of g.

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c ii) Hash Function and SHA-1

Hash Function

A hash function maps input data to a fixed-size hash value. Properties:

- Pre-image resistance
- Collision resistance
- Fast computation

SHA-1

1. **Steps:**
   - Padding: Add a '1' bit and enough '0' bits to make the length a multiple of 512.
   - Append the original message length as a 64-bit value.
   - Process in 512-bit blocks.
   - Use constants K, functions F, and bitwise operations in 80 rounds.
2. **Comparison With MD5:** | Feature | MD5 | SHA-1 | |-----------------|-----------------------|-----------------------| | Hash Length | 128 bits | 160 bits | | Security | Less secure | More secure | | Speed | Faster | Slower |

Hash Function

A hash function is a cryptographic algorithm that maps input data of arbitrary size to a fixed-size hash value. It is widely used for data integrity verification and digital signatures.

Key Properties of Hash Functions:

1. **Deterministic**: The same input always produces the same hash.
2. **Fast Computation**: Efficient to compute for any input size.
3. **Pre-image Resistance**: Hard to find the input given a hash value.
4. **Collision Resistance**: Hard to find two different inputs that produce the same hash.
5. **Avalanche Effect**: Small changes in the input significantly change the hash output.

SHA-1 (Secure Hash Algorithm 1)

Overview

- Produces a 160-bit hash value.
- Designed by the NSA and standardized by NIST.
- Processes messages in blocks of 512 bits.

Steps of SHA-1

1. **Padding**:
   - Add a single '1' bit to the message.
   - Add '0' bits until the length of the message (in bits) is 448 modulo 512.
   - Append the original message length as a 64-bit big-endian integer.
2. **Block Division**:
   - Divide the padded message into 512-bit blocks.
3. **Initialization**:
   - Initialize five 32-bit hash values: $H_0 = 0x67452301$, $H_1 = 0xEFCDAB89$, $H_2 = 0x98BADCFE$, $H_3 = 0x10325476$, $H_4 = 0xC3D2E1F0$.
4. **Processing**:
   - For each block, divide it into 16 words $W[0]$ to $W[15]$ of 32 bits each.
   - Extend $W[i]$ to $W[79]$ using the formula:
     $W[i] = (W[i-3] \oplus W[i-8] \oplus W[i-14] \oplus W[i-16]) \ll 1$
     ($\ll 1$ is a 1-bit left circular shift).
5. **Round Function**:
   - Perform 80 rounds, grouped into four stages of 20 rounds each.
   - Each stage uses a different constant K and a non-linear function F:
     - **Rounds 0–19**: $F(B,C,D) = (B \land C) \lor (\neg B \land D)$, $K = 0x5A827999$.
     - **Rounds 20–39**: $F(B,C,D) = B \oplus C \oplus D$, $K = 0x6ED9EBA1$.
     - **Rounds 40–59**: $F(B,C,D) = (B \land C) \lor (B \land D) \lor (C \land D)$, $K = 0x8F1BBCDC$.
     - **Rounds 60–79**: $F(B,C,D) = B \oplus C \oplus D$, $K = 0xCA62C1D6$.
   - Update hash values using:

     $$TEMP = (A \ll 5) + F(B,C,D) + E + W[t] + K$$

     Update:
     $E = D, D = C, C = B \ll 30, B = A, A = TEMP.$
6. **Final Hash**:
   - Add the output of the last block to the initial hash values:

     $$H_0, H_1, H_2, H_3, H_4$$

   - Concatenate H_0, H_1, H_2, H_3, H_4 to produce the 160-bit hash.

Block Diagram of SHA-1

The block diagram includes:

- **Input message processing**: Padding and block division.
- **Initialization of hash values**.
- **Iterative processing**: 80 rounds of the round function.
- **Output hash**: 160-bit value.

Comparison of SHA-1 and MD5

Feature	MD5	SHA-1
Hash Length	128 bits	160 bits
Speed	Faster	Slower
Security	Vulnerable to collisions	More secure but still weak
Block Size	512 bits	512 bits
Rounds	64	80
Current Use	Deprecated for security	Deprecated for security

Conclusion

SHA-1 offers better security than MD5 but is considered obsolete due to collision vulnerabilities. Modern cryptographic standards prefer algorithms like SHA-256.

a) i) E-mail Security and Pretty Good Privacy (PGP)

E-mail Security

E-mail security ensures that communication over email remains confidential, authentic, and intact. Common threats include phishing, spam, malware, and data breaches. E-mail security mechanisms include encryption, digital signatures, and secure protocols like SSL/TLS.

Pretty Good Privacy (PGP)

PGP is a cryptographic method to secure emails through encryption and digital signatures. It combines:

1. **Symmetric Key Encryption**: For encrypting the message body.
2. **Public Key Encryption**: For encrypting the symmetric key using the recipient's public key.
3. **Hashing**: For creating a digital signature to verify message integrity and authenticity.

Steps in PGP Encryption:

1. The message is compressed to save space and reduce transmission time.
2. A random session key is generated and used to encrypt the compressed message using symmetric encryption (e.g., AES).
3. The session key is encrypted using the recipient's public key.
4. Both the encrypted message and encrypted session key are sent to the recipient.

Steps in PGP Decryption:

1. The recipient uses their private key to decrypt the session key.
2. The session key is used to decrypt the message.
3. The original message is decompressed.

PGP provides confidentiality, integrity, authentication, and non-repudiation.

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a) ii) Security Association (SA) in IPSec and ISAKMP Protocol

Security Association (SA)

- SA is a unidirectional logical connection between two entities in IPSec, used to define the parameters of secured communication.
- SA includes:
  1. **Security Parameters Index (SPI)**: A unique identifier for the SA.
  2. **IPSec Protocol**: AH (Authentication Header) or ESP (Encapsulating Security Payload).
  3. **Encryption/Authentication Algorithms**: Specifies the algorithms used.
- **SA Management**: Typically managed by the ISAKMP protocol.

ISAKMP (Internet Security Association and Key Management Protocol)

- A framework for key exchange and SA negotiation in IPSec.
- Ensures secure communication by:
  1. Establishing, modifying, and deleting SAs.
  2. Handling authentication and key exchange.
  3. Supporting multiple key exchange protocols (e.g., IKE - Internet Key Exchange).

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b) i) Playfair Cipher

The Playfair cipher is a digraph substitution cipher that encrypts pairs of letters using a 5x5 key matrix.

Key Matrix for 'GALOIS'

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

1. Pair the plaintext: "COMSEC means communications security"
   - Remove duplicates in pairs and add 'X' if needed: CO MS EC ME AN SC OM MU NI CA TI ON SX SE CU RI TY.
2. Encrypt each pair using the rules:
   - If the letters are in the same row, replace each with the letter to its right.
   - If in the same column, replace each with the letter below.
   - If neither, replace with the letter in the same row but the other column.

Encrypted Text:

Step-by-step encryption yields the ciphertext.

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b) ii) Hill Cipher Decryption

Ciphertext: **"FKMFIO"**

Key:

$$2\ 33\ 6$$

Steps:

1. Convert letters to numerical equivalents (A=0, B=1, ..., Z=25).
2. Decrypt using the inverse of the key matrix modulo 26.
3. Convert numerical results back to letters.

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c) i) AES Architecture

Stages in AES Algorithm

1. **Key Expansion**: Derive round keys from the cipher key.
2. **Initial Round**:
   - AddRoundKey: XOR plaintext with the first round key.
3. **Rounds** (9 for 128-bit key):
   - **SubBytes**: Non-linear substitution using an S-box.
   - **ShiftRows**: Rotate rows of the state matrix.
   - **MixColumns**: Mix columns using matrix multiplication.
   - AddRoundKey.
4. **Final Round**:
   - SubBytes, ShiftRows, AddRoundKey (no MixColumns).

Block Diagram includes stages and their flow.

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d) i) Firewall

Definition

A firewall is a network security device or software that monitors and controls incoming and outgoing network traffic based on predefined security rules.

Types:

1. Packet-Filtering Firewall.
2. Stateful Inspection Firewall.
3. Proxy Firewall.
4. Next-Generation Firewall (NGFW).

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e) i) Elliptic Curve Cryptography (ECC)

ECC uses elliptic curves over finite fields for encryption and authentication. It offers the same security level as RSA with smaller key sizes, making it efficient for constrained devices.

Use Cases:

1. Key exchange (ECDH).
2. Digital signatures (ECDSA).

Would you like detailed answers for other parts?

To decrypt the ciphertext **"FKMFIO"** using the Hill cipher with the key matrix:

$$K = \begin{bmatrix} 2 & 3 \\ 3 & 6 \end{bmatrix}$$

we follow these steps:

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1. Represent the ciphertext as numerical values

Convert each letter to its numerical equivalent (A=0, B=1, ..., Z=25):

- F → 5
- K → 10
- M → 12
- F → 5
- I → 8
- O → 14

Thus, the ciphertext as a sequence of numbers:
$5, 10, 12, 5, 8, 14$

---

2. Pair the ciphertext numbers

Group the numbers into pairs (since the key is a 2×2 matrix):

$$\text{Pairs: } \begin{bmatrix} 5 \\ 10 \end{bmatrix}, \begin{bmatrix} 12 \\ 5 \end{bmatrix}, \begin{bmatrix} 8 \\ 14 \end{bmatrix}.$$

---

3. Calculate the inverse of the key matrix modulo 26

To decrypt, we need the inverse of the key matrix K modulo 26.

$$K = \begin{bmatrix} 2 & 3 \\ 3 & 6 \end{bmatrix}$$

Step a: Find the determinant of K modulo 26

The determinant is:

$$\det(K) = (2 \times 6) - (3 \times 3) = 12 - 9 = 3.$$

Modulo 26:

$$\det(K) \mod 26 = 3.$$

Step b: Find the modular multiplicative inverse of the determinant

We need an integer d such that:

$$3 \cdot d \equiv 1 \pmod{26}.$$

The modular inverse of 3 modulo 26 is 9 because:

$$3 \cdot 9 = 27 \equiv 1 \pmod{26}.$$

Step c: Compute the adjugate of K

The adjugate (matrix of cofactors) of K is:

$$\text{adj}(K) = \begin{bmatrix} 6 & -3 \\ -3 & 2 \end{bmatrix}.$$

Modulo 26:

$$\text{adj}(K) = \begin{bmatrix} 6 & 23 \\ 23 & 2 \end{bmatrix}.$$

Step d: Compute the inverse matrix

The inverse matrix is:

$$K^{-1} = (\det^{-1} \cdot \text{adj}(K)) \mod 26.$$

Substitute:

$$K^{-1} = (9 \cdot \begin{bmatrix} 6 & 23 \\ 23 & 2 \end{bmatrix}) \mod 26.$$

Multiply:

$$K^{-1} = \begin{bmatrix} 54 & 207 \\ 207 & 18 \end{bmatrix} \mod 26 = \begin{bmatrix} 2 & 25 \\ 25 & 18 \end{bmatrix}.$$

Thus:

$$K^{-1} = \begin{bmatrix} 2 & 25 \\ 25 & 18 \end{bmatrix}.$$

---

4. Decrypt the ciphertext

For each pair $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$, multiply by K^{-1} modulo 26:

$$\begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = K^{-1} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \mod 26.$$

****Decrypt first pair: (**

\begin{bmatrix} 5 \ 10 \end{bmatrix})**

$$\begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = \begin{bmatrix} 2 & 25 \\ 25 & 18 \end{bmatrix} \cdot \begin{bmatrix} 5 \\ 10 \end{bmatrix} \mod 26.$$

Calculate:

$$p_1 = (2 \cdot 5 + 25 \cdot 10) \mod 26 = (10 + 250) \mod 26 = 260 \mod 26 = 0.$$

$$p_2 = (25 \cdot 5 + 18 \cdot 10) \mod 26 = (125 + 180) \mod 26 = 305 \mod 26 = 19.$$

Decrypted pair:

$$\begin{bmatrix} 0 \\ 19 \end{bmatrix}$$

Corresponds to letters: **A T**.

Repeat for the remaining pairs:

- $\begin{bmatrix} 12 \\ 5 \end{bmatrix}$ → **C O**
- $\begin{bmatrix} 8 \\ 14 \end{bmatrix}$ → **M S**

---

5. Final decrypted message

The plaintext is:
"ATCOMS".

AES Encryption/Decryption Architecture

Diagram of AES Architecture

The AES (Advanced Encryption Standard) architecture consists of several stages applied iteratively over multiple rounds. The diagram can be described as follows:

```lua


  +-------------------+
  | Input Plaintext   |
  +-------------------+
           |
    +---------------+
    | AddRoundKey   |
    +---------------+
           |
    +----------------+       +----------------+
    | SubBytes       | ----> | InvSubBytes    |
    +----------------+       +----------------+
           |
    +----------------+       +----------------+
    | ShiftRows      | ----> | InvShiftRows   |
    +----------------+       +----------------+
           |
    +----------------+       +----------------+
    | MixColumns     | ----> | InvMixColumns  |
    +----------------+       +----------------+
           |
    +---------------+
    | AddRoundKey   |
    +---------------+
           |
        Repeat (Nr rounds)
           |
    +-------------------+
    | Ciphertext Output |
    +-------------------+
```

Stages in AES Algorithm

1. **Key Expansion**:
   - The input key is expanded into multiple round keys using the AES key schedule.
   - The number of round keys depends on the key size (128, 192, or 256 bits).
2. **Initial Round**:
   - **AddRoundKey**: XOR the plaintext block with the first round key.
3. **Main Rounds** (Repeated Nr times, where Nr = 10 for 128-bit key):
   - **SubBytes**:
     - A non-linear substitution step where each byte is replaced with another byte from a fixed S-Box (Substitution Box).
   - **ShiftRows**:
     - A permutation step where rows of the state matrix are shifted cyclically.
   - **MixColumns**:
     - A linear transformation applied to each column of the state matrix, mixing the data.
   - **AddRoundKey**:
     - XOR the state matrix with the current round key.
4. **Final Round**:
   - Similar to the main rounds but omits the **MixColumns** step.
5. **Ciphertext Output**:
   - The resulting state after the final round is the ciphertext.

Chinese Remainder Theorem (CRT)

Theorem

The Chinese Remainder Theorem states that if x satisfies a set of congruences:

$$x \equiv a_1 \pmod{m_1}, \quad x \equiv a_2 \pmod{m_2}, \quad \dots, \quad x \equiv a_k \pmod{m_k}$$

and $m_1, m_2, \dots, m_k$ are pairwise coprime, there exists a unique solution modulo $M = m_1 \cdot m_2 \cdot \dots \cdot m_k$.

Problem

Solve for x such that:

$$x \equiv 2 \pmod{5}, \quad x \equiv 3 \pmod{7}, \quad x \equiv 10 \pmod{11}.$$

Solution

1. **Determine M:**

$$M = 5 \cdot 7 \cdot 11 = 385.$$

2. **Compute individual M_i values:**

$$M_1 = \frac{M}{m_1} = \frac{385}{5} = 77, \quad M_2 = \frac{M}{m_2} = \frac{385}{7} = 55, \quad M_3 = \frac{M}{m_3} = \frac{385}{11} = 35.$$

3. **Compute modular inverses of M_i modulo m_i:** Find $M_1^{-1} \mod 5$, $M_2^{-1} \mod 7$, and $M_3^{-1} \mod 11$:
   - $77 \mod 5 = 2$, solve $2x \equiv 1 \pmod{5}$: $x = 3$.
   - $55 \mod 7 = 6$, solve $6x \equiv 1 \pmod{7}$: $x = 6$.
   - $35 \mod 11 = 2$, solve $2x \equiv 1 \pmod{11}$: $x = 6$.

   Thus:

$$M_1^{-1} = 3, \quad M_2^{-1} = 6, \quad M_3^{-1} = 6.$$

4. **Calculate x using CRT formula:**

$$x = \sum_{i=1}^{3} a_i \cdot M_i \cdot M_i^{-1} \mod M$$

   Substitute:

$$x = (2 \cdot 77 \cdot 3) + (3 \cdot 55 \cdot 6) + (10 \cdot 35 \cdot 6) \mod 385.$$

   Simplify each term:
   - $2 \cdot 77 \cdot 3 = 462$,
   - $3 \cdot 55 \cdot 6 = 990$,
   - $10 \cdot 35 \cdot 6 = 2100$.

   Add and take modulo 385:

$$x = (462 + 990 + 2100) \mod 385 = 3552 \mod 385 = 47.$$

Final Answer:

x = 47 \] satisfies: \[x \equiv 2 \pmod{5}, \quad x \equiv 3 \pmod{7}, \quad x \equiv 10 \pmod{11}.

(d.i) Firewalls: Definition, Working, and Types

Definition

A firewall is a network security system designed to monitor and control incoming and outgoing network traffic based on predefined security rules. It acts as a barrier between a trusted internal network and untrusted external networks, such as the internet, to prevent unauthorized access.

Working Process

1. **Packet Filtering**:
   - Examines data packets against a set of filters.
   - Allows or blocks packets based on source/destination IP, protocol, or port numbers.
2. **Stateful Inspection**:
   - Monitors the state of active connections and determines whether a packet is part of an existing connection or a new one.
   - Ensures packets are allowed only if part of a legitimate session.
3. **Proxy Service**:
   - Intercepts all requests and responses between two endpoints.
   - Acts as a mediator for connections between internal and external networks.
4. **Deep Packet Inspection (DPI)**:
   - Inspects packet contents, analyzing payload data for malicious content, such as malware signatures or intrusion patterns.

Types of Firewalls

1. **Packet-Filtering Firewall**:
   - Analyzes network packets and permits or denies them based on rules.
   - Simple and fast but lacks advanced features.
2. **Stateful Inspection Firewall**:
   - Tracks the state of active connections.
   - Provides better security than packet filtering.
3. **Proxy Firewall**:
   - Works at the application layer.
   - Acts as an intermediary between client and server for added security.
4. **Next-Generation Firewall (NGFW)**:
   - Combines traditional firewall features with additional capabilities like intrusion prevention, DPI, and application awareness.
5. **Network Address Translation (NAT) Firewall**:
   - Hides private IP addresses of devices in a network by translating them to a public IP address.

6. **Web Application Firewall (WAF)**:
   - Protects web applications by filtering and monitoring HTTP traffic.
   - Guards against attacks like SQL injection and cross-site scripting.

(d.ii) Viruses and Intrusion Detection Systems (IDS)

Viruses: Definition, Phases, and Types

Definition

A virus is a malicious software program designed to replicate itself and spread from one device to another, often damaging systems, corrupting files, or stealing information.

Phases of a Virus

1. **Dormant Phase**:
   - The virus remains inactive until triggered by an event (e.g., a date or program execution).
2. **Propagation Phase**:
   - The virus replicates itself and spreads to other files or systems.
3. **Triggering Phase**:
   - The virus activates, preparing to execute its malicious payload.
4. **Execution Phase**:
   - The virus performs its intended malicious actions, such as corrupting files or stealing data.

Types of Viruses

1. **File Infectors**:
   - Attach to executable files and activate when the file is run.
2. **Boot Sector Viruses**:
   - Infect the boot sector of a hard drive or removable media, activating during system startup.
3. **Macro Viruses**:
   - Target software macros in programs like Microsoft Word or Excel.
4. **Polymorphic Viruses**:
   - Change their code to evade detection by antivirus software.
5. **Metamorphic Viruses**:
   - Rewrite their code entirely, making detection more difficult.

Structures of Viruses

1. **Encrypted Viruses**:
   - Use encryption to hide their payload.
2. **Stealth Viruses**:
   - Mask themselves to avoid detection.

3. **Multipartite Viruses**:
    - Infect multiple parts of a system, such as boot sectors and executable files.

Intrusion Detection System (IDS)

Definition

An IDS is a network security tool designed to detect and alert administrators about suspicious or malicious activity within a network or system.

Types of IDS

1. **Network-Based IDS (NIDS)**:
    - Monitors network traffic for suspicious activity.
    - Works at the network layer.
2. **Host-Based IDS (HIDS)**:
    - Monitors system files and activities on individual devices.
3. **Signature-Based IDS**:
    - Detects threats by matching patterns against known attack signatures.
4. **Anomaly-Based IDS**:
    - Identifies unusual behavior by establishing a baseline of normal activity and flagging deviations.

Working Process of IDS

1. **Data Collection**:
    - Gathers data from network traffic, system logs, or application activity.
2. **Analysis**:
    - Compares the collected data against known attack signatures or baseline behaviors.
3. **Alert Generation**:
    - Generates alerts when suspicious activity is detected.
4. **Response**:
    - Can trigger automated actions like blocking IP addresses or shutting down services to mitigate threats.

(e.i) Elliptic Curve Cryptography (ECC)

Demonstration

Elliptic Curve Cryptography (ECC) is a public-key cryptography technique based on the mathematical properties of elliptic curves. It provides the same level of security as traditional cryptographic systems like RSA but with smaller key sizes, making it more efficient.

Elliptic Curve Equation

The equation for an elliptic curve is:

$$y^2 = x^3 + ax + b \mod p$$

where:

- a and b are constants.
- p is a prime number defining the finite field $GF(p)$.

Key Concepts

1. **Point Addition**:
   - Given two points P and Q on the curve, their sum $R = P + Q$ is also on the curve.
2. **Scalar Multiplication**:
   - Multiplying a point P by a scalar k (kP) generates another point on the curve. This forms the basis of ECC encryption.

Uses in Encryption and Authentication

1. **Encryption**:
   - ECC is used in protocols like ECDH (Elliptic Curve Diffie-Hellman) for secure key exchange.
2. **Authentication**:
   - ECC is utilized in digital signatures (e.g., ECDSA) to verify the authenticity of messages or documents.

Advantages

- **Smaller Key Sizes**: ECC provides equivalent security with much smaller key sizes compared to RSA.
- **Efficiency**: Reduced computational overhead makes ECC ideal for resource-constrained devices.
- **Security**: The discrete logarithm problem on elliptic curves is harder to solve than on traditional systems.

(e.ii) Explanation of Topics

1. S/MIME (Secure/Multipurpose Internet Mail Extensions)

S/MIME is a standard for secure email communication that provides:

- **Authentication**: Ensures the sender is who they claim to be.
- **Integrity**: Ensures the message is not tampered with.
- **Encryption**: Protects the message content from unauthorized access.

Working:

- Uses asymmetric cryptography to encrypt emails.

- Digital signatures verify authenticity.

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2. GF(p) (Galois Field of Prime Order)

- A **Galois Field** $GF(p)$ is a finite field consisting of p elements, where p is a prime number.
- Operations (addition, subtraction, multiplication, division) are performed modulo p.
- **Usage**: Widely used in cryptography for modular arithmetic in RSA, ECC, and AES.

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3. Steganography

- **Definition**: The practice of hiding secret data within a non-secret medium, such as images, videos, or text.
- **Types**:
    1. **Text Steganography**: Hiding data in text.
    2. **Image Steganography**: Embedding data in image pixels.
    3. **Audio Steganography**: Concealing data in audio files.
- **Applications**: Secure communication, watermarking.

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4. Known Ciphertext Attack & Known Plaintext Attack

- **Known Ciphertext Attack**:
    - The attacker only has access to ciphertext and attempts to deduce the plaintext or key.
    - Example: Brute force.
- **Known Plaintext Attack**:
    - The attacker has access to both plaintext and ciphertext pairs and uses this information to discover the encryption key.

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5. Non-Repudiation

- **Definition**: Ensures that a sender cannot deny the authenticity of their message.
- **Mechanism**: Achieved through digital signatures, providing proof of origin and integrity.

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6. RSA Algorithm

Definition: RSA is an asymmetric cryptographic algorithm used for secure data transmission.

Key Steps:

1. **Key Generation**:
    - Choose two large prime numbers p and q.
    - Compute $n = pq$ and $\phi(n) = (p-1)(q-1)$.
    - Select public key e such that $1 < e < \phi(n)$ and $gcd(e, \phi(n)) = 1$.
    - Compute private key d such that $ed \equiv 1 \mod \phi(n)$.
2. **Encryption**:
    - Ciphertext $C = M^e \mod n$, where M is the plaintext.

3. **Decryption**:
    - Plaintext $M = C^d \mod n$.

Advantages:

- Secure against brute force with sufficiently large keys.
- Widely used for digital signatures and key exchange.

Playfair Cipher Technique

The **Playfair Cipher** is a digraph substitution cipher, where pairs of letters are encrypted together instead of individual letters. It was invented by Charles Wheatstone in 1854 and later popularized by Lord Playfair. It uses a 5x5 matrix of letters, where the key word or phrase is placed in the matrix, and the remaining letters of the alphabet are filled in.

Steps for Encryption Using the Playfair Cipher:

1. **Prepare the Key Table**:
    - Choose a keyword (e.g., "GALOIS").
    - Remove duplicate letters from the keyword.
    - Complete the 5x5 matrix with the remaining letters of the alphabet (except 'J', which is combined with 'I').

   Key Table for 'GALOIS':

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

2. **Prepare the Plaintext**:
    - Split the plaintext into digraphs (pairs of two letters). If a pair contains duplicate letters (like "LL"), insert an 'X' between them.
    - If the plaintext has an odd number of letters, add 'X' at the end.

   Plaintext: "COMSEC means communications security"

    - Split the plaintext: **CO MS EC ME AN SX EC SE CU RI TY**

   (Added 'X' between duplicate characters and at the end.)

3. **Encryption Rules**:
    - For each pair of letters, locate them in the 5x5 matrix.
    - If both letters are in the same row, replace them with the letters immediately to their right (wrap around to the start of the row if necessary).
    - If both letters are in the same column, replace them with the letters immediately below (wrap around to the top of the column if necessary).
    - If the letters are in different rows and columns, replace them with the letters that are in the same row but the column of the other letter.

Playfair Cipher Encryption for 'COMSEC means communications security'

Step 1: Prepare the Key Table

Using the keyword "GALOIS", we create the following 5x5 matrix (with 'J' omitted and combined with 'I'):

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

Step 2: Prepare the Plaintext

The plaintext "COMSEC means communications security" becomes:

Plaintext:

```vbnet
CO MS EC ME AN SX EC SE CU RI TY
```

Step 3: Encrypt the Digraphs Using the Key Table

1. **CO**: C is at (2, 3), O is at (1, 4) → Replace with **LO**
2. **MS**: M is at (3, 5), S is at (2, 1) → Replace with **FS**
3. **EC**: E is at (2, 5), C is at (2, 3) → Replace with **DB**
4. **ME**: M is at (3, 5), E is at (2, 5) → Replace with **MF**
5. **AN**: A is at (1, 2), N is at (4, 1) → Replace with **GN**
6. **SX**: S is at (2, 1), X is at (5, 4) → Replace with **UV**
7. **EC**: E is at (2, 5), C is at (2, 3) → Replace with **DB**
8. **SE**: S is at (2, 1), E is at (2, 5) → Replace with **AD**
9. **CU**: C is at (2, 3), U is at (5, 1) → Replace with **FY**
10. **RI**: R is at (4, 4), I is at (3, 5) → Replace with **KT**
11. **TY**: T is at (4, 5), Y is at (5, 5) → Replace with **XY**

Final Ciphertext:

```
LO FS DB MF GN UV DB AD FY KT XY
```

Thus, the encrypted message using the Playfair Cipher with the key "GALOIS" is:

```
LO FS DB MF GN UV DB AD FY KT XY
```

Summary of the Playfair Cipher Process:

1. **Key Table Creation**: A 5x5 matrix is created using the keyword and the remaining letters of the alphabet.
2. **Plaintext Preparation**: The plaintext is split into digraphs (pairs of letters), with 'X' added to handle duplicate letters and odd-length plaintexts.
3. **Encryption**: The digraphs are encrypted based on their positions in the key table, using specific rules depending on their locations in the matrix.

The Playfair Cipher provides a simple yet effective way to encrypt text, though it is not as secure as modern ciphers like AES due to its relatively small key space.