Cryptography
Lab Assignment – 4
Github:

Q1: Key Management and Distribution System

Simulates a Key Distribution Center (KDC) for symmetric key distribution.

Code:

```
import os
import json
import time
from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes
from cryptography.hazmat.primitives import hashes, serialization
from cryptography.hazmat.primitives.asymmetric import rsa, padding
from cryptography.hazmat.backends import default_backend
import base64

class KeyDistributionCenter:
    """Simulates a trusted KDC for symmetric key distribution"""

    def __init__(self):
        self.master_keys = {}  # Store master keys for each user
        self.session_keys = {}  # Track active session keys
        self.key_escrow = {}   # Escrowed keys for recovery

    def register_user(self, user_id):
        """Register a user and generate their master key"""
        master_key = os.urandom(32)  # 256-bit key
        self.master_keys[user_id] = master_key
        # Key escrow - store encrypted backup
        self.key_escrow[user_id] = {
            'key': base64.b64encode(master_key).decode(),
            'timestamp': time.time(),
            'rotations': 0
        }
        print(f"✓ User '{user_id}' registered with KDC")
        return master_key

    def request_session_key(self, user_a, user_b):
        """
        Simulate Needham-Schroeder protocol:
        1. A requests session key for communication with B
        2. KDC generates session key
        3. KDC encrypts session key with A's and B's master keys
        """
        if user_a not in self.master_keys or user_b not in self.master_keys:
            raise ValueError("Both users must be registered")

        # Generate session key
        session_key = os.urandom(32)
        session_id = f"{user_a}_{user_b}_{int(time.time())}"

        # Encrypt session key for User A
        ticket_a = self._encrypt_ticket(session_key, self.master_keys[user_a],
user_b)

        # Encrypt session key for User B (ticket)
        ticket_b = self._encrypt_ticket(session_key, self.master_keys[user_b],
user_a)

        self.session_keys[session_id] = {
            'key': session_key,
            'users': (user_a, user_b),
            'created': time.time()
        }

        print(f"✓ Session key generated for {user_a} <-> {user_b}")
        return ticket_a, ticket_b, session_id

    def _encrypt_ticket(self, session_key, master_key, peer_id):
        """Encrypt session key with user's master key"""
        iv = os.urandom(16)
        cipher = Cipher(
            algorithms.AES(master_key),
            modes.CBC(iv),
            backend=default_backend()
    )
    encryptor = cipher.encryptor()

    # Pad session key to block size
    padded_key = session_key + b'\x00' * (16 - len(session_key) % 16)
    encrypted = encryptor.update(padded_key) + encryptor.finalize()

    return {
        'iv': base64.b64encode(iv).decode(),
        'encrypted_key': base64.b64encode(encrypted).decode(),
        'peer': peer_id
    }

def rotate_key(self, user_id):
    """Simulate key rotation for a user"""
    if user_id not in self.master_keys:
        raise ValueError("User not registered")

    old_key = self.master_keys[user_id]
    new_key = os.urandom(32)

    # Update master key
    self.master_keys[user_id] = new_key

    # Update escrow
    self.key_escrow[user_id]['key'] = base64.b64encode(new_key).decode()
```

```
        self.key_escrow[user_id]['rotations'] += 1
        self.key_escrow[user_id]['timestamp'] = time.time()

        print(f"✓ Key rotated for user '{user_id}' (rotation
#{self.key_escrow[user_id]['rotations']})")
        return new_key


class AsymmetricKeyManager:
    """Manages asymmetric key pairs and distribution"""

    def __init__(self):
        self.public_keys = {}
        self.private_keys = {}

    def generate_keypair(self, user_id):
        """Generate RSA key pair for a user"""
        private_key = rsa.generate_private_key(
            public_exponent=65537,
            key_size=2048,
            backend=default_backend()
        )
        public_key = private_key.public_key()

        self.private_keys[user_id] = private_key
        self.public_keys[user_id] = public_key
        print(f"✓ RSA key pair generated for '{user_id}'")
        return private_key, public_key

    def get_public_key(self, user_id):
        """Simulate public key directory lookup"""
        return self.public_keys.get(user_id)

    def encrypt_with_public_key(self, message, recipient_id):
        """Encrypt message with recipient's public key"""
        public_key = self.get_public_key(recipient_id)
        if not public_key:
            raise ValueError(f"No public key for {recipient_id}")

        encrypted = public_key.encrypt(
            message.encode() if isinstance(message, str) else message,
            padding.OAEP(
                mgf=padding.MGF1(algorithm=hashes.SHA256()),
                algorithm=hashes.SHA256(),
                label=None
            )
        )
        return encrypted


def demonstrate_key_distribution():
```

```
"""Demonstrate both symmetric and asymmetric key distribution"""

print("=" * 60)
print("KEY DISTRIBUTION DEMONSTRATION")
print("=" * 60)

# Symmetric Key Distribution via KDC
print("\n[1] SYMMETRIC KEY DISTRIBUTION (KDC Model)")
print("-" * 60)
kdc = KeyDistributionCenter()

# Register users
kdc.register_user("Alice")
kdc.register_user("Bob")
kdc.register_user("Charlie")

# Request session key
ticket_a, ticket_b, session_id = kdc.request_session_key("Alice", "Bob")
print(f"   Session ID: {session_id}")

# Demonstrate key rotation
print("\n[2] KEY ROTATION")
print("-" * 60)
kdc.rotate_key("Alice")
kdc.rotate_key("Alice")  # Rotate again
```

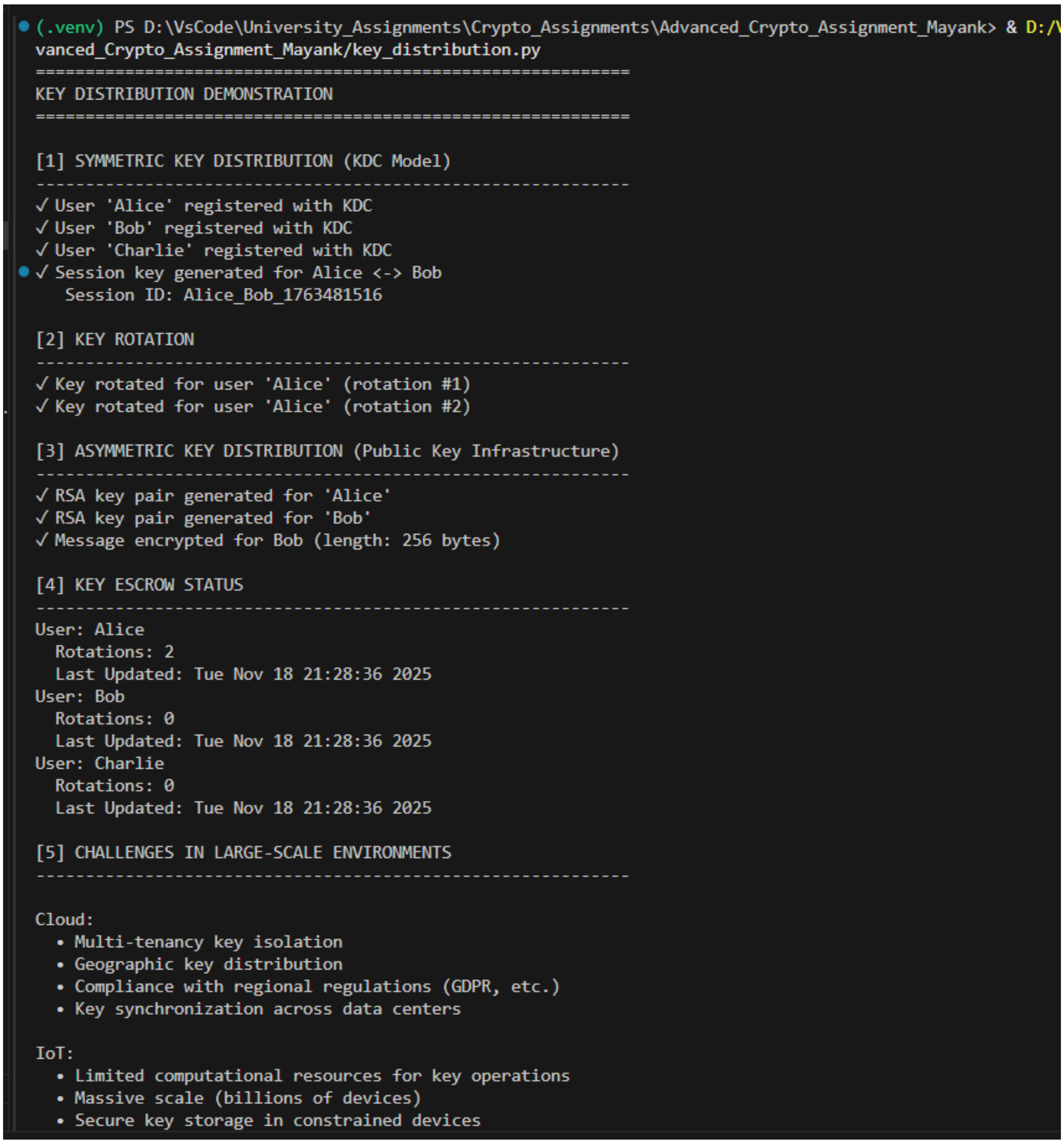
```
    # Asymmetric Key Distribution
    print("\n[3] ASYMMETRIC KEY DISTRIBUTION (Public Key
Infrastructure)")
    print("-" * 60)
    key_manager = AsymmetricKeyManager()

    key_manager.generate_keypair("Alice")
    key_manager.generate_keypair("Bob")

    # Demonstrate encryption
    message = "Secret message for Bob"
    encrypted = key_manager.encrypt_with_public_key(message, "Bob")
    print(f"✓ Message encrypted for Bob (length: {len(encrypted)} bytes)")

    # Key Escrow Report
    print("\n[4] KEY ESCROW STATUS")
    print("-" * 60)
    for user, escrow_data in kdc.key_escrow.items():
        print(f"User: {user}")
        print(f"  Rotations: {escrow_data['rotations']}")
        print(f"  Last Updated: {time.ctime(escrow_data['timestamp'])}")

    # Challenges Discussion
    print("\n[5] CHALLENGES IN LARGE-SCALE ENVIRONMENTS")
    print("-" * 60)
    challenges = {
```

```
    "Cloud": [
        "Multi-tenancy key isolation",
        "Geographic key distribution",
        "Compliance with regional regulations (GDPR, etc.)",
        "Key synchronization across data centers"
    ],
    "IoT": [
        "Limited computational resources for key operations",
        "Massive scale (billions of devices)",
        "Secure key storage in constrained devices",
        "Battery-efficient key management protocols"
    ],
    "General": [
        "Key rotation without service disruption",
        "Secure key escrow and recovery mechanisms",
        "Quantum-resistant key exchange migration",
        "Insider threat mitigation"
    ]
}

for category, items in challenges.items():
    print(f"\n{category}:")
    for item in items:
        print(f"  • {item}")
```

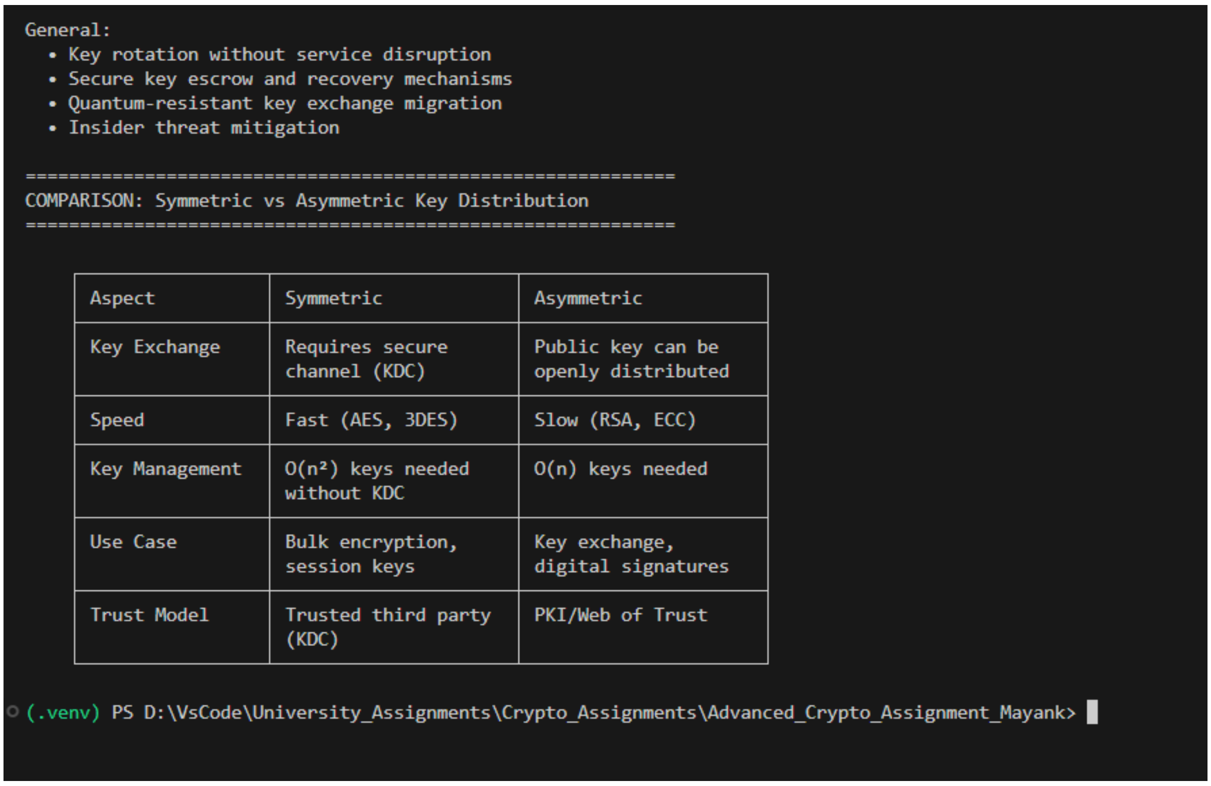
```
if __name__ == "__main__":
    demonstrate_key_distribution()

    print("\n" + "=" * 60)
    print("COMPARISON: Symmetric vs Asymmetric Key Distribution")
    print("=" * 60)

    comparison = """

┌───────────────────┬─────────────────────────┬────
─────────────────────┐
    │ Aspect          │ Symmetric            │ Asymmetric          │

├───────────────────┼─────────────────────────┼────
─────────────────────┤
    │ Key Exchange    │ Requires secure      │ Public key can be     │
    │               │ channel (KDC)        │ openly distributed  │

├───────────────────┼─────────────────────────┼────
─────────────────────┤
    │ Speed           │ Fast (AES, 3DES)     │ Slow (RSA, ECC)       │

├───────────────────┼─────────────────────────┼────
─────────────────────┤
    │ Key Management  │ O(n²) keys needed    │ O(n) keys needed        │
    │               │ without KDC          │                 │

├───────────────────┼─────────────────────────┼────
─────────────────────┤
```

```
  │ Use Case        │ Bulk encryption,    │ Key exchange,        │
  │                 │ session keys        │ digital signatures   │
├──────────────────────┼──────────────────────────┼────────
──────────────────────┤
  │ Trust Model     │ Trusted third party │ PKI/Web of Trust     │
  │                 │ (KDC)               │                      │
└──────────────────────┴──────────────────────────┴────────
──────────────────────┘
  """
  print(comparison)
```

Output:



```
(.venv) PS D:\VsCode\University_Assignments\Crypto_Assignments\Advanced_Crypto_Assignment_Mayank> & D:/\
vanced_Crypto_Assignment_Mayank/key_distribution.py
============================================================
KEY DISTRIBUTION DEMONSTRATION
============================================================

[1] SYMMETRIC KEY DISTRIBUTION (KDC Model)
------------------------------------------------------------
✓ User 'Alice' registered with KDC
✓ User 'Bob' registered with KDC
✓ User 'Charlie' registered with KDC
✓ Session key generated for Alice <-> Bob
   Session ID: Alice_Bob_1763481516

[2] KEY ROTATION
------------------------------------------------------------
✓ Key rotated for user 'Alice' (rotation #1)
✓ Key rotated for user 'Alice' (rotation #2)

[3] ASYMMETRIC KEY DISTRIBUTION (Public Key Infrastructure)
------------------------------------------------------------
✓ RSA key pair generated for 'Alice'
✓ RSA key pair generated for 'Bob'
✓ Message encrypted for Bob (length: 256 bytes)

[4] KEY ESCROW STATUS
------------------------------------------------------------
User: Alice
  Rotations: 2
  Last Updated: Tue Nov 18 21:28:36 2025
User: Bob
  Rotations: 0
  Last Updated: Tue Nov 18 21:28:36 2025
User: Charlie
  Rotations: 0
  Last Updated: Tue Nov 18 21:28:36 2025

[5] CHALLENGES IN LARGE-SCALE ENVIRONMENTS
------------------------------------------------------------

Cloud:
  • Multi-tenancy key isolation
  • Geographic key distribution
  • Compliance with regional regulations (GDPR, etc.)
  • Key synchronization across data centers

IoT:
  • Limited computational resources for key operations
  • Massive scale (billions of devices)
  • Secure key storage in constrained devices
```



```
General:
  • Key rotation without service disruption
  • Secure key escrow and recovery mechanisms
  • Quantum-resistant key exchange migration
  • Insider threat mitigation

============================================================
COMPARISON: Symmetric vs Asymmetric Key Distribution
============================================================
```

Aspect	Symmetric	Asymmetric
Key Exchange	Requires secure channel (KDC)	Public key can be openly distributed
Speed	Fast (AES, 3DES)	Slow (RSA, ECC)
Key Management	O(n²) keys needed without KDC	O(n) keys needed
Use Case	Bulk encryption, session keys	Key exchange, digital signatures
Trust Model	Trusted third party (KDC)	PKI/Web of Trust

```
(.venv) PS D:\VsCode\University_Assignments\Crypto_Assignments\Advanced_Crypto_Assignment_Mayank>
```

Q-2 Secure Email Using PGP-like Implementation

Demonstrates Hybrid Encryption (RSA + AES) and Digital Signatures

Code:

```
import os

import base64

from datetime import datetime

from cryptography.hazmat.primitives import hashes, serialization

from cryptography.hazmat.primitives.asymmetric import rsa, padding as asym_padding

from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes

from cryptography.hazmat.primitives import padding as sym_padding

from cryptography.hazmat.backends import default_backend


class SimplePGPDemo:
```

```
"""
PGP demonstration using pure Python cryptography library.
Implements 'Hybrid Encryption':
1. Message encrypted with symmetric key (AES)
2. Symmetric key encrypted with asymmetric public key (RSA)
"""

def __init__(self):
    self.private_keys = {}
    self.public_keys = {}

def generate_key_pair(self, user_id):
    """Generate RSA key pair for user"""
    print(f"Generating 2048-bit RSA keys for {user_id}...")
    private_key = rsa.generate_private_key(
        public_exponent=65537,
        key_size=2048,
        backend=default_backend()
    )
    public_key = private_key.public_key()

    self.private_keys[user_id] = private_key
    self.public_keys[user_id] = public_key

    # Save keys to files (simulation)
    self._save_private_key(user_id, private_key)
```

```
        self._save_public_key(user_id, public_key)

        print(f"✓ Key pair generated for {user_id}")
        return private_key, public_key

    def _save_private_key(self, user_id, private_key):
        """Save private key to PEM file"""
        pem = private_key.private_bytes(
            encoding=serialization.Encoding.PEM,
            format=serialization.PrivateFormat.PKCS8,
            encryption_algorithm=serialization.NoEncryption()
        )
        # Using sanitize filename to prevent errors
        filename = f"{user_id.replace('@','_').replace('.','_')}_private.pem"

        # Ensure directory exists
        if not os.path.exists("emails"):
            os.makedirs("emails")

        filepath = os.path.join("emails", filename)
        with open(filepath, 'wb') as f:
            f.write(pem)

    def _save_public_key(self, user_id, public_key):
        """Save public key to PEM file"""
        pem = public_key.public_bytes(
        encoding=serialization.Encoding.PEM,
        format=serialization.PublicFormat.SubjectPublicKeyInfo
    )
    filename = f"{user_id.replace('@','_').replace('.','_')}_public.pem"

    # Ensure directory exists
    if not os.path.exists("emails"):
        os.makedirs("emails")

    filepath = os.path.join("emails", filename)
    with open(filepath, 'wb') as f:
        f.write(pem)

def encrypt_message(self, message, recipient_id):
    """Encrypt message for recipient using hybrid encryption"""
    if recipient_id not in self.public_keys:
        raise ValueError(f"Public key for {recipient_id} not found!")

    public_key = self.public_keys[recipient_id]

    # 1. Generate random AES key (Session Key) and IV
    aes_key = os.urandom(32)  # 256-bit AES key
    iv = os.urandom(16)       # 128-bit IV

    # 2. Pad message to AES block size (PKCS7)
    padder = sym_padding.PKCS7(128).padder()
    message_bytes = message.encode('utf-8')
    padded_data = padder.update(message_bytes) + padder.finalize()

    # 3. Encrypt message with AES (Symmetric)
    cipher = Cipher(
        algorithms.AES(aes_key),
        modes.CBC(iv),
        backend=default_backend()
    )
    encryptor = cipher.encryptor()
    encrypted_message = encryptor.update(padded_data) + encryptor.finalize()

    # 4. Encrypt AES key with recipient's public key (Asymmetric/RSA)
    encrypted_key = public_key.encrypt(
        aes_key,
        asym_padding.OAEP(
            mgf=asym_padding.MGF1(algorithm=hashes.SHA256()),
            algorithm=hashes.SHA256(),
            label=None
        )
    )

    # 5. Combine: [Encrypted AES Key (256 bytes)] + [IV (16 bytes)] +
[Encrypted Message]
    combined = encrypted_key + iv + encrypted_message
    encrypted_b64 = base64.b64encode(combined).decode('utf-8')
```

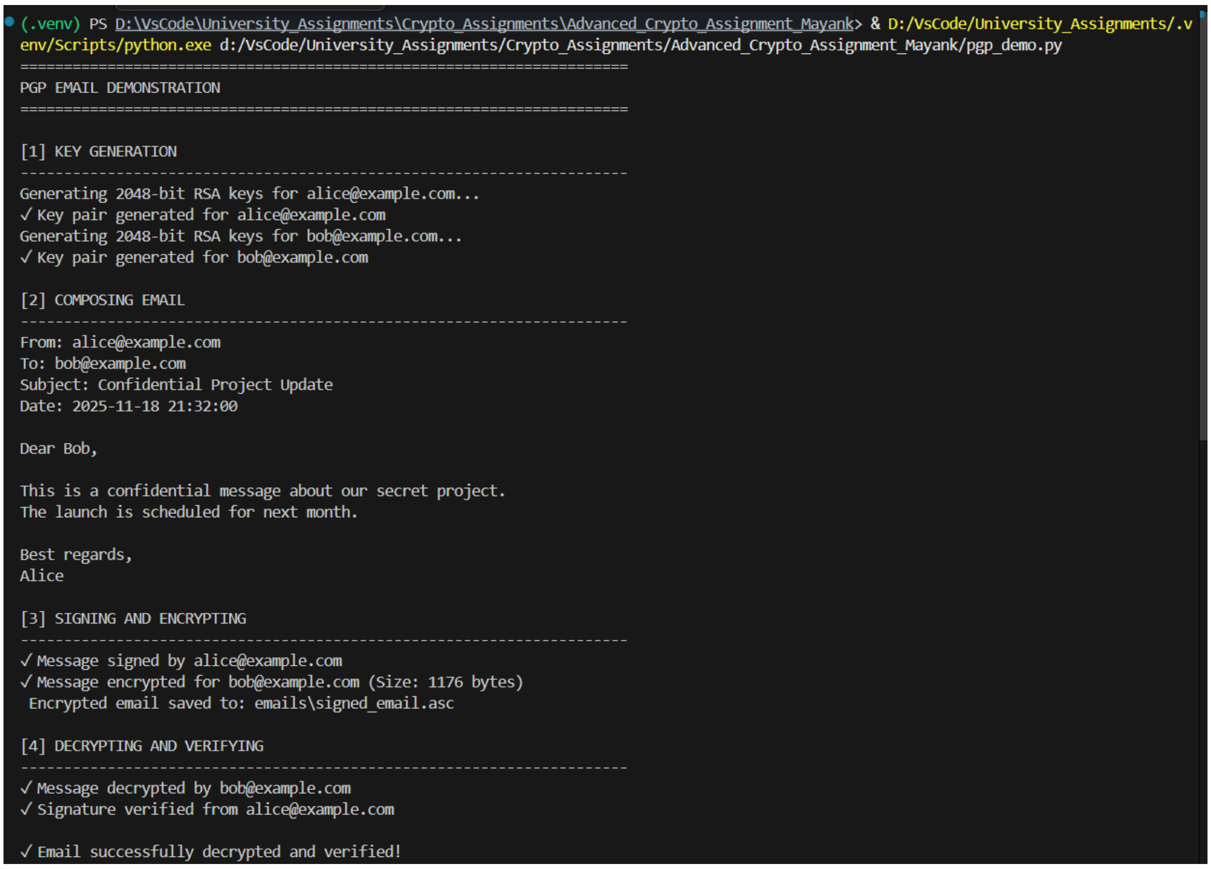
```
        print(f"✓ Message encrypted for {recipient_id} (Size:
{len(encrypted_b64)} bytes)")
        return encrypted_b64

    def decrypt_message(self, encrypted_message_b64, recipient_id):
        """Decrypt message using hybrid decryption"""
        if recipient_id not in self.private_keys:
            raise ValueError(f"Private key for {recipient_id} not found!")

        private_key = self.private_keys[recipient_id]

        try:
            combined = base64.b64decode(encrypted_message_b64)

            # Extract parts (Assuming 2048-bit RSA key = 256 bytes encrypted key)
            encrypted_key_len = 256
            iv_len = 16

            encrypted_key = combined[:encrypted_key_len]
            iv = combined[encrypted_key_len : encrypted_key_len + iv_len]
            encrypted_message = combined[encrypted_key_len + iv_len:]

            # 1. Decrypt AES key with recipient's private key (RSA)
            aes_key = private_key.decrypt(
                encrypted_key,
            asym_padding.OAEP(
                mgf=asym_padding.MGF1(algorithm=hashes.SHA256()),
                algorithm=hashes.SHA256(),
                label=None
            )
        )

        # 2. Decrypt message with AES
        cipher = Cipher(
            algorithms.AES(aes_key),
            modes.CBC(iv),
            backend=default_backend()
        )
        decryptor = cipher.decryptor()
        padded_message = decryptor.update(encrypted_message) +
decryptor.finalize()

        # 3. Remove PKCS7 padding
        unpadder = sym_padding.PKCS7(128).unpadder()
        decrypted_message_bytes = unpadder.update(padded_message) +
unpadder.finalize()

        print(f"✓ Message decrypted by {recipient_id}")
        return decrypted_message_bytes.decode('utf-8')

    except Exception as e:
        print(f"Error decrypting: {e}")
        return None

    def sign_message(self, message, sender_id):
        """Create digital signature"""
        private_key = self.private_keys[sender_id]

        signature = private_key.sign(
            message.encode('utf-8'),
            asym_padding.PSS(
                mgf=asym_padding.MGF1(hashes.SHA256()),
                salt_length=asym_padding.PSS.MAX_LENGTH
            ),
            hashes.SHA256()
        )

        signature_b64 = base64.b64encode(signature).decode('utf-8')
        print(f"✓ Message signed by {sender_id}")
        return signature_b64

    def verify_signature(self, message, signature_b64, sender_id):
        """Verify digital signature"""
        public_key = self.public_keys[sender_id]
        signature = base64.b64decode(signature_b64)

        try:
            public_key.verify(
                signature,
                message.encode('utf-8'),
                asym_padding.PSS(
                    mgf=asym_padding.MGF1(hashes.SHA256()),
                    salt_length=asym_padding.PSS.MAX_LENGTH
                ),
                hashes.SHA256()
            )
            print(f"✓ Signature verified from {sender_id}")
            return True
        except Exception as e:
            print(f"✗ Signature verification failed: {e}")
            return False

    def create_signed_email(self, message, sender_id, recipient_id):
        """Create encrypted and signed email"""
        # 1. Sign the cleartext message
        signature = self.sign_message(message, sender_id)

        # 2. Combine message and signature
        # In real PGP, this is more complex (compression, packets),
        # but for this demo, we append the signature.
        signed_payload = f"{message}\n\n---SIGNATURE---\n{signature}"

        # 3. Encrypt the combined payload for the recipient
        encrypted = self.encrypt_message(signed_payload, recipient_id)
```

```
        return encrypted

    def read_signed_email(self, encrypted_email, recipient_id, sender_id):
        """Decrypt and verify signed email"""
        # 1. Decrypt
        decrypted_payload = self.decrypt_message(encrypted_email, recipient_id)

        if not decrypted_payload:
            return None

        # 2. Split message and signature
        separator = "\n\n---SIGNATURE---\n"
        if separator not in decrypted_payload:
            print("✗ Invalid email format: Signature block missing")
            return {'message': decrypted_payload, 'verified': False, 'sender':
'Unknown'}

        message, signature = decrypted_payload.split(separator)

        # 3. Verify signature using the extracted message content
        verified = self.verify_signature(message, signature, sender_id)

        return {
            'message': message,
            'verified': verified,
            'sender': sender_id
        }


def demonstrate_pgp():
    """Demonstrate PGP email encryption and signing"""

    print("=" * 70)
    print("PGP EMAIL DEMONSTRATION")
    print("=" * 70)

    pgp = SimplePGPDemo()

    # Ensure emails directory exists
    if not os.path.exists("emails"):
        os.makedirs("emails")

    # Generate key pairs
    print("\n[1] KEY GENERATION")
    print("-" * 70)
    pgp.generate_key_pair("alice@example.com")
    pgp.generate_key_pair("bob@example.com")

    # Create email message
    print("\n[2] COMPOSING EMAIL")
    print("-" * 70)
    email_message = """From: alice@example.com
To: bob@example.com
Subject: Confidential Project Update
Date: {}

Dear Bob,

This is a confidential message about our secret project.
The launch is scheduled for next month.

Best regards,
Alice""".format(datetime.now().strftime("%Y-%m-%d %H:%M:%S"))

    print(email_message)

    # Create signed and encrypted email
    print("\n[3] SIGNING AND ENCRYPTING")
    print("-" * 70)
    encrypted_email = pgp.create_signed_email(
        email_message,
        "alice@example.com",
        "bob@example.com"
    )

    # Save encrypted email
    file_path = os.path.join("emails", "signed_email.asc")
```

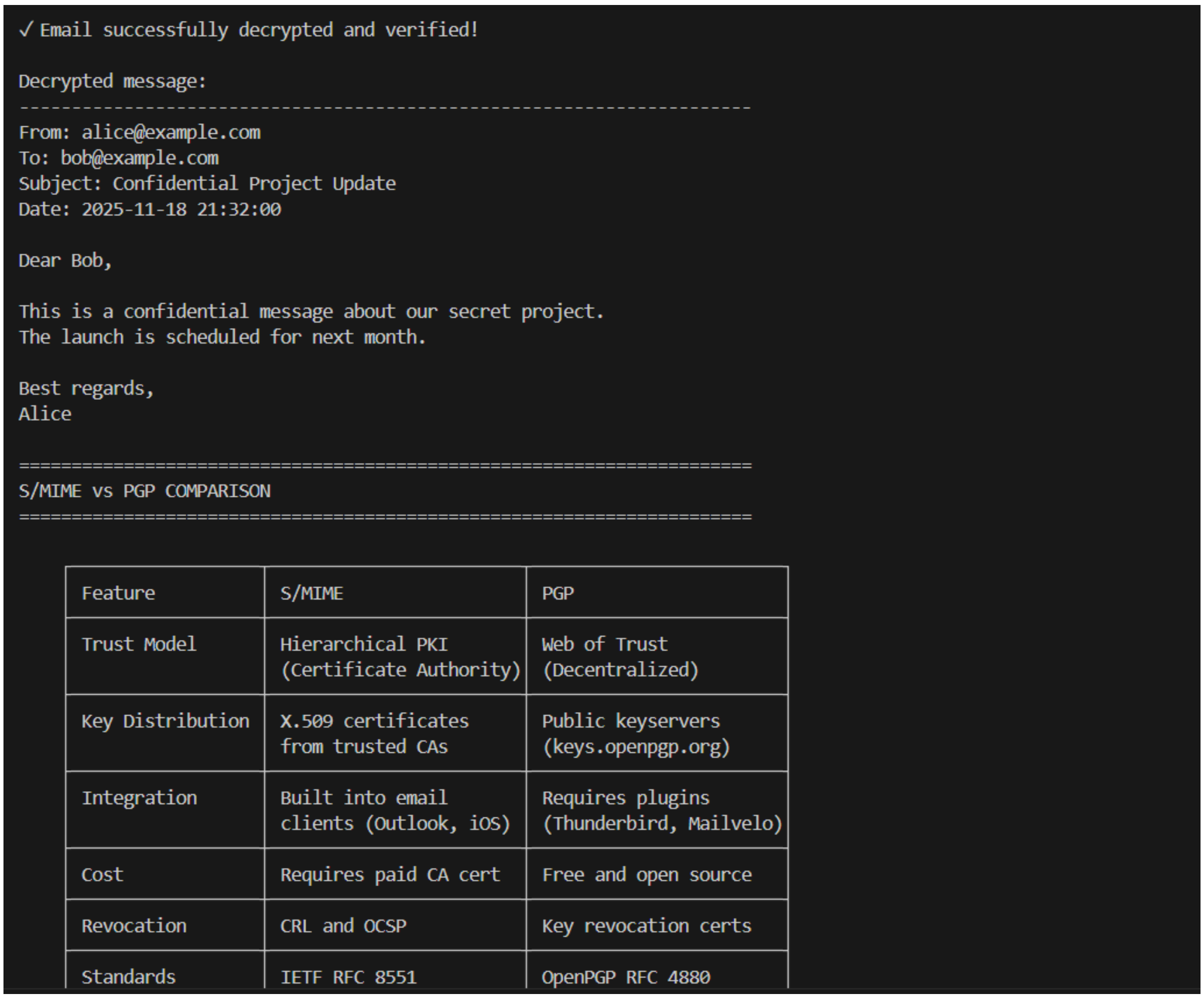
```
with open(file_path, "w") as f:
    f.write("-----BEGIN PGP MESSAGE-----\n\n")
    f.write(encrypted_email)
    f.write("\n-----END PGP MESSAGE-----\n")

print(f" Encrypted email saved to: {file_path}")

# Bob receives and decrypts
print("\n[4] DECRYPTING AND VERIFYING")
print("-" * 70)

# Simulating reading from file
with open(file_path, "r") as f:
    content = f.read()
    # simplistic parsing for demo
    lines = content.strip().split('\n')
    # Removing header/footer roughly
    clean_encrypted = lines[2] if len(lines) > 3 else encrypted_email

result = pgp.read_signed_email(
    encrypted_email, # Passing the raw base64 string
    "bob@example.com",
    "alice@example.com"
)

if result and result['verified']:
    print("\n✓ Email successfully decrypted and verified!")
    print("\nDecrypted message:")
    print("-" * 70)
    print(result['message'])
else:
    print("\n✗ Failed to decrypt or verify.")

# Comparison
print("\n" + "=" * 70)
print("S/MIME vs PGP COMPARISON")
print("=" * 70)

comparison = """
┌──────────────────────┬──────────────────────────────┬
─────────────────────────────┐
│ Feature          │ S/MIME               │ PGP              │
├──────────────────────┼──────────────────────────────┼
─────────────────────────────┤
│ Trust Model      │ Hierarchical PKI       │ Web of Trust         │
│                  │ (Certificate Authority)│ (Decentralized)      │
├──────────────────────┼──────────────────────────────┼
─────────────────────────────┤
│ Key Distribution │ X.509 certificates     │ Public keyservers      │
│                  │ from trusted CAs       │ (keys.openpgp.org)     │
```

```
├──────────────────┼─────────────────────────┼
───────────────────────┤
│ Integration      │ Built into email      │ Requires plugins      │
│                  │ clients (Outlook, iOS) │ (Thunderbird, Mailvelo)│
├──────────────────┼─────────────────────────┼
───────────────────────┤
│ Cost             │ Requires paid CA cert │ Free and open source  │
├──────────────────┼─────────────────────────┼
───────────────────────┤
│ Revocation       │ CRL and OCSP          │ Key revocation certs  │
├──────────────────┼─────────────────────────┼
───────────────────────┤
│ Standards        │ IETF RFC 8551         │ OpenPGP RFC 4880      │
├──────────────────┼─────────────────────────┼
───────────────────────┤
│ Best For         │ Corporate email       │ Privacy-focused users │
│                  │ Enterprise use        │ Personal communication │
└──────────────────┴─────────────────────────┴
───────────────────────┘
    """
    print(comparison)


if __name__ == "__main__":
    demonstrate_pgp()
```

Output:



```
(.venv) PS D:\VsCode\University_Assignments\Crypto_Assignments\Advanced_Crypto_Assignment_Mayank> & D:/VsCode/University_Assignments/.v
env/Scripts/python.exe d:/VsCode/University_Assignments/Crypto_Assignments/Advanced_Crypto_Assignment_Mayank/pgp_demo.py
======================================================================
PGP EMAIL DEMONSTRATION
======================================================================

[1] KEY GENERATION
----------------------------------------------------------------------
Generating 2048-bit RSA keys for alice@example.com...
✓ Key pair generated for alice@example.com
Generating 2048-bit RSA keys for bob@example.com...
✓ Key pair generated for bob@example.com

[2] COMPOSING EMAIL
----------------------------------------------------------------------
From: alice@example.com
To: bob@example.com
Subject: Confidential Project Update
Date: 2025-11-18 21:32:00

Dear Bob,

This is a confidential message about our secret project.
The launch is scheduled for next month.

Best regards,
Alice

[3] SIGNING AND ENCRYPTING
----------------------------------------------------------------------
✓ Message signed by alice@example.com
✓ Message encrypted for bob@example.com (Size: 1176 bytes)
 Encrypted email saved to: emails\signed_email.asc

[4] DECRYPTING AND VERIFYING
----------------------------------------------------------------------
✓ Message decrypted by bob@example.com
✓ Signature verified from alice@example.com

✓ Email successfully decrypted and verified!
```


```
✓ Email successfully decrypted and verified!

Decrypted message:
----------------------------------------------------------------------
From: alice@example.com
To: bob@example.com
Subject: Confidential Project Update
Date: 2025-11-18 21:32:00

Dear Bob,

This is a confidential message about our secret project.
The launch is scheduled for next month.

Best regards,
Alice

======================================================================
S/MIME vs PGP COMPARISON
======================================================================
```

Feature	S/MIME	PGP
Trust Model	Hierarchical PKI (Certificate Authority)	Web of Trust (Decentralized)
Key Distribution	X.509 certificates from trusted CAs	Public keyservers (keys.openpgp.org)
Integration	Built into email clients (Outlook, iOS)	Requires plugins (Thunderbird, Mailvelo)
Cost	Requires paid CA cert	Free and open source
Revocation	CRL and OCSP	Key revocation certs
Standards	IETF RFC 8551	OpenPGP RFC 4880

Q3: SSL/TLS SECURE COMMUNICATION PROTOCOL ANALYSIS

Solution :

==

Q3: SSL/TLS SECURE COMMUNICATION PROTOCOL ANALYSIS

==

OPTION A: SSL/TLS HTTPS CONNECTION ANALYSIS

1. PROTOCOL OVERVIEW

===
=======================

TLS (Transport Layer Security) is the successor to SSL and provides:

- Authentication: Verify server (and optionally client) identity
- Confidentiality: Encrypt data in transit
- Integrity: Detect message tampering

Current Version: TLS 1.3 (RFC 8446)

Legacy Versions: TLS 1.2, TLS 1.1, TLS 1.0, SSL 3.0 (deprecated)

2. TLS HANDSHAKE PROCESS (TLS 1.2)

===
=======================

Step-by-Step Breakdown:

```
[CLIENT]                                    [SERVER]

1. ClientHello -->
   - TLS version: 1.2
   - Cipher suites supported
   - Random number (Client Random)
   - Session ID
   - Supported extensions (SNI, ALPN)

                              <-- 2. ServerHello
                                  - Selected cipher suite
```

```
                                   - Random (Server Random)
                                   - Session ID

                                 <-- 3. Certificate
                                   - Server's X.509 cert
                                   - Certificate chain

                                 <-- 4. ServerKeyExchange
                                   - DH parameters (if using DHE)

                                 <-- 5. ServerHelloDone

6. ClientKeyExchange -->
   - Pre-master secret (encrypted with server's public key)

7. ChangeCipherSpec -->
   - Switch to encrypted communication

8. Finished -->
   - Encrypted handshake verification

                                 <-- 9. ChangeCipherSpec

                                 <-- 10. Finished

[ENCRYPTED APPLICATION DATA EXCHANGE]
```

3. TLS 1.3 IMPROVEMENTS

==

Reduced Handshake (1-RTT):

- Combined messages for faster connection
- Forward secrecy by default (ephemeral keys only)
- Removed weak cipher suites (RC4, DES, 3DES, MD5, SHA-1)

Supported Cipher Suites (TLS 1.3):

- TLS_AES_128_GCM_SHA256
- TLS_AES_256_GCM_SHA384
- TLS_CHACHA20_POLY1305_SHA256

4. CERTIFICATE VALIDATION PROCESS

==

Certificate Chain Verification:

```
[End-Entity Certificate]
        ↓ (signed by)
[Intermediate CA Certificate]
        ↓ (signed by)
```

[Root CA Certificate] (in browser trust store)

Validation Steps:

1. Check certificate validity period (Not Before/Not After)
2. Verify certificate signature using issuer's public key
3. Check certificate revocation status (CRL or OCSP)
4. Validate certificate purpose (Extended Key Usage)
5. Verify hostname matches (Subject Alternative Name)
6. Ensure root CA is in trusted store

Example Certificate Fields:

Subject: CN=example.com, O=Example Inc, C=US

Issuer: CN=DigiCert TLS RSA SHA256 2020 CA1

Validity:

Not Before: Jan 1 00:00:00 2024 GMT

Not After : Jan 1 23:59:59 2025 GMT

Subject Alternative Names:

DNS:example.com

DNS:*.example.com

Public Key: RSA 2048 bits

Signature Algorithm: sha256WithRSAEncryption

5. SYMMETRIC KEY NEGOTIATION

==

Key Derivation Process:

```
Client Random (32 bytes)
   +
Server Random (32 bytes)
   +
Pre-Master Secret (48 bytes, encrypted with server's public key)
   ↓
[PRF - Pseudorandom Function with HMAC]
   ↓
Master Secret (48 bytes)
   ↓
[Key Expansion]
   ↓
├── Client Write MAC Key
├── Server Write MAC Key
├── Client Write Encryption Key
├── Server Write Encryption Key
├── Client Write IV
└── Server Write IV
```

Example Cipher Suite: TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256

- ECDHE: Elliptic Curve Diffie-Hellman Ephemeral (key exchange)
- RSA: Authentication algorithm
- AES_128_GCM: Encryption (AES 128-bit with Galois/Counter Mode)

- SHA256: Message authentication

6. BROWSER DEVELOPER TOOLS ANALYSIS

==

How to Inspect HTTPS Connection:

Chrome DevTools:

1. Open DevTools (F12)
2. Navigate to Security tab
3. Refresh the page
4. Observe:
   - Connection status
   - Certificate details
   - TLS version
   - Cipher suite

Example Output:

```
Connection: Secure (TLS 1.3)
Cipher Suite: TLS_AES_128_GCM_SHA256
Key Exchange: X25519
Certificate: Valid (DigiCert)
Certificate Transparency: Compliant
Connection: Secure (TLS 1.3)
```

Cipher Suite: TLS_AES_128_GCM_SHA256

Key Exchange: X25519

Certificate: Valid (DigiCert)

Certificate Transparency: Compliant

text

Wireshark Capture Analysis:

Filter: ssl or tls

Packet Breakdown:

Client Hello (TLS 1.2)

SNI: www.example.com

Cipher Suites: 15 suites

Server Hello

Version: TLS 1.2

Cipher: TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256

Certificate

Length: 4321 bytes

Certificate Count: 3

Server Key Exchange

Curve: secp256r1

Public Key: 65 bytes

text

7. COMMON SSL/TLS ATTACKS AND MITIGATIONS

==

Attack	Description	Mitigation
POODLE	SSL 3.0 padding oracle	Disable SSL 3.0
BEAST	CBC mode vulnerability	Use TLS 1.2+ with AEAD
Heartbleed	OpenSSL buffer over-read	Update OpenSSL
CRIME/BREACH	Compression oracle	Disable TLS compression
Downgrade Attack	Force use of weak protocols	TLS_FALLBACK_SCSV
MITM (ARP spoofing)	Certificate substitution	Certificate pinning
Weak Cipher Suites	RC4, DES, Export ciphers	Modern cipher suites only

8. BEST PRACTICES

==

Server Configuration:

✓ Use TLS 1.3 or TLS 1.2 minimum

✓ Disable SSL 3.0, TLS 1.0, TLS 1.1

✓ Use strong cipher suites (AEAD only)

✓ Enable Perfect Forward Secrecy (ECDHE/DHE)

✓ Implement HSTS (HTTP Strict Transport Security)

✓ Use OCSP Stapling for faster validation

✓ Enable Certificate Transparency

✓ Regular certificate rotation

Client Configuration:

✓ Verify certificate chain

✓ Check certificate revocation (CRL/OCSP)

✓ Validate hostname

✓ Reject self-signed certificates in production

✓ Implement certificate pinning for critical apps

9. PERFORMANCE CONSIDERATIONS

==

Optimization Techniques:

- Session Resumption (Session IDs or Session Tickets)
- OCSP Stapling (reduce client-side validation delay)
- TLS 1.3 0-RTT (zero round-trip time for resumed connections)
- HTTP/2 or HTTP/3 multiplexing over single TLS connection

Benchmark (typical):

- TLS 1.2 Full Handshake: ~2 RTT + cert validation (100-300ms)
- TLS 1.3 Full Handshake: ~1 RTT (50-150ms)
- TLS 1.3 Resumed (0-RTT): ~0 RTT (minimal overhead)

10. TESTING TOOLS

==

1. OpenSSL:

```
   $ openssl s_client -connect example.com:443 -tls1_3
```

2. SSL Labs (Qualys):

   https://www.ssllabs.com/ssltest/

3. testssl.sh:

```
   $ ./testssl.sh https://example.com
```

4. Nmap with SSL scripts:

```
   $ nmap --script ssl-enum-ciphers -p 443 example.com
```

==

CONCLUSION

==

TLS provides the cryptographic foundation for secure internet communication.

Proper implementation requires:

- Up-to-date protocol versions
- Strong cryptographic algorithms
- Proper certificate management
- Regular security audits
- Performance optimization

The evolution to TLS 1.3 has significantly improved both security and performance, removing legacy vulnerabilities while reducing connection latency.

Q4: Blockchain Cryptography Simulation

Demonstrates blockchain fundamentals including hashing, digital signatures, Merkle trees, and consensus mechanisms

Code:

```
import hashlib
import json
import time
from datetime import datetime
from cryptography.hazmat.primitives.asymmetric import rsa, padding
from cryptography.hazmat.primitives import hashes, serialization
from cryptography.hazmat.backends import default_backend
```

```
import base64

class MerkleTree:
    """Implements Merkle Tree for efficient transaction verification"""

    def __init__(self, transactions):
        self.transactions = transactions
        self.tree = self.build_tree()
        self.root = self.tree[-1][0] if self.tree else None

    def hash_data(self, data):
        """Hash a single piece of data"""
        return hashlib.sha256(data.encode() if isinstance(data, str) else
data).hexdigest()

    def build_tree(self):
        """Build Merkle tree from transactions"""
        if not self.transactions:
            return []

        # Level 0: Hash all transactions
        current_level = [self.hash_data(tx) for tx in self.transactions]
        tree = [current_level.copy()]

        # Build tree bottom-up
        while len(current_level) > 1:
            next_level = []

            # Process pairs
            for i in range(0, len(current_level), 2):
                if i + 1 < len(current_level):
                    combined = current_level[i] + current_level[i + 1]
                else:
                    # Odd number: duplicate last hash
                    combined = current_level[i] + current_level[i]

                next_level.append(self.hash_data(combined))

            tree.append(next_level)
            current_level = next_level

        return tree

    def get_proof(self, transaction_index):
        """Get Merkle proof for a transaction"""
        if transaction_index >= len(self.transactions):
            return None

        proof = []
        index = transaction_index

        for level in self.tree[:-1]:  # Exclude root
            if index % 2 == 0:
                # Left node: need right sibling
                if index + 1 < len(level):
                    proof.append(('R', level[index + 1]))
                else:
                    proof.append(('R', level[index]))  # Duplicate
            else:
                # Right node: need left sibling
                proof.append(('L', level[index - 1]))

            index = index // 2

        return proof

    def verify_proof(self, transaction, proof, root):
        """Verify Merkle proof"""
        current_hash = self.hash_data(transaction)

        for direction, sibling_hash in proof:
            if direction == 'L':
                combined = sibling_hash + current_hash
            else:
                combined = current_hash + sibling_hash
            current_hash = self.hash_data(combined)

        return current_hash == root
```

```
class Block:
    """Represents a single block in the blockchain"""

    def __init__(self, index, transactions, previous_hash, difficulty=4):
        self.index = index
        self.timestamp = time.time()
        self.transactions = transactions
        self.previous_hash = previous_hash
        self.difficulty = difficulty
        self.nonce = 0
        self.merkle_tree = MerkleTree([json.dumps(tx, sort_keys=True) for tx in
transactions])
        self.merkle_root = self.merkle_tree.root
        self.hash = self.calculate_hash()

    def calculate_hash(self):
        """Calculate block hash"""
        block_data = {
            'index': self.index,
            'timestamp': self.timestamp,
            'transactions': self.transactions,
            'previous_hash': self.previous_hash,
            'merkle_root': self.merkle_root,
            'nonce': self.nonce
        }
        block_string = json.dumps(block_data, sort_keys=True)
        return hashlib.sha256(block_string.encode()).hexdigest()

    def mine_block(self):
        """Proof of Work mining"""
        target = '0' * self.difficulty
        print(f"Mining block {self.index} (difficulty: {self.difficulty})...", end='',
flush=True)
        start_time = time.time()

        while self.hash[:self.difficulty] != target:
            self.nonce += 1
            self.hash = self.calculate_hash()

        elapsed = time.time() - start_time
        print(f" Mined! (nonce: {self.nonce}, time: {elapsed:.2f}s)")
        return self.hash

    def to_dict(self):
        """Convert block to dictionary"""
        return {
            'index': self.index,
            'timestamp': self.timestamp,
            'datetime': datetime.fromtimestamp(self.timestamp).strftime('%Y-%m-
%d %H:%M:%S'),
            'transactions': self.transactions,
            'previous_hash': self.previous_hash,
            'merkle_root': self.merkle_root,
            'nonce': self.nonce,
            'hash': self.hash
        }

class DigitalWallet:
    """Manages cryptographic keys for blockchain transactions"""

    def __init__(self, owner):
        self.owner = owner
        self.private_key = rsa.generate_private_key(
            public_exponent=65537,
            key_size=2048,
            backend=default_backend()
        )
        self.public_key = self.private_key.public_key()
        self.address = self.generate_address()

    def generate_address(self):
        """Generate wallet address from public key"""
        public_pem = self.public_key.public_bytes(
            encoding=serialization.Encoding.PEM,
            format=serialization.PublicFormat.SubjectPublicKeyInfo
        )
        address_hash = hashlib.sha256(public_pem).hexdigest()
        return address_hash[:40]  # Bitcoin-style address
```

```
def sign_transaction(self, transaction):
    """Sign transaction with private key"""
    transaction_string = json.dumps(transaction, sort_keys=True)
    signature = self.private_key.sign(
        transaction_string.encode(),
        padding.PSS(
            mgf=padding.MGF1(hashes.SHA256()),
            salt_length=padding.PSS.MAX_LENGTH
        ),
        hashes.SHA256()
    )
    return base64.b64encode(signature).decode()

def verify_transaction(self, transaction, signature, public_key):
    """Verify transaction signature"""
    try:
        transaction_string = json.dumps(transaction, sort_keys=True)
        signature_bytes = base64.b64decode(signature)
        public_key.verify(
            signature_bytes,
            transaction_string.encode(),
            padding.PSS(
                mgf=padding.MGF1(hashes.SHA256()),
                salt_length=padding.PSS.MAX_LENGTH
            ),
                hashes.SHA256()
            )
            return True
        except:
            return False

class Blockchain:
    """Blockchain implementation with Proof of Work consensus"""

    def __init__(self, difficulty=4):
        self.chain = []
        self.difficulty = difficulty
        self.pending_transactions = []
        self.mining_reward = 50
        self.wallets = {}

        # Create genesis block
        self.create_genesis_block()

    def create_genesis_block(self):
        """Create the first block"""
        genesis_block = Block(0, [{
            'from': 'genesis',
            'to': 'network',
            'amount': 0,
            'timestamp': time.time()
        }], '0', self.difficulty)
        genesis_block.mine_block()
        self.chain.append(genesis_block)
        print("✓ Genesis block created")

    def get_latest_block(self):
        """Get the most recent block"""
        return self.chain[-1]

    def add_transaction(self, transaction, signature, sender_wallet):
        """Add a signed transaction to pending pool"""
        # Verify signature
        if not sender_wallet.verify_transaction(transaction, signature,
sender_wallet.public_key):
            print("✗ Invalid transaction signature")
            return False

        transaction['signature'] = signature
        self.pending_transactions.append(transaction)
        print(f"✓ Transaction added: {transaction['from'][:8]}... →
{transaction['to'][:8]}... ({transaction['amount']} coins)")
        return True

    def mine_pending_transactions(self, miner_address):
        """Mine a new block with pending transactions"""
        if not self.pending_transactions:
```

```
    print("No transactions to mine")
    return False

# Add mining reward transaction
reward_tx = {
    'from': 'network',
    'to': miner_address,
    'amount': self.mining_reward,
    'timestamp': time.time(),
    'signature': 'mining_reward'
}

transactions = self.pending_transactions + [reward_tx]

# Create and mine new block
new_block = Block(
    len(self.chain),
    transactions,
    self.get_latest_block().hash,
    self.difficulty
)
new_block.mine_block()

# Add to chain
self.chain.append(new_block)
self.pending_transactions = []
```

```
        print(f"✓ Block {new_block.index} added to chain")
        return new_block

    def validate_chain(self):
        """Validate entire blockchain"""
        print("\nValidating blockchain...")

        for i in range(1, len(self.chain)):
            current_block = self.chain[i]
            previous_block = self.chain[i - 1]

            # Check hash
            if current_block.hash != current_block.calculate_hash():
                print(f"✗ Block {i} hash is invalid")
                return False

            # Check link to previous block
            if current_block.previous_hash != previous_block.hash:
                print(f"✗ Block {i} is not properly linked")
                return False

            # Check proof of work
            if current_block.hash[:self.difficulty] != '0' * self.difficulty:
                print(f"✗ Block {i} does not meet difficulty requirement")
                return False
        print("✓ Blockchain is valid")
        return True

    def demonstrate_tampering(self):
        """Show that tampering is detectable"""
        if len(self.chain) < 2:
            print("Need at least 2 blocks to demonstrate tampering")
            return

        print("\n" + "="*70)
        print("TAMPER-PROOFING DEMONSTRATION")
        print("="*70)

        # Show original state
        print("\nOriginal blockchain is valid:")
        self.validate_chain()

        # Tamper with a block
        print(f"\n⚠ Attempting to tamper with block 1...")
        original_amount = self.chain[1].transactions[0]['amount']
        self.chain[1].transactions[0]['amount'] = 999999
        print(f"  Changed transaction amount: {original_amount} → 999999")

        # Show detection
        print("\nValidating tampered blockchain:")
        self.validate_chain()

        # Restore
        self.chain[1].transactions[0]['amount'] = original_amount
        print(f"\n✓ Restored original value: {original_amount}")

    def get_balance(self, address):
        """Calculate balance for an address"""
        balance = 0

        for block in self.chain:
            for tx in block.transactions:
                if tx['to'] == address:
                    balance += tx['amount']
                if tx['from'] == address:
                    balance -= tx['amount']

        return balance

    def display_chain(self):
        """Display the entire blockchain"""
        print("\n" + "="*70)
        print("BLOCKCHAIN STATE")
        print("="*70)

        for block in self.chain:
```

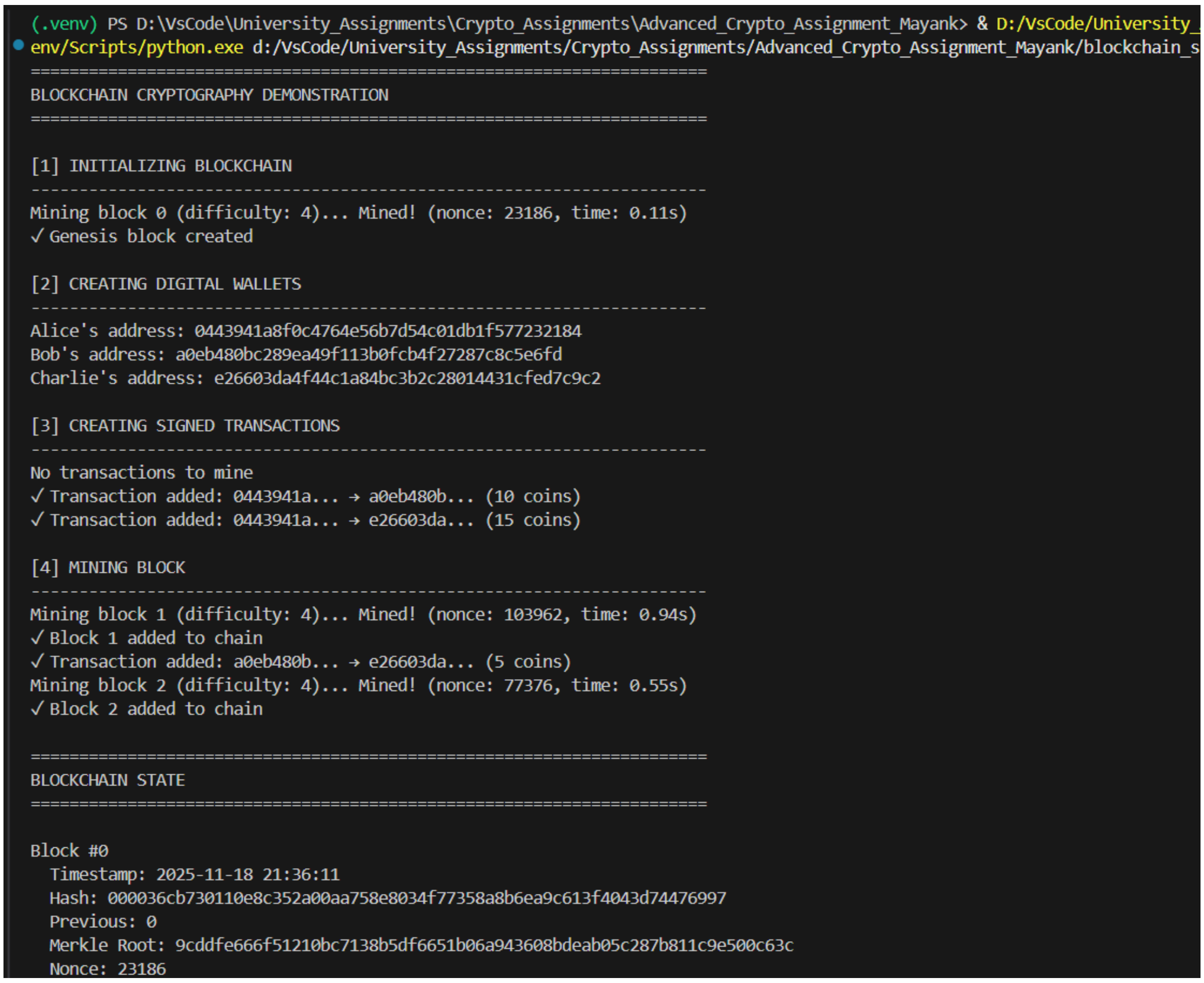
```
        print(f"\nBlock #{block.index}")
        print(f"  Timestamp:
{datetime.fromtimestamp(block.timestamp).strftime('%Y-%m-%d
%H:%M:%S')}")
        print(f"  Hash: {block.hash}")
        print(f"  Previous: {block.previous_hash}")
        print(f"  Merkle Root: {block.merkle_root}")
        print(f"  Nonce: {block.nonce}")
        print(f"  Transactions: {len(block.transactions)}")
        for i, tx in enumerate(block.transactions, 1):
            print(f"    {i}. {tx['from'][:8]}... → {tx['to'][:8]}... : {tx['amount']}
coins")


def demonstrate_blockchain():
    """Full blockchain demonstration"""


    print("="*70)
    print("BLOCKCHAIN CRYPTOGRAPHY DEMONSTRATION")
    print("="*70)


    # Create blockchain
    print("\n[1] INITIALIZING BLOCKCHAIN")
    print("-"*70)
    blockchain = Blockchain(difficulty=4)


    # Create wallets
    print("\n[2] CREATING DIGITAL WALLETS")
print("-"*70)
alice_wallet = DigitalWallet("Alice")
bob_wallet = DigitalWallet("Bob")
charlie_wallet = DigitalWallet("Charlie")

print(f"Alice's address: {alice_wallet.address}")
print(f"Bob's address: {bob_wallet.address}")
print(f"Charlie's address: {charlie_wallet.address}")

# Create and sign transactions
print("\n[3] CREATING SIGNED TRANSACTIONS")
print("-"*70)

# Give Alice some initial coins (simulate)
blockchain.mine_pending_transactions(alice_wallet.address)

# Alice sends to Bob
tx1 = {
    'from': alice_wallet.address,
    'to': bob_wallet.address,
    'amount': 10,
    'timestamp': time.time()
}
sig1 = alice_wallet.sign_transaction(tx1)
blockchain.add_transaction(tx1, sig1, alice_wallet)
```

```
# Alice sends to Charlie
tx2 = {
    'from': alice_wallet.address,
    'to': charlie_wallet.address,
    'amount': 15,
    'timestamp': time.time()
}
sig2 = alice_wallet.sign_transaction(tx2)
blockchain.add_transaction(tx2, sig2, alice_wallet)

# Mine block
print("\n[4] MINING BLOCK")
print("-"*70)
blockchain.mine_pending_transactions(bob_wallet.address)

# Bob sends to Charlie
tx3 = {
    'from': bob_wallet.address,
    'to': charlie_wallet.address,
    'amount': 5,
    'timestamp': time.time()
}
sig3 = bob_wallet.sign_transaction(tx3)
blockchain.add_transaction(tx3, sig3, bob_wallet)

# Mine another block
```

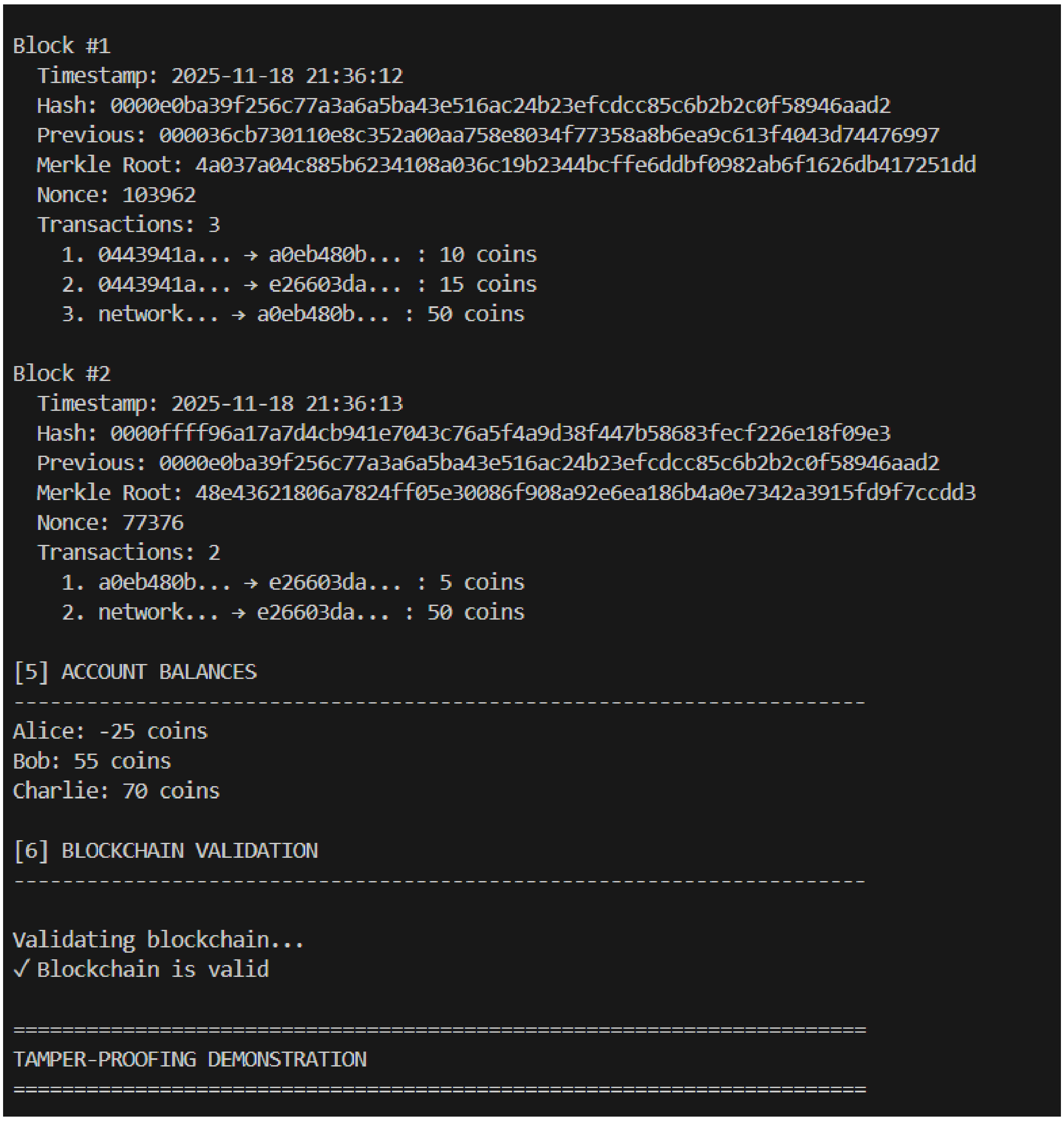
```
blockchain.mine_pending_transactions(charlie_wallet.address)

# Display blockchain
blockchain.display_chain()

# Show balances
print("\n[5] ACCOUNT BALANCES")
print("-"*70)
print(f"Alice: {blockchain.get_balance(alice_wallet.address)} coins")
print(f"Bob: {blockchain.get_balance(bob_wallet.address)} coins")
print(f"Charlie: {blockchain.get_balance(charlie_wallet.address)} coins")

# Validate chain
print("\n[6] BLOCKCHAIN VALIDATION")
print("-"*70)
blockchain.validate_chain()

# Demonstrate tampering
blockchain.demonstrate_tampering()

# Merkle tree demonstration
print("\n[7] MERKLE TREE VERIFICATION")
print("-"*70)
block = blockchain.chain[1]
merkle_tree = block.merkle_tree
```

```
print(f"Merkle Root: {merkle_tree.root}")
print(f"Transactions in block: {len(block.transactions)}")

# Verify a transaction
tx_index = 0
tx = json.dumps(block.transactions[tx_index], sort_keys=True)
proof = merkle_tree.get_proof(tx_index)
is_valid = merkle_tree.verify_proof(tx, proof, merkle_tree.root)

print(f"\nVerifying transaction {tx_index}:")
print(f"  Proof length: {len(proof)} hashes")
print(f"  Valid: {is_valid}")

# Consensus discussion
print("\n[8] CONSENSUS MECHANISMS")
print("-"*70)
consensus_info = """
PROOF OF WORK (PoW) - Used in Bitcoin
• Miners compete to solve cryptographic puzzle
• First to find valid nonce broadcasts block
• Energy intensive but highly secure
• Difficulty adjusts based on network hashrate

PROOF OF STAKE (PoS) - Used in Ethereum 2.0
• Validators stake cryptocurrency to validate blocks
• Selected based on stake amount and age
• Energy efficient compared to PoW
• Risk of "nothing at stake" problem

DELEGATED PROOF OF STAKE (DPoS)
• Stakeholders vote for delegates
• Delegates validate transactions
• Faster but more centralized

PRACTICAL BYZANTINE FAULT TOLERANCE (PBFT)
• Used in permissioned blockchains
• Consensus through voting among known validators
• Fast but requires known participants
"""
print(consensus_info)

# Public key cryptography in blockchain
print("\n[9] PUBLIC KEY CRYPTOGRAPHY ROLE")
print("-"*70)
crypto_role = """
In Bitcoin/Ethereum:

1. Wallet Address Generation:
   Private Key → Public Key → Address (via hashing)

2. Transaction Signing:
   • User signs transaction with private key (ECDSA)
```

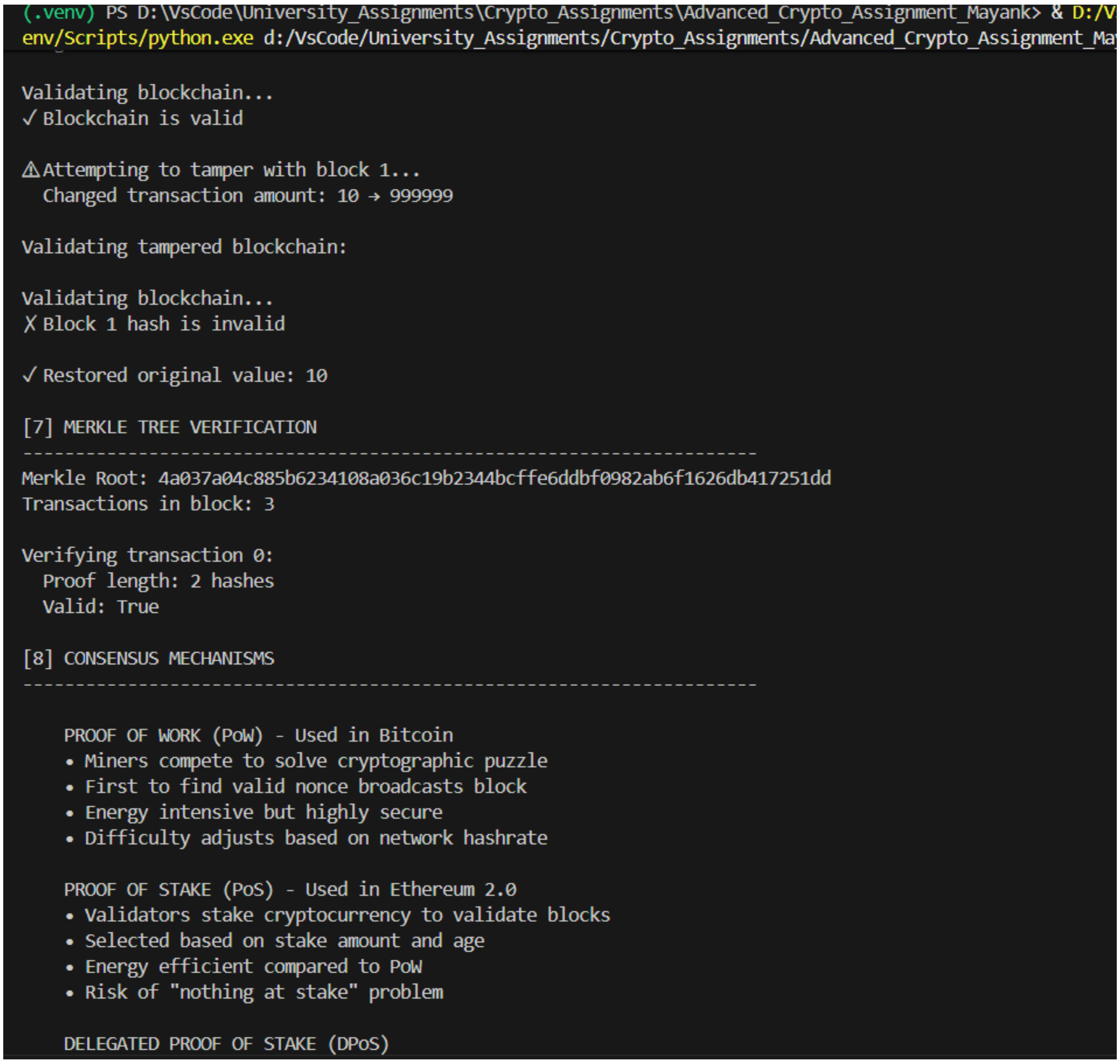
```
        • Network verifies with public key
        • Proves ownership without revealing private key

    3. Non-repudiation:
        • Signed transactions cannot be denied
        • Immutable record on blockchain

    4. Elliptic Curve Cryptography (ECC):
        • Bitcoin uses secp256k1 curve
        • 256-bit private key
        • Smaller keys than RSA for same security

    5. Hash Functions:
        • SHA-256 for Bitcoin
        • Keccak-256 for Ethereum
        • RIPEMD-160 for address generation
    """
    print(crypto_role)


if __name__ == "__main__":
    demonstrate_blockchain()
```
Output:



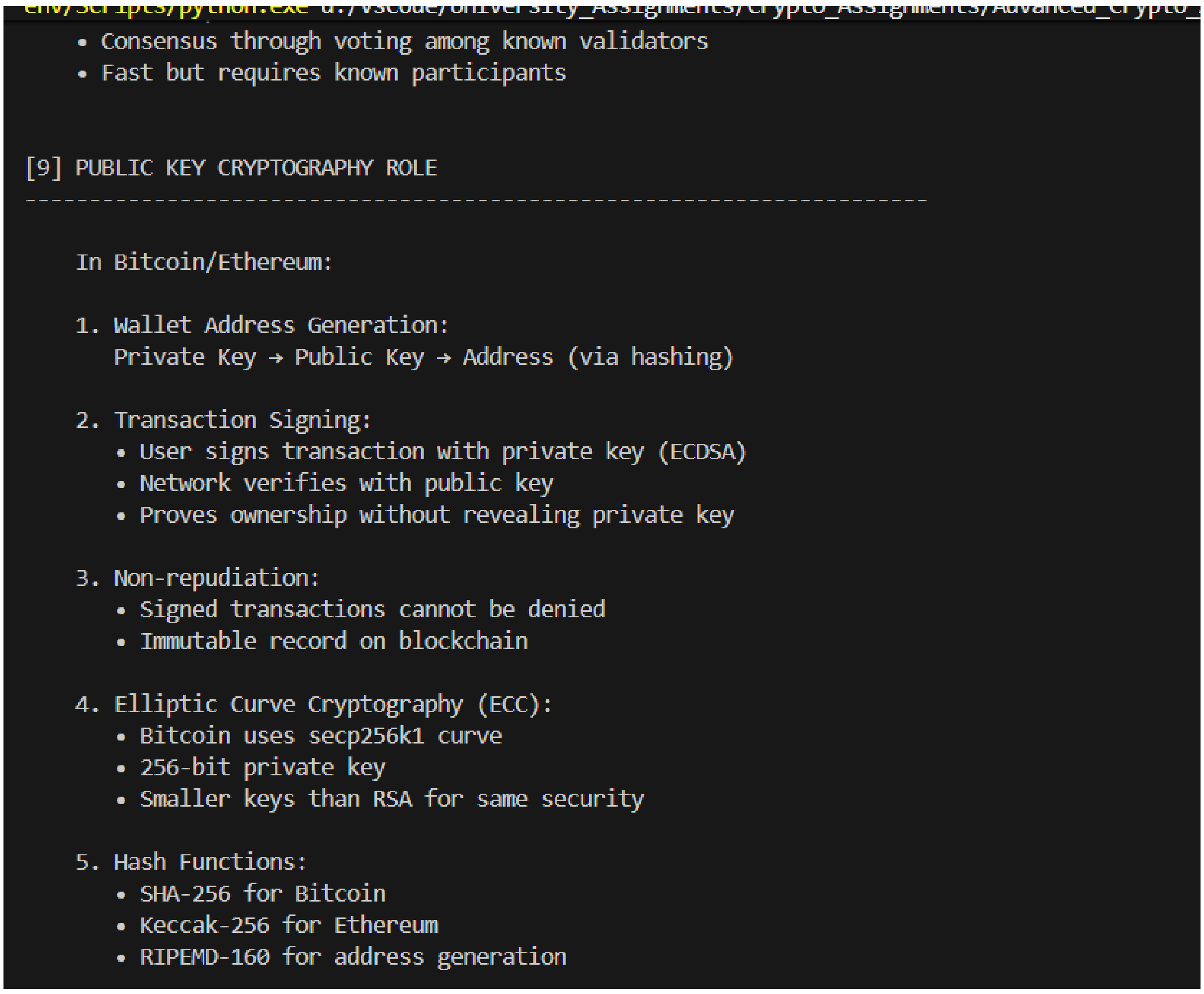
```
(.venv) PS D:\VsCode\University_Assignments\Crypto_Assignments\Advanced_Crypto_Assignment_Mayank> & D:/VsCode/University_
env/Scripts/python.exe d:/VsCode/University_Assignments/Crypto_Assignments/Advanced_Crypto_Assignment_Mayank/blockchain_s
======================================================================
BLOCKCHAIN CRYPTOGRAPHY DEMONSTRATION
======================================================================

[1] INITIALIZING BLOCKCHAIN
----------------------------------------------------------------------
Mining block 0 (difficulty: 4)... Mined! (nonce: 23186, time: 0.11s)
✓ Genesis block created

[2] CREATING DIGITAL WALLETS
----------------------------------------------------------------------
Alice's address: 0443941a8f0c4764e56b7d54c01db1f577232184
Bob's address: a0eb480bc289ea49f113b0fcb4f27287c8c5e6fd
Charlie's address: e26603da4f44c1a84bc3b2c28014431cfed7c9c2

[3] CREATING SIGNED TRANSACTIONS
----------------------------------------------------------------------
No transactions to mine
✓ Transaction added: 0443941a... → a0eb480b... (10 coins)
✓ Transaction added: 0443941a... → e26603da... (15 coins)

[4] MINING BLOCK
----------------------------------------------------------------------
Mining block 1 (difficulty: 4)... Mined! (nonce: 103962, time: 0.94s)
✓ Block 1 added to chain
✓ Transaction added: a0eb480b... → e26603da... (5 coins)
Mining block 2 (difficulty: 4)... Mined! (nonce: 77376, time: 0.55s)
✓ Block 2 added to chain

======================================================================
BLOCKCHAIN STATE
======================================================================

Block #0
  Timestamp: 2025-11-18 21:36:11
  Hash: 000036cb730110e8c352a00aa758e8034f77358a8b6ea9c613f4043d74476997
  Previous: 0
  Merkle Root: 9cddfe666f51210bc7138b5df6651b06a943608bdeab05c287b811c9e500c63c
  Nonce: 23186
```



```
Block #1
  Timestamp: 2025-11-18 21:36:12
  Hash: 0000e0ba39f256c77a3a6a5ba43e516ac24b23efcdcc85c6b2b2c0f58946aad2
  Previous: 000036cb730110e8c352a00aa758e8034f77358a8b6ea9c613f4043d74476997
  Merkle Root: 4a037a04c885b6234108a036c19b2344bcffe6ddbf0982ab6f1626db417251dd
  Nonce: 103962
  Transactions: 3
    1. 0443941a... → a0eb480b... : 10 coins
    2. 0443941a... → e26603da... : 15 coins
    3. network... → a0eb480b... : 50 coins

Block #2
  Timestamp: 2025-11-18 21:36:13
  Hash: 0000ffff96a17a7d4cb941e7043c76a5f4a9d38f447b58683fecf226e18f09e3
  Previous: 0000e0ba39f256c77a3a6a5ba43e516ac24b23efcdcc85c6b2b2c0f58946aad2
  Merkle Root: 48e43621806a7824ff05e30086f908a92e6ea186b4a0e7342a3915fd9f7ccdd3
  Nonce: 77376
  Transactions: 2
    1. a0eb480b... → e26603da... : 5 coins
    2. network... → e26603da... : 50 coins

[5] ACCOUNT BALANCES
----------------------------------------------------------------------
Alice: -25 coins
Bob: 55 coins
Charlie: 70 coins

[6] BLOCKCHAIN VALIDATION
----------------------------------------------------------------------

Validating blockchain...
✓ Blockchain is valid

======================================================================
TAMPER-PROOFING DEMONSTRATION
======================================================================
```



```
(.venv) PS D:\VsCode\University_Assignments\Crypto_Assignments\Advanced_Crypto_Assignment_Mayank> & D:/V
env/Scripts/python.exe d:/VsCode/University_Assignments/Crypto_Assignments/Advanced_Crypto_Assignment_Ma

Validating blockchain...
✓ Blockchain is valid

⚠ Attempting to tamper with block 1...
  Changed transaction amount: 10 → 999999

Validating tampered blockchain:

Validating blockchain...
✗ Block 1 hash is invalid

✓ Restored original value: 10

[7] MERKLE TREE VERIFICATION
----------------------------------------------------------------------
Merkle Root: 4a037a04c885b6234108a036c19b2344bcffe6ddbf0982ab6f1626db417251dd
Transactions in block: 3

Verifying transaction 0:
  Proof length: 2 hashes
  Valid: True

[8] CONSENSUS MECHANISMS
----------------------------------------------------------------------

    PROOF OF WORK (PoW) - Used in Bitcoin
    • Miners compete to solve cryptographic puzzle
    • First to find valid nonce broadcasts block
    • Energy intensive but highly secure
    • Difficulty adjusts based on network hashrate

    PROOF OF STAKE (PoS) - Used in Ethereum 2.0
    • Validators stake cryptocurrency to validate blocks
    • Selected based on stake amount and age
    • Energy efficient compared to PoW
    • Risk of "nothing at stake" problem

    DELEGATED PROOF OF STAKE (DPoS)
```



```
env/Scripts/python.exe d:/vscode/University_Assignments/Crypto_Assignments/Advanced_Crypto_
    • Consensus through voting among known validators
    • Fast but requires known participants


[9] PUBLIC KEY CRYPTOGRAPHY ROLE
----------------------------------------------------------------------

    In Bitcoin/Ethereum:

    1. Wallet Address Generation:
       Private Key → Public Key → Address (via hashing)

    2. Transaction Signing:
       • User signs transaction with private key (ECDSA)
       • Network verifies with public key
       • Proves ownership without revealing private key

    3. Non-repudiation:
       • Signed transactions cannot be denied
       • Immutable record on blockchain

    4. Elliptic Curve Cryptography (ECC):
       • Bitcoin uses secp256k1 curve
       • 256-bit private key
       • Smaller keys than RSA for same security

    5. Hash Functions:
       • SHA-256 for Bitcoin
       • Keccak-256 for Ethereum
       • RIPEMD-160 for address generation
```