20CYS205 – MODERN CRYPTOGRAPHY

IMPLEMENT AND CRYPTANALYSE PAILLIER ENCRYPTION SCHEME

Submitted by

REDDICHERLA THANUJ	– CB.EN.U4CYS22056
S MOHANA VAMSI	– CB.EN.U4CYS22057
SARIDE SOMESWARA SAI SRI CHAKRI	– CB.EN.U4CYS22059
SHREE HARINI T	– CB.EN.U4CYS22060

Under the guidance of

Aravind Vishnu S

Research Scholar

Amrita Vishwa Vidyapeetham, Coimbatore

TIFAC-CORE IN CYBER SECURITY AMRITA SCHOOL OF ENGINEERING

AMRITA VISHWA VIDYAPEETHAM

COIMBATORE - 641 112

2023

Table of Contents

Table of Figures

Schema:

Key generation:

1. Pick two large prime numbers p and q randomly. Confirm that *gcd*(pq, (p-1)(q-1)) is 1. If not, pick another pair of prime numbers.
2. Compute **n = p*q.**
3. Define function **L(x) = (x−1) / n.**
4. Compute carmichael function □(n) **= LCM(p-1, q-1).**
5. Pick a random integer **g** , such that g belongs to $Z^*_{n\times n}$ and order of g is non-zero multiple of n.
6. Calculate the modular multiplicative inverse □ **= (L(g^{λ} mod n^2))$^{-1}$ mod n.** If no □ exists, then restart from step 1.
7. The public key is **(n, g),** which can be used for encryption.
8. The private key is □ which can be used for decryption.

Encryption:

1. Any block m of the message in the range $0 \le m < n$ can be encrypted
2. Pick any random number **r** in the range $0 < r < n$, gcd(r,n) = 1
3. Compute the ciphertext **c = g^m * r^n mod n^2** .

Decryption:

- c will be such that $0 < c < n^2$.
- Now the plaintext can be recalculated as **m = L(c^{λ} mod n^2).μ mod** n.
- Also, **λ** and **μ** can be recalculated from the public key.

Correctness:

$c = g^m \times r^n \pmod{n^2}$
$c^{\lambda} = g^{m\lambda} \times r^{n\lambda} \pmod{n^2}$
$r^{n\lambda} \pmod{n^2} = (r^{\lambda})^n \pmod{n^2}$
$\quad = (r^{(p-1)(q-1)/gcd(p-1,q-1)})^n \pmod{n^2}$
$\rightarrow r^{(p-1)} = 1 \pmod{p}$
$\quad r\text{^}((p-1)(q-1)/gcd(p-1,q-1)) = 1 \pmod{p}$
$\quad r^{(q-1)} = 1 \pmod{q}$
$\quad r\text{^}((p-1)(q-1)/gcd(p-1,q-1)) = 1 \pmod{q}$
$\quad r(p-1)(q-1)/gcd(p-1,q-1) = 1 \pmod{pq}$
$\quad r^{\lambda} = 1 \pmod{n}$
$\quad r^{n\lambda} = 1 \pmod{n^2}$

$\rightarrow c^{\lambda} = g^{m\lambda} \times r^{n\lambda} \pmod{n^2}$
$\quad = g^{m\lambda} \pmod{n^2}$
$\quad = (1+n)^{m\lambda} \pmod{n^2}$
$\quad = 1+n(m\lambda) \pmod{n^2}$

$L(c^{\lambda} \pmod{n^2}) = 1+n(m\lambda)-1/n \pmod{n}$
$\quad = nm\lambda/n \pmod{n}$
$\quad = m\lambda \pmod{n}$

$L(g^\lambda \pmod{n^2}) = 1+n\lambda-1/n$
$= \lambda$

$L(c^\lambda \pmod{n^2}) / L(g^\lambda \pmod{n^2}) = m\lambda/\lambda = m$

Homomorphic Properties of Paillier cryptosystem:

The Paillier cryptosystem is a partially homomorphic encryption scheme. It allows two types of computation:

- Addition of two ciphertexts.
- Multiplication of ciphertext by a plaintext number.

We majorly uses Addition of two cipher texts property in the applications.

Example:

Key generation:

p = 13
q = 17

n = p * q
n = 13 * 17
n = 221

λ = LCM(p-1, q-1)
λ = LCM(12 , 16)
λ = 48

g ∈ (1,n^2)
Let,

g = 4886

$\mu = (L(g^\lambda \bmod n^2))^{-1}$

μ = [L[4886^48(mod 221^2)]]^-1 (mod221)
μ = [L[30720]]^-1 (mod 221)   {Where, L(x)=(x-1)/n}
μ = [(30720-1)/221]^-1 (mod 221)
μ = (139)^-1 (mod 221)
μ = 159

Encryption:

Message1 = 123
r = 5

C1 = (g^m)*(r^n) (mod n^2)
C1 = (4886^123)*(5^221) (mod 221^2)
C1 = (42021)*(42996) (mod 221^2)
C1 = 8644

∴ Cipher text (C1) is 8644

Message2 = 11
r = 3
C2 = (g^m)*(r^n) (mod n^2)
C2 = (4886^11)*(3^221) (mod 221^2)
C2 = (15450)*(24696) (mod 221^2)
C2 = 7308

∴ Cipher text (C2) is 7308

According to Additive Homomorphism, when two cipher texts are multiplied, then the decryption of the result will be the sum of their plain texts.

C = C1*C2(mod n^2) = 8644*7308 (mod 221^2)
C = 63170352(mod 48841)
C = 18939

Now decrypting the resulted cipher text (C)

Decryption:

M = [L(C^ λ mod n^2)*μ] (mod n)
M = [L(18939^48 (mod 48841))* 159] (mod 221)
M = [L(13703)*159] (mod 221)
M = [62*159] (mod 221)
M = 9858 (mod 221)
M = 134 = 123+11

∴ Hence proved, as product of two cipher texts will result in sum of the plain texts

Applications:

Applications of paillier cryptosystem are:

1. Electronic voting:
   Let us suppose an election counting scheme where the number of votes from each center must be encrypted to be sent to the election board. Palliers scheme comes to use in this by sending an aggregated cipher text, consisting of encrypted data from each center . This is further decrypted by the board

Python code:

```
import random

def is_prime(n, k=5):
    if n <= 1:
        return False
    if n <= 3:
         return True
     if n % 2 == 0:
        return False

    # Miller-Rabin primality test
    def miller_rabin(n, d, r):
        a = random.randint(2, n - 2)
        x = mod_exp(a, d, n)
        if x == 1 or x == n - 1:
            return True
        for i in range(r - 1):
            x = mod_exp(x, 2, n)
            if x == n - 1:
                return True
        return False

    d, r = n - 1, 0
    while d % 2 == 0:
        d //= 2
        r += 1

    for i in range(k):
        if not miller_rabin(n, d, r):
            return False

    return True

def generate_strong_prime(bits):
    while True:
        potential_prime = random.getrandbits(bits)
        if potential_prime % 2 == 0:
            potential_prime += 1
        if is_prime(potential_prime):
            return potential_prime

def gcd(a, b):
    while b:
        a, b = b, a % b
    return a

def lcm(a, b):
    return (a * b) // gcd(a, b)

def extended_gcd(a, b):
    x0, x1, y0, y1 = 1, 0, 0, 1
    while b != 0:
        q, r = divmod(a, b)
        a, b = b, r
        x0, x1 = x1, x0 - q * x1
        y0, y1 = y1, y0 - q * y1
    return a, x0, y0

def multiplicative_inverse(a, n):
    gcd, x, y = extended_gcd(a, n)
    if gcd != 1:
        raise ValueError(f"The multiplicative inverse does not exist for {a} (mod {n}).")
    else:
        return x % n

def mod_exp(a, b, n):
    result = 1
    a = a % n

    while b > 0:
        if b % 2 == 1:
            result = (result * a) % n

        a = (a * a) % n
        b //= 2

    return result

def text_to_long(text):
    text_bytes = text.encode('utf-8')
    text_long = int.from_bytes(text_bytes, byteorder='big')
    return(text_long)

def long_to_text(long_msg):
    text_bytes = long_msg.to_bytes((long_msg.bit_length() + 7) // 8, byteorder='big')
    text = text_bytes.decode('utf-8')
    return(text)

def generate_keys():
    bits = 1024
    p = generate_strong_prime(bits)
    q = generate_strong_prime(bits)

    n = p*q
    g = 1+n
    lamda = lcm((p-1),(q-1))

    n_squared = n**2
    temp = mod_exp(g, lamda, n_squared)
    temp1 = temp-1
    quotient, remainder = divmod(temp1, n)
    if (remainder!=0):
        raise ValueError(f"Something went wrong")

    mu = multiplicative_inverse(quotient, n)

    public_key = [n, g]
    private_key = [lamda, mu]

    return(public_key, private_key)

def encrypt_msg(msg, public_key):
    msg_long = text_to_long(msg)
    n = public_key[0]
    g = public_key[1]

    def select_r(n):
        while True:
            r = random.randint(0, n)
            if gcd(r, n) == 1:
                return r

    r = select_r(n)
    n_squared = n**2
    temp = mod_exp(g, msg_long, n_squared)
    temp1 = mod_exp(r, n, n_squared)
    cipher_text = (temp*temp1)%n_squared
    return(cipher_text)

def decrypt_msg(cipher_text, public_key, private_key):
    lamda = private_key[0]
    mu = private_key[1]
    n = public_key[0]
    n_squared = n**2
    temp = mod_exp(cipher_text, lamda, n_squared)
    temp = temp - 1
    quotient, remainder = divmod(temp, n)
    if (remainder!=0):
        raise ValueError(f"Something went wrong")
    plain_long = (quotient*mu)%n
    plain_text = long_to_text(plain_long)
    return(plain_text)

print("Generating Keys ....................")
print()
public_key, private_key = generate_keys()
print("n value : ", public_key[0])
print()
print("g value : ", public_key[1])
print()
print("Encryption:")
msg = input("Enter your plain text >> ")
plain_long = text_to_long(msg)
print("Plain text in long : ", plain_long)
cipher_text = encrypt_msg(msg, public_key)
```

```
cipher_hex = hex(cipher_text)
print("Cipher_text : ", cipher_hex)
print()
print("Decryption:")
plain_text_back = decrypt_msg(cipher_text, public_key, private_key)
print("Plain_text : ", plain_text_back)
print("Print Any Key to Exit.........")
input()
```

- **The above code uses g value as n+1**

-
  ```
  def get_random_g(n, lamda):
     gcd1 = 0
     n_squared = n**2
     while gcd1 != 1:
        g = random.randint(0, n_squared)
        temp = mod_exp(g, lamda, n_squared)
        temp1 = temp-1
        quotient, remainder = divmod(temp1, n)
        gcd1 = gcd(quotient, n)
        if (remainder != 0):
           gcd1 = 0
     return (g)
  ```

If you add this function then the random g value will be calculated.

UI codes:

HTML Code:

```
<!DOCTYPE html>
<html lang="en">
<head>
   <meta charset="UTF-8">
   <meta name="viewport" content="width=device-width, initial-scale=1.0">
   <link href="https://fonts.googleapis.com/css?family=Poppins" rel="stylesheet">
   <link href="../css/style1.css" rel="stylesheet">
   <title>Paillier Cryptosystem UI</title>
</head>
<body>

   <div class="navbar">
      <h1>Paillier Cryptosystem</h1>
      <button class="Go_back" onclick="window.location.href='../index.html'">Go Back</button>
   </div>
   <div class="rectangle-bar"></div>
   <div class="container">

      <!-- Corrected centering of text -->
      <h1 style="text-align: center;">Calculate here</h1>

      <!-- Key Generation Section -->
      <div class="section">
         <button id="genkeys">Generate Keys</button>
         <div id="keysOutput" class="output"></div>
```

```
        </div>

        <!-- Encryption Section -->
        <div class="section">
            <label for="plaintext">Enter Plaintext:</label>
            <input type="text" id="plaintext" placeholder="Type your message...">
            <button id="enc">Encrypt</button>
            <div id="encryptionOutput" class="output"></div>
        </div>

        <!-- Decryption Section -->
        <div class="section">
            <label for="ciphertext">Enter Ciphertext:</label>
            <input type="text" id="ciphertext" placeholder="Paste your ciphertext...">
            <button id="dec">Decrypt</button>
            <div id="decryptionOutput" class="output"></div>
        </div>
        <script src="../js/script.js"></script>
    </div>
</body>
</html>
```

JavaScript Code:

```
function isPrime(num, k = 5) {
    if (num <= 1n) return false;
    if (num <= 3n) return true;

    // Write (num - 1) as 2^s * d
    let s = 0n;
    let d = num - 1n;
    while (d % 2n === 0n) {
        s++;
        d /= 2n;
    }

    const witness = (a, n) => {
        if (a <= 1n || a >= n - 1n) return false;

        let x = mod_exp(a, d, n);
        if (x === 1n || x === n - 1n) return false;

        for (let i = 1n; i < s; i++) {
            x = mod_exp(x, 2n, n);
            if (x === n - 1n) return false;
        }

        return true;
    };

    for (let i = 0; i < k; i++) {
        const a = getRandomBigInt(2n, num - 1n);
        if (witness(a, num)) return false;
    }

    return true;
}

function getRandomBigInt(min, max) {
    const range = max - min + 1n;
    const random = BigInt(Math.floor(Math.random() * Number(range)));
    return min + random;
}

function generateRandomBigInt(minDigits, maxDigits) {
    if (minDigits < 1 || maxDigits < minDigits) {
      throw new Error('Invalid digit range');
    }
    const randomDigits = Array.from({ length: Math.floor(Math.random() * (maxDigits - minDigits
+ 1)) + minDigits }, () =>
      Math.floor(Math.random() * 10)
    ).join('');
    const randomBigInt = BigInt(randomDigits);
    return randomBigInt;
}

function generatePrimeWithDigits(min, max) {
    while (true){
        let primeCandidate = generateRandomBigInt(min, max);

        if (primeCandidate % 2n === 0) {
            primeCandidate++;
        }

        if (isPrime(primeCandidate)) {
            return primeCandidate;
        }
    }
}

function mod_exp(base, exponent, modulus) {
    if (modulus === 1n) return 0n;
    let result = 1n;
    base = base % modulus;
    while (exponent > 0n) {
        if (exponent % 2n === 1n) {
            result = (result * base) % modulus;
        }
        exponent = exponent >> 1n;
        base = (base * base) % modulus;
    }
    return result;
}
function modExp(a, b, n) {
    a = BigInt(a);
    b = BigInt(b);
    n = BigInt(n);

    let result = BigInt(1);
    a = a % n;

    while (b > 0n) {
        if (b % 2n === 1n) {
            result = (result * a) % n;
        }
        a = (a * a) % n;
        b = b / 2n;
    }

    return result;
}
function gcd(a, b) {
    return b === 0n ? a : gcd(b, a % b);
}

function lcm(a, b) {
    return (a * b) / gcd(a, b);
}

function extendedGCD(a, b) {
    if (b === 0n) {
        return [a, 1n, 0n];
    } else {
        const [d, x, y] = extendedGCD(b, a % b);
        return [d, y, x - y * (a / b)];
    }
}

function multiplicativeInverse(a, n) {
    const [g, x, y] = extendedGCD(a, n);

    if (g !== 1n) {
        throw new Error("Inverse does not exist");
    }

    return (x % n + n) % n;
}
```

```
function textToLong(text) {
    const encoder = new TextEncoder();
    const textBytes = encoder.encode(text);
    const textLong = BigInt('0x' + Array.from(textBytes).map(byte => byte.toString(16).padStart(2,
'0')).join(''));
    return textLong;
}

function longToText(longMsg) {
    const hexString = longMsg.toString(16).padStart((longMsg.toString(16).length + 1) & ~1, '0');
    const hexArray = hexString.match(/.{2}/g);

    if (!hexArray) {
        throw new Error('Invalid hex string');
    }

    const bytes = Uint8Array.from(hexArray.map(byte => parseInt(byte, 16)));
    const decoder = new TextDecoder('utf-8');
    return decoder.decode(bytes);
}

function divmod(a, b) {
    const quotient = a / b;
    const remainder = a % b;
    return [quotient, remainder];
}

function generateTwoPrimesWithDigits(min, max) {
    const prime1 = generatePrimeWithDigits(min, max);
    console.log("Prime 1 : ",prime1);
    const prime2 = generatePrimeWithDigits(min, max);
    console.log("Prime 2 : ",prime2);
    return{prime1, prime2}
}

function generate_random_g(n,lamda){
    let gcd1 = 0;
    let n_square = n ** 2n;
    const numberOfDigits = n_square.toString().length;
    let g = 1n;
    while (gcd!==1n){
        g = generateRandomBigInt(2, numberOfDigits-1);
        const temp = mod_exp(g, lamda, n_square);
        const temp1 = temp - 1n;
        const [quotient, remainder] = divmod(temp1, n);
        gcd1 = gcd(quotient, n);
        if (remainder!==0n){
          gcd1 = 0;
        }
        if (gcd1===1n){
          break;
        }
    }
    return(g);
  }

function generateKeys(){
    const { prime1, prime2 } = generateTwoPrimesWithDigits(90, 100);
    const prime_1 = BigInt(prime1);
    const prime_2 = BigInt(prime2);
    const n = prime_1*prime_2;
    const lamda = lcm(prime_1 - 1n, prime_2 - 1n);
    const g = generate_random_g(n,lamda);

    const n_squared = n ** 2n;
    const temp = mod_exp(g, lamda, n_squared);
    const temp1 = temp - 1n;

    const [quotient, remainder] = divmod(temp1, n);
    if (remainder !== 0n) {
        throw new Error("Something went wrong");
    }

    const mu = multiplicativeInverse(quotient, n);
    return[n,g,lamda,mu];
}

function encrypt(n,g,plaintext) {
    //const plaintext = document.getElementById('plaintext').value;
    const plain = textToLong(plaintext);
    const plain_long = BigInt(plain);
    console.log("Given Text in integer format : ",plain_long);

    let r = generatePrimeWithDigits(5, 10);
    let n_squared = n * n;
    let temp = modExp(g, plain_long, n_squared);
    let temp1 = modExp(r, n, n_squared);
    let ciphertext = (temp * temp1) % n_squared;
    let cipherhex = ciphertext.toString(16);
    return(cipherhex);
}

function decrypt(n,lamda,mu,cipherhex){
    const ciphertext = BigInt("0x" + cipherhex);
    let n_squared = n * n;
    let temp = modExp(ciphertext,lamda,n_squared);
    temp = temp - 1n;
    const [quotient, remainder] = divmod(temp, n);
    if (remainder !== 0n) {
        throw new Error("Something went wrong");
    }
    let plain_long = (quotient*mu)%n;
    let plaintext = longToText(plain_long);
    return(plaintext);
}

let n,g,lamda,mu;

document.getElementById('genkeys').addEventListener('click', async function () {
    try {
        [n, g, lamda, mu] = await generateKeys();

        const keysOutput = `
            <p>Public Key (n, g): (${n}, ${g})</p>
            <p>Private Key (lambda, mu): (${lamda}, ${mu})</p>
        `;

        document.getElementById('keysOutput').innerHTML = keysOutput;
    } catch (error) {
        console.error(error);
        document.getElementById('keysOutput').innerHTML = '<p>Error generating keys</p>';
    }
});

document.getElementById('enc').addEventListener('click', async function () {
    const plaintext = document.getElementById('plaintext').value;
    const ciphertext = await encrypt(n,g,plaintext);
    document.getElementById('encryptionOutput').innerHTML = `
        <p>Ciphertext: ${ciphertext}</p>
    `;
    document.getElementById('ciphertext').value= ciphertext
});

document.getElementById('dec').addEventListener('click', async function () {
    const ciphertext = document.getElementById('ciphertext').value;
    const plaintext = await decrypt(n,lamda,mu,ciphertext);
    document.getElementById('decryptionOutput').innerHTML = `
        <p>Plaintext: ${plaintext}</p>
    `;
});
```

Application Codes:

HTML Code:

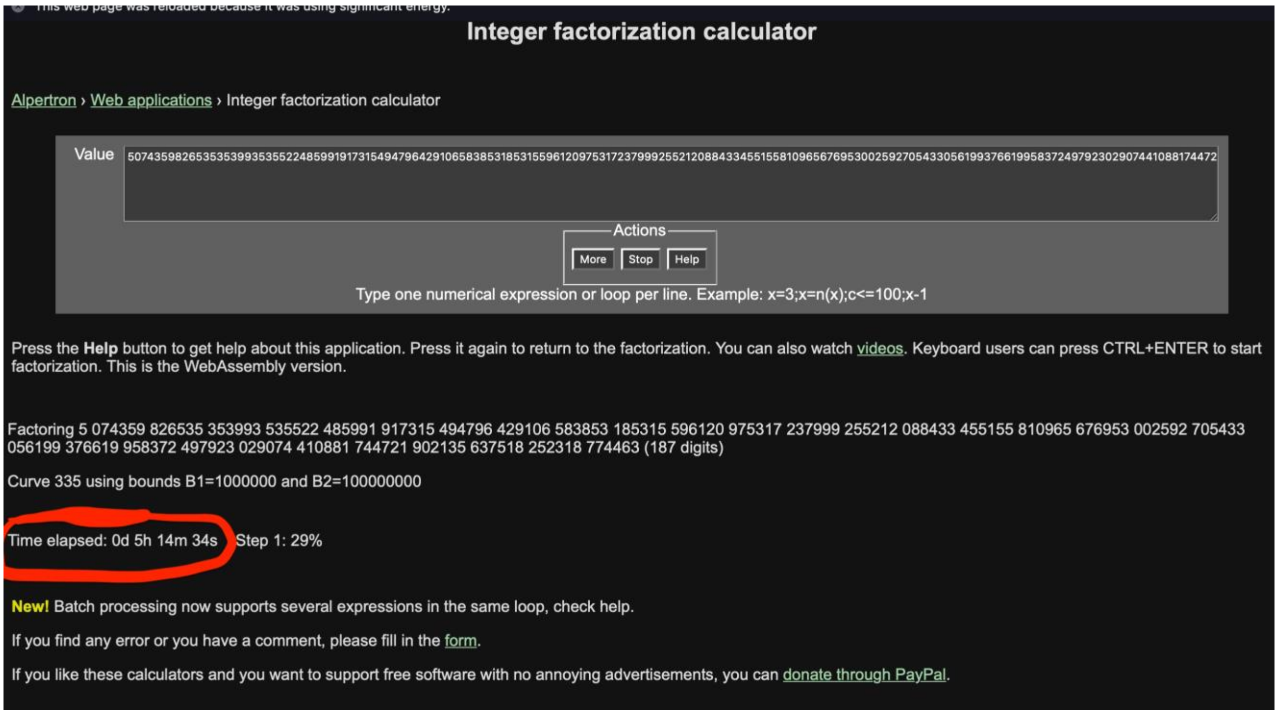
```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <link href="https://fonts.googleapis.com/css?family=Poppins" rel="stylesheet">
    <link href="../css/application.css" rel="stylesheet">
    <title>Application | Paillier Cryptosystem</title>

</head>
<body>
    <div class="navbar">
        <h1>Paillier Cryptosystem</h1>
        <button class="Go_back" onclick="window.location.href='../index.html'">Go Back</button>
    </div>
    <div class="rectangle-bar"></div>
    <div class="section1">
        <label for="reg1">Enter number of votes in region 1:</label>
        <input type="number" id="reg1" min="0"><br><br>
        <button id="enc1" style="font-size: 1vw;">Encrypt</button>
        <div id="encryptionOutput1"></div><br><br><br><br><br><br><br>
    </div>
    <div class="section2">
        <label for="reg2">Enter number of votes in region 2:</label>
        <input type="number" id="reg2" min="0"><br><br>
        <button id="enc2" style="font-size: 1vw;">Encrypt</button>
        <div id="encryptionOutput2"></div><br><br><br><br><br><br><br>
    </div>
    <div class="section3">
        <div id="mulcipher" style="width: 40vw; overflow-wrap:break-word;"></div><br>
        <button id="dec" style="font-size: 1vw; position: relative; left: 43%;">Decrypt</button><br>
        <div id="decryptionOutput"></div>
    </div>
    <script src="../js/script2.js"></script>
</body>
</html>
```

JavaScript Code:

```javascript
function isPrime(num, k = 5) {
    if (num <= 1n) return false;
    if (num <= 3n) return true;

    // Write (num - 1) as 2^s * d
    let s = 0n;
    let d = num - 1n;
    while (d % 2n === 0n) {
        s++;
        d /= 2n;
    }

    const witness = (a, n) => {
        if (a <= 1n || a >= n - 1n) return false;
        let x = mod_exp(a, d, n);
        if (x === 1n || x === n - 1n) return false;

        for (let i = 1n; i < s; i++) {
            x = mod_exp(x, 2n, n);
            if (x === n - 1n) return false;
        }

        return true;
    };

    for (let i = 0; i < k; i++) {
        const a = getRandomBigInt(2n, num - 1n);
        if (witness(a, num)) return false;
    }

    return true;
}

function getRandomBigInt(min, max) {
    const range = max - min + 1n;
    const random = BigInt(Math.floor(Math.random() * Number(range)));
    return min + random;
}

function generateRandomBigInt(minDigits, maxDigits) {
    if (minDigits < 1 || maxDigits < minDigits) {
      throw new Error('Invalid digit range');
    }
    const randomDigits = Array.from({ length: Math.floor(Math.random() * (maxDigits - minDigits + 1)) +
minDigits }, () =>
      Math.floor(Math.random() * 10)
    ).join('');
    const randomBigInt = BigInt(randomDigits);
    return randomBigInt;
}

function generatePrimeWithDigits(min, max) {
    while (true){
        let primeCandidate = generateRandomBigInt(min, max);

        if (primeCandidate % 2n === 0) {
            primeCandidate++;
        }

        if (isPrime(primeCandidate)) {
            return primeCandidate;
        }
    }
}

function mod_exp(base, exponent, modulus) {
    if (modulus === 1n) return 0n;
    let result = 1n;
    base = base % modulus;
    while (exponent > 0n) {
        if (exponent % 2n === 1n) {
            result = (result * base) % modulus;
        }
        exponent = exponent >> 1n;
        base = (base * base) % modulus;
    }
    return result;
}
function modExp(a, b, n) {
    a = BigInt(a);
    b = BigInt(b);
    n = BigInt(n);

    let result = BigInt(1);
    a = a % n;

    while (b > 0n) {
        if (b % 2n === 1n) {
            result = (result * a) % n;
        }
        a = (a * a) % n;
        b = b / 2n;
    }

    return result;
}
function gcd(a, b) {
    return b === 0n ? a : gcd(b, a % b);
}

function lcm(a, b) {
    return (a * b) / gcd(a, b);
}

function extendedGCD(a, b) {
    if (b === 0n) {
        return [a, 1n, 0n];
    } else {
        const [d, x, y] = extendedGCD(b, a % b);
        return [d, y, x - y * (a / b)];
    }
}

function multiplicativeInverse(a, n) {
    const [g, x, y] = extendedGCD(a, n);

    if (g !== 1n) {
        throw new Error("Inverse does not exist");
    }

    return (x % n + n) % n;
}

function textToLong(text) {
    const encoder = new TextEncoder();
    const textBytes = encoder.encode(text);
    const textLong = BigInt('0x' + Array.from(textBytes).map(byte => byte.toString(16).padStart(2,
'0')).join(''));
    return textLong;
}

function longToText(longMsg) {
    const hexString = longMsg.toString(16).padStart((longMsg.toString(16).length + 1) & ~1, '0');
    const hexArray = hexString.match(/.{2}/g);

    if (!hexArray) {
        throw new Error('Invalid hex string');
    }

    const bytes = Uint8Array.from(hexArray.map(byte => parseInt(byte, 16)));
    const decoder = new TextDecoder('utf-8');
    return decoder.decode(bytes);
}

function divmod(a, b) {
    const quotient = a / b;
    const remainder = a % b;
    return [quotient, remainder];
}

function generateTwoPrimesWithDigits(min, max) {
    const prime1 = generatePrimeWithDigits(min, max);
    console.log("Prime 1 : ",prime1);
    const prime2 = generatePrimeWithDigits(min, max);
    console.log("Prime 2 : ",prime2);
    return{prime1, prime2}
}

function generate_random_g(n,lamda){
    let gcd1 = 0;
    let n_square = n ** 2n;
    const numberOfDigits = n_square.toString().length;
    let g = 1n;
    while (gcd!==1n){
        g = generateRandomBigInt(2, numberOfDigits-1);
        const temp = mod_exp(g, lamda, n_square);
        const temp1 = temp - 1n;
        const [quotient, remainder] = divmod(temp1, n);
        gcd1 = gcd(quotient, n);
        if (remainder!==0n){
          gcd1 = 0;
        }
        if (gcd1===1n){
          break;
        }
    }
    return(g);
  }

function generateKeys(){
    const { prime1, prime2 } = generateTwoPrimesWithDigits(10, 15);
    const prime_1 = BigInt(prime1);
    const prime_2 = BigInt(prime2);
    const n = prime_1*prime_2;
    const lamda = lcm(prime_1 - 1n, prime_2 - 1n);
    const g = generate_random_g(n,lamda);

    const n_squared = n ** 2n;
    const temp = mod_exp(g, lamda, n_squared);
    const temp1 = temp - 1n;

    const [quotient, remainder] = divmod(temp1, n);
    if (remainder !== 0n) {
        throw new Error("Something went wrong");
    }

    const mu = multiplicativeInverse(quotient, n);
    return[n,g,lamda,mu];
}

function encrypt(n,g,plaintext) {
    let r = generatePrimeWithDigits(5, 10);
    let n_squared = n * n;
    let temp = modExp(g, plaintext, n_squared);
    let temp1 = modExp(r, n, n_squared);
    let ciphertext = (temp * temp1) % n_squared;
    return(ciphertext);
}

function decrypt(n,lamda,mu,ciphertext){
    let n_squared = n * n;
    let temp = modExp(ciphertext,lamda,n_squared);
    temp = temp - 1n;
    const [quotient, remainder] = divmod(temp, n);
    if (remainder !== 0n) {
        throw new Error("Something went wrong");
    }
    let plain_long = (quotient*mu)%n;
    return(plain_long);
}

let n,g,lamda,mu,ciphertext1,ciphertext2,mulciphertext;


try {
    [n, g, lamda, mu] = generateKeys();
    console.log("n: ",n);
    console.log("g: ",g);
    console.log("lamda: ",lamda);
    console.log("mu: ",mu);
} catch (error) {
    console.error(error);
}

document.getElementById('enc1').addEventListener('click', async function () {
    const plaintext = document.getElementById('reg1').value;
    ciphertext1 = await encrypt(n,g,plaintext);
    document.getElementById('encryptionOutput1').innerHTML = `
        <p>Ciphertext: ${ciphertext1}</p>
    `;
});

document.getElementById('enc2').addEventListener('click', async function () {
    const plaintext = document.getElementById('reg2').value;
    ciphertext2 = await encrypt(n,g,plaintext);
    document.getElementById('encryptionOutput2').innerHTML = `
        <p>Ciphertext: ${ciphertext2}</p>
    `;
    mulciphertext = ciphertext1*ciphertext2;
    document.getElementById('mulcipher').innerHTML=`
        <p>Resultant Ciphertext: ${mulciphertext}</p>
    `

});
```

```
document.getElementById('dec').addEventListener('click', async function () {
    const plaintext = await decrypt(n,lamda,mu,mulciphertext);
    document.getElementById('decryptionOutput').innerHTML = `
        <p>Total Votes: ${plaintext}</p>
    `;
});
```

Hard problem:



This web page was reloaded because it was using significant energy.

Integer factorization calculator

Alpertron › Web applications › Integer factorization calculator

Value 507435982653535399353552248599191731549479642910658385318531559612097531723799925521208843345515581096567695300259270543305619937661995837249792302907441088174472

Type one numerical expression or loop per line. Example: x=3;x=n(x);c<=100;x-1

Press the **Help** button to get help about this application. Press it again to return to the factorization. You can also watch videos. Keyboard users can press CTRL+ENTER to start factorization. This is the WebAssembly version.

Factoring 5 074359 826535 353993 535522 485991 917315 494796 429106 583853 185315 596120 975317 237999 255212 088433 455155 810965 676953 002592 705433 056199 376619 958372 497923 029074 410881 744721 902135 637518 252318 774463 (187 digits)

Curve 335 using bounds B1=1000000 and B2=100000000

Time elapsed: 0d 5h 14m 34s Step 1: 29%

New! Batch processing now supports several expressions in the same loop, check help.

If you find any error or you have a comment, please fill in the form.

If you like these calculators and you want to support free software with no annoying advertisements, you can donate through PayPal.

Here, online factoriser runner for 5hrs but its unable to factorise the key generated by the algorithm. So, hard problem of the paillier is factorization

User Interface

Home Page:

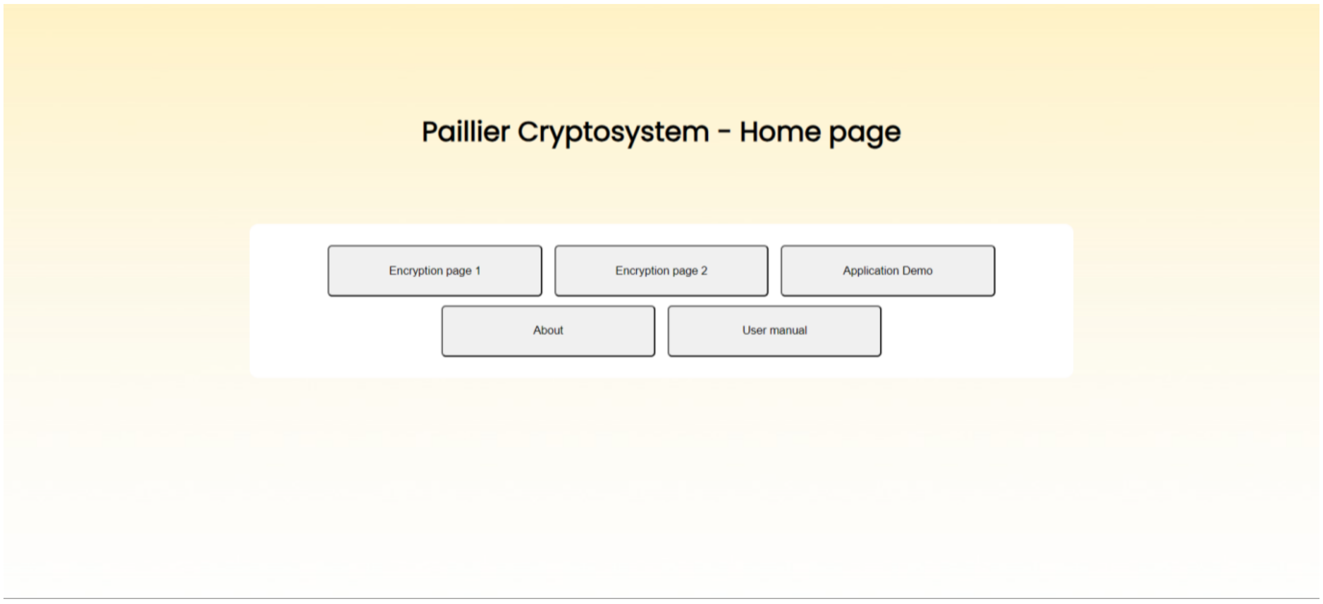


Figure 1 Home Page

Encryption page 1

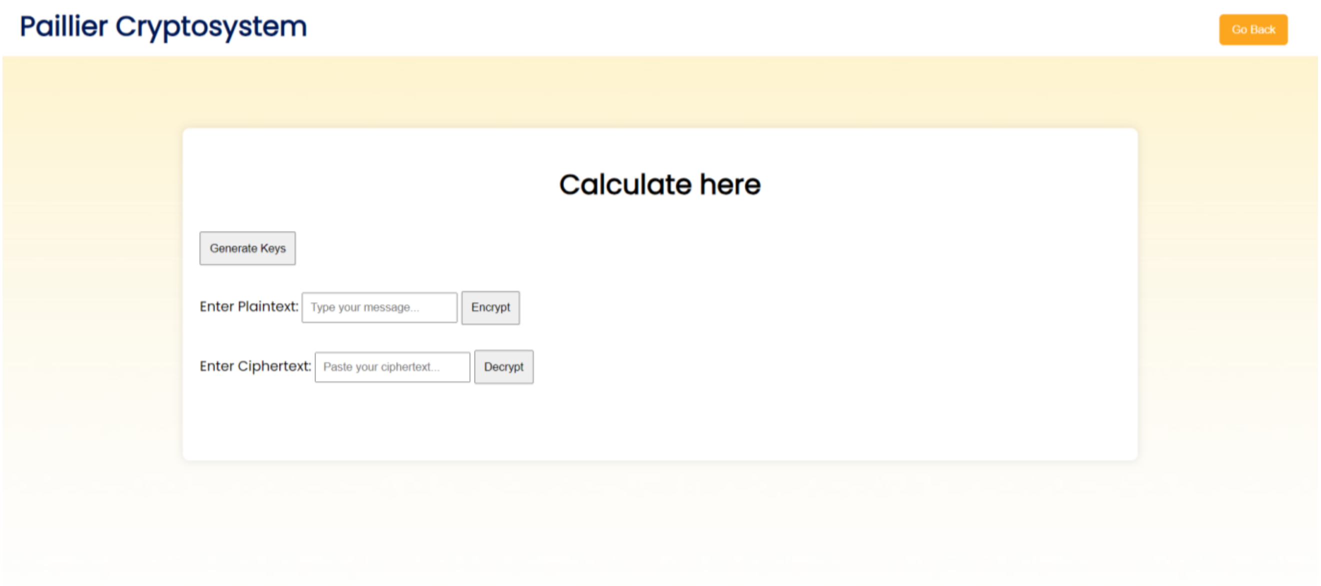
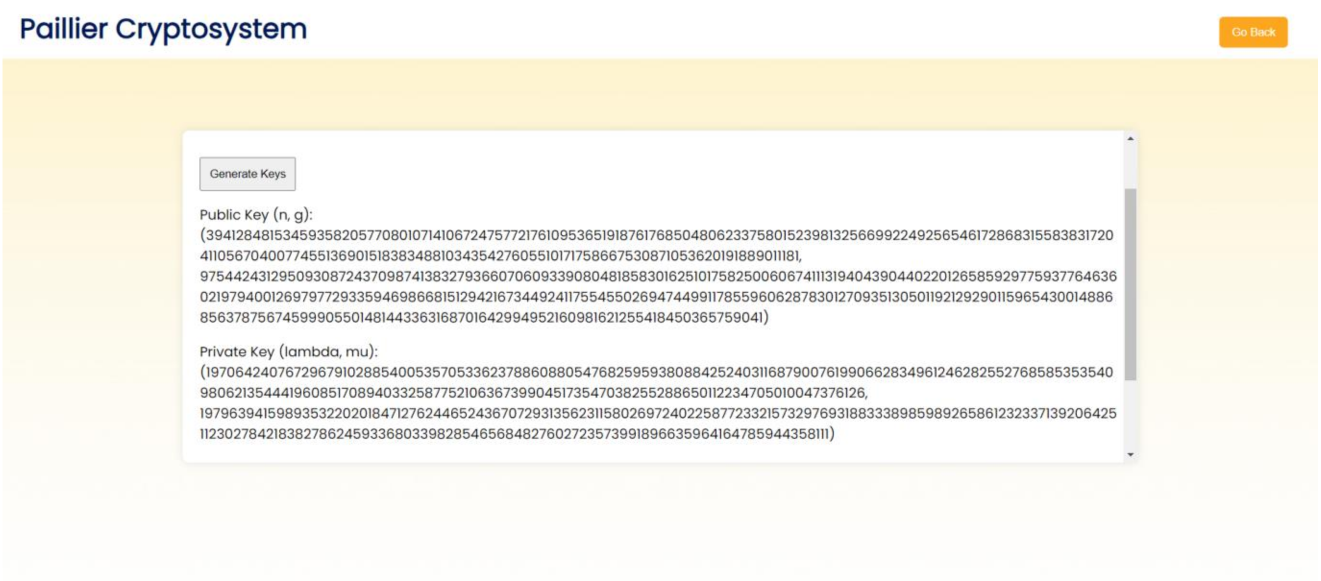


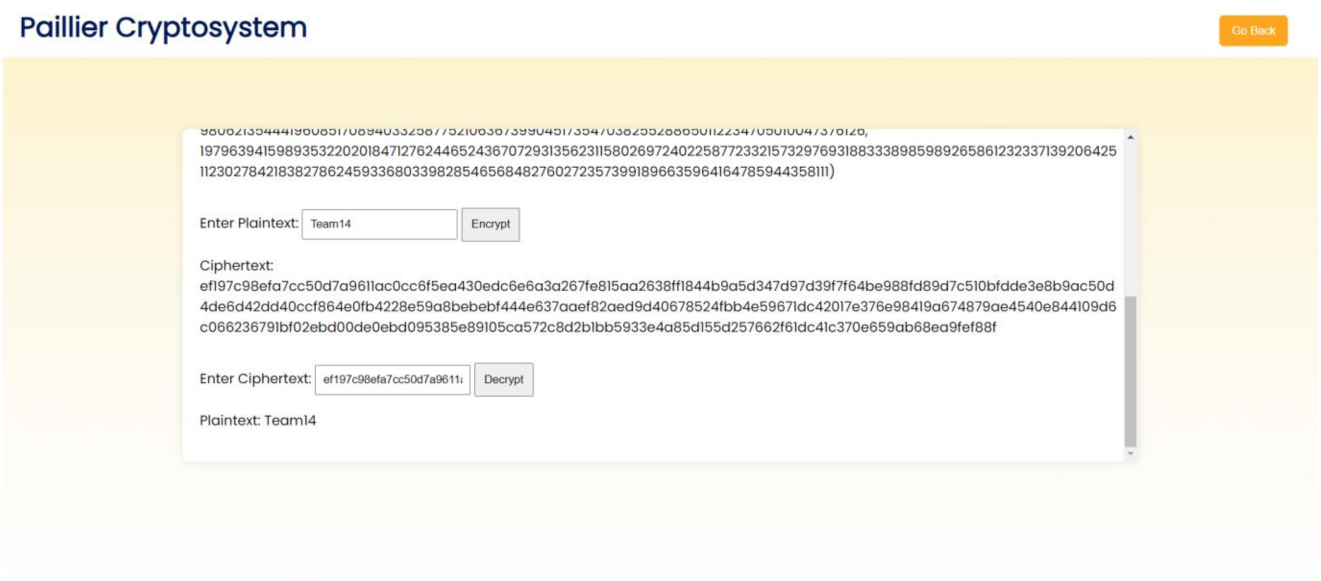
Figure 2 Encryption Page - 1



Public Key (n, g):
(3941284815345935820577080107141067247577217610953651918761768504806233758015239813256699224925654617286831558383172041105670400774551369015183834881034354276055101717586675308710536201918890111 81,
97544243129509308724370987413832793660706093390804818583016251017582500606741113194043904402201265859297759377646360219794001269797729335946986681512942167344924117554550269474499117855960628783012709351305011921292901159654300148868563787567459990550148144336316870164299495216098162125541845036575904 1)

Private Key (lambda, mu):
(1970642407672967910288540053570533623788608805476825959380884252403116879007619906628349612462825527685853535409806213544419608517089403325877521063673990451735470382552886501122347050100473761 26,
197963941598935322020184712762446524367072931356231158026972402258772332157329769318833389859892658612323371392064251123027842183827862459336803398285465684827602723573991896635964164785944358111)

Figure 3 Generation of keys



980621354441960851708940332587752106367399045173547038255288650112234705010047376126,
197963941598935322020184712762446524367072931356231158026972402258772332157329769318833389859892658612323371392064251123027842183827862459336803398285465684827602723573991896635964164785944358111)

Enter Plaintext: Team14

Ciphertext:
ef197c98efa7cc50d7a9611ac0cc6f5ea430edc6e6a3a267fe815aa2638ff1844b9a5d347d97d39f7f64be988fd89d7c510bfdde3e8b9ac50d4de6d42dd40ccf864e0fb4228e59a8bebebf444e637aaef82aed9d40678524fbb4e59671dc42017e376e98419a674879ae4540e844109d6c06623679 1bf02ebd00de0ebd095385e89105ca572c8d2b1bb5933e4a85d155d257662f61dc41c370e659ab68ea9fef88f

Enter Ciphertext: ef197c98efa7cc50d7a9611a

Plaintext: Team14

Figure 4 Encryption / Decryption

Encryption page 2

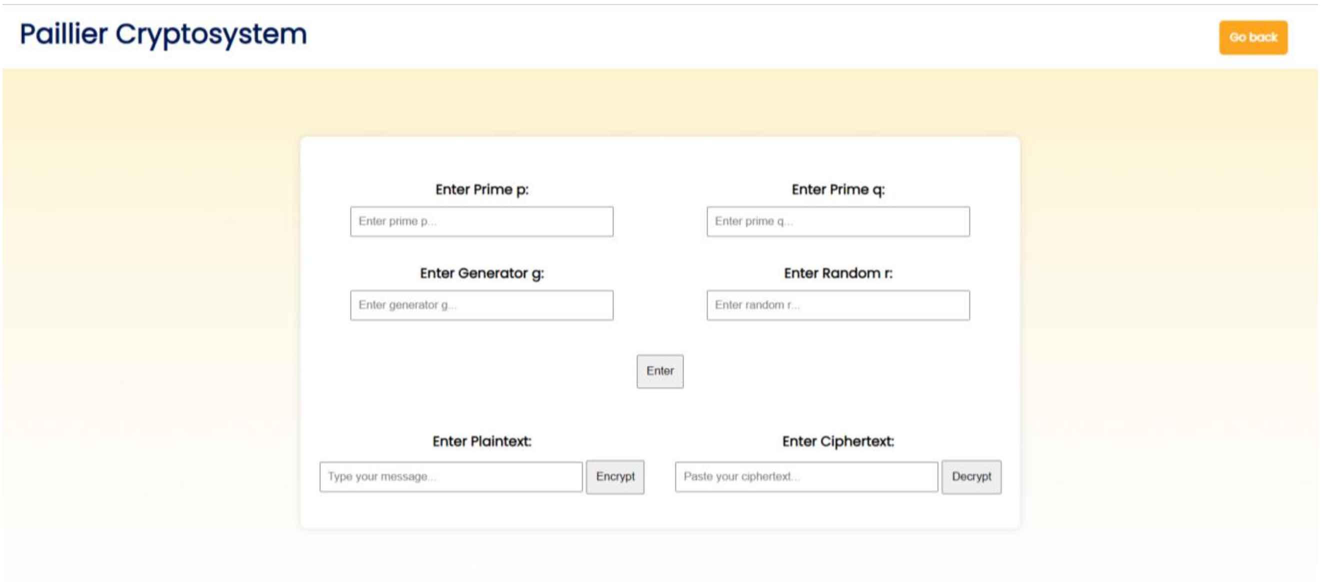
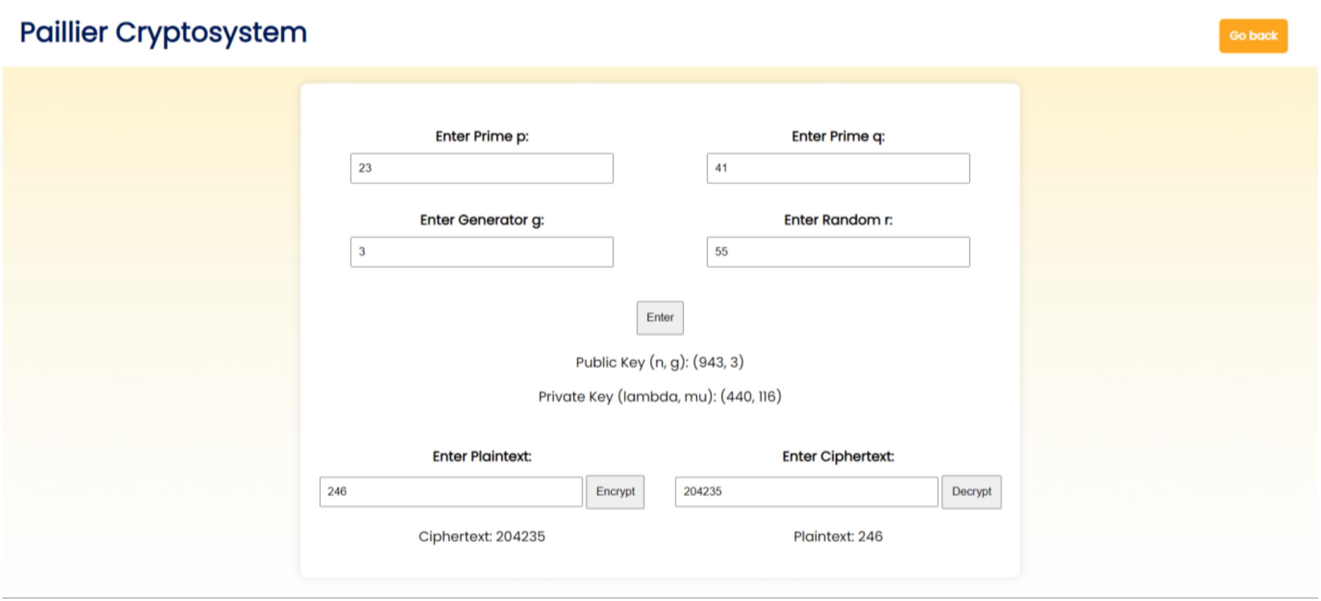

Paillier Cryptosystem

Figure 5 Encryption Page - 2


Paillier Cryptosystem

Enter Prime p: 23

Enter Prime q: 41

Enter Generator g: 3

Enter Random r: 55

Public Key (n, g): (943, 3)

Private Key (lambda, mu): (440, 116)

Enter Plaintext: 246

Enter Ciphertext: 204235

Ciphertext: 204235

Plaintext: 246

Figure 6 Encryption / Decryption

Application Demo

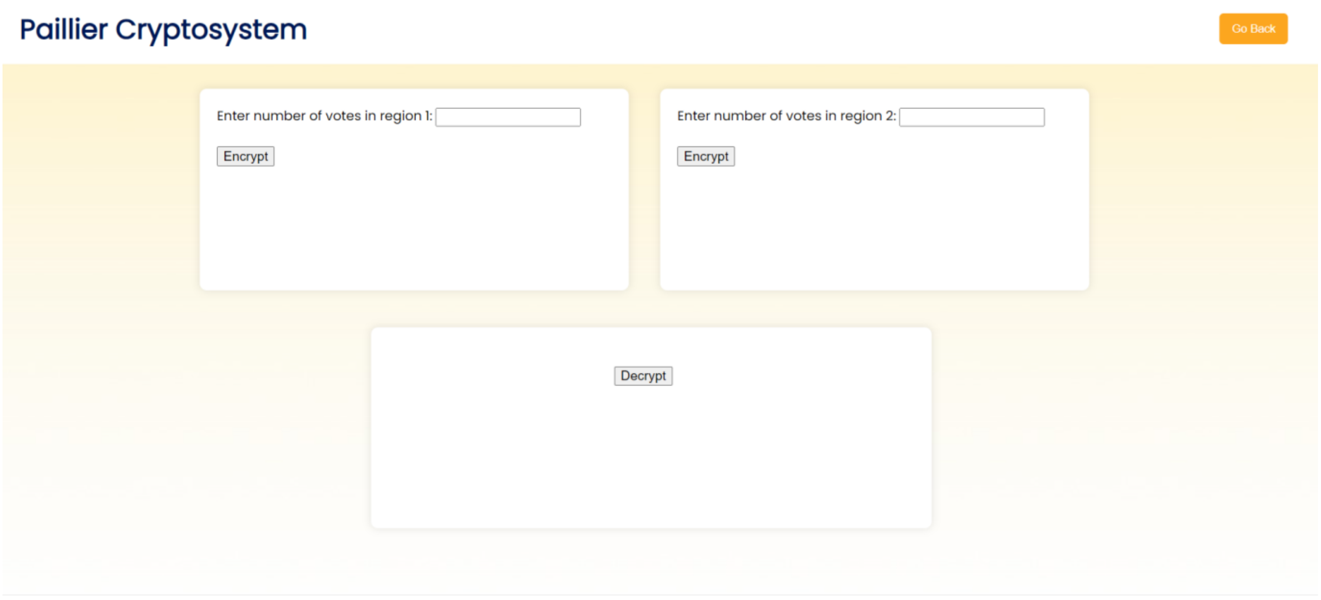
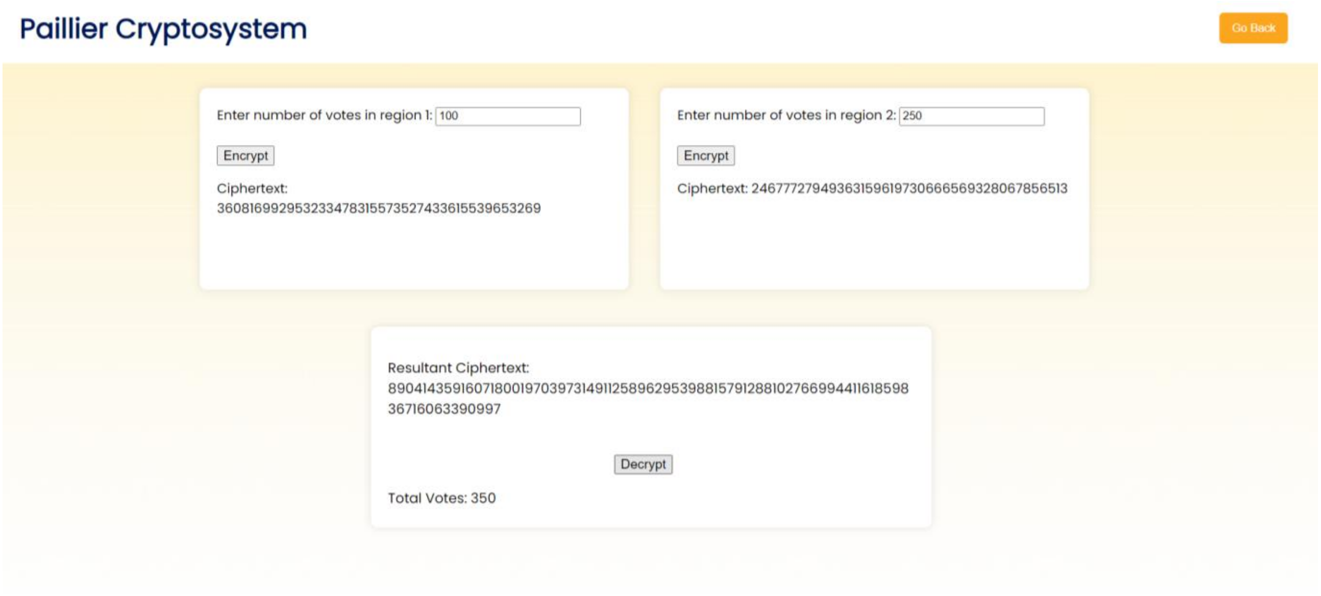

Paillier Cryptosystem
Go Back
Enter number of votes in region 1:
Encrypt
Enter number of votes in region 2:
Encrypt
Decrypt

Figure 7 Application Demo



Enter number of votes in region 1: 100

Ciphertext:
360816992953233478315573527433615539653269

Enter number of votes in region 2: 250

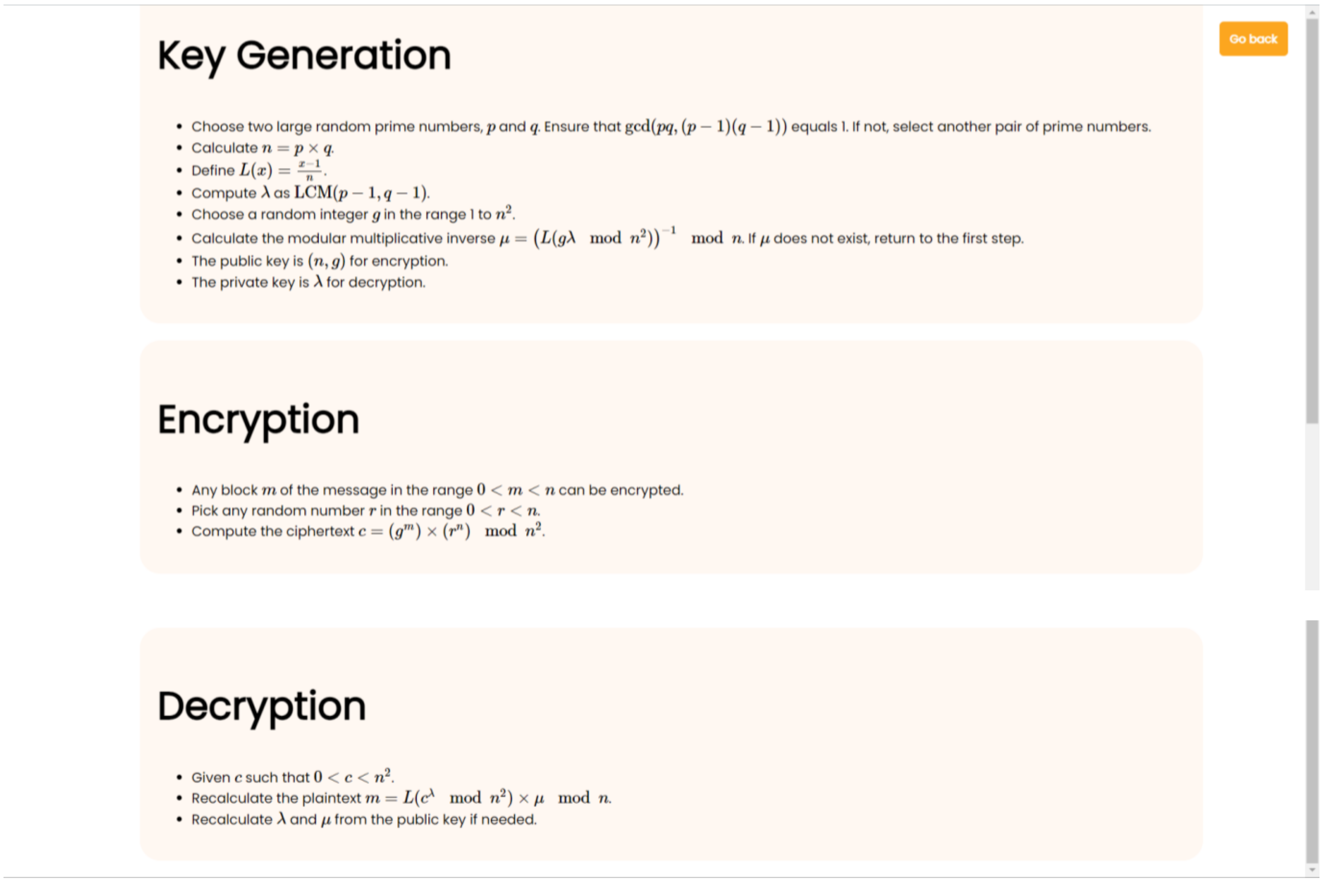
Ciphertext: 24677727949363159619730666569328067856513

Resultant Ciphertext:
89041435916071800197039731491125896295398815791288102766994411618598
36716063390997

Total Votes: 350

Figure 8 Encryption / Decryption

About



Key Generation

- Choose two large random prime numbers, p and q. Ensure that $\gcd(pq, (p-1)(q-1))$ equals 1. If not, select another pair of prime numbers.
- Calculate $n = p \times q$.
- Define $L(x) = \frac{x-1}{n}$.
- Compute λ as $\mathrm{LCM}(p-1, q-1)$.
- Choose a random integer g in the range 1 to n^2.
- Calculate the modular multiplicative inverse $\mu = \left(L(g\lambda \mod n^2)\right)^{-1} \mod n$. If μ does not exist, return to the first step.
- The public key is (n, g) for encryption.
- The private key is λ for decryption.

Encryption

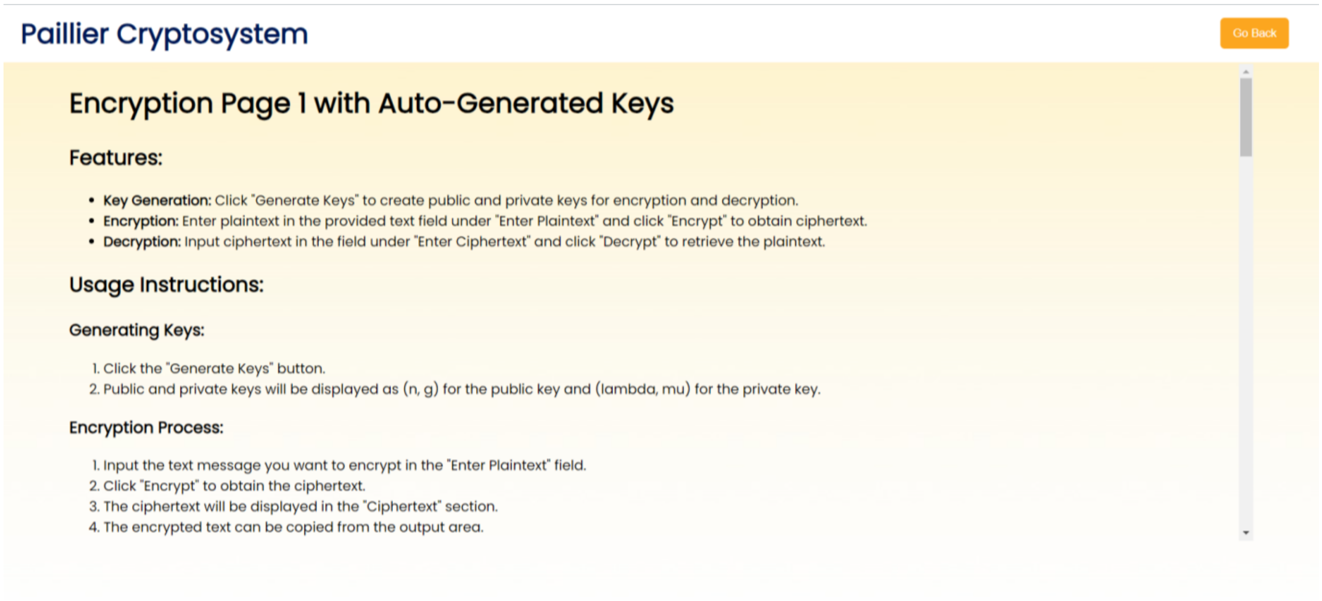
- Any block m of the message in the range $0 < m < n$ can be encrypted.
- Pick any random number r in the range $0 < r < n$.
- Compute the ciphertext $c = (g^m) \times (r^n) \mod n^2$.

Decryption

- Given c such that $0 < c < n^2$.
- Recalculate the plaintext $m = L(c^\lambda \mod n^2) \times \mu \mod n$.
- Recalculate λ and μ from the public key if needed.

Figure 9 About

User Manual



Encryption Page 1 with Auto-Generated Keys

Features:

- **Key Generation:** Click "Generate Keys" to create public and private keys for encryption and decryption.
- **Encryption:** Enter plaintext in the provided text field under "Enter Plaintext" and click "Encrypt" to obtain ciphertext.
- **Decryption:** Input ciphertext in the field under "Enter Ciphertext" and click "Decrypt" to retrieve the plaintext.

Usage Instructions:

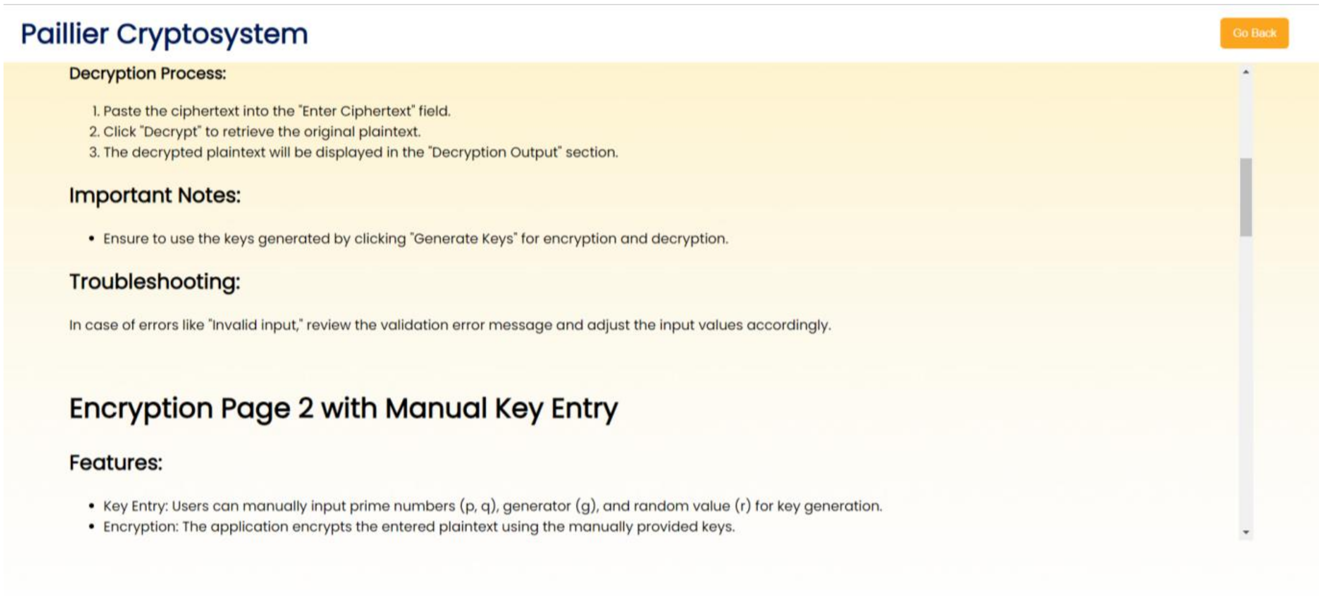
Generating Keys:

1. Click the "Generate Keys" button.
2. Public and private keys will be displayed as (n, g) for the public key and (lambda, mu) for the private key.

Encryption Process:

1. Input the text message you want to encrypt in the "Enter Plaintext" field.
2. Click "Encrypt" to obtain the ciphertext.
3. The ciphertext will be displayed in the "Ciphertext" section.
4. The encrypted text can be copied from the output area.

Figure 10 User - manual



Decryption Process:

1. Paste the ciphertext into the "Enter Ciphertext" field.
2. Click "Decrypt" to retrieve the original plaintext.
3. The decrypted plaintext will be displayed in the "Decryption Output" section.

Important Notes:

- Ensure to use the keys generated by clicking "Generate Keys" for encryption and decryption.

Troubleshooting:

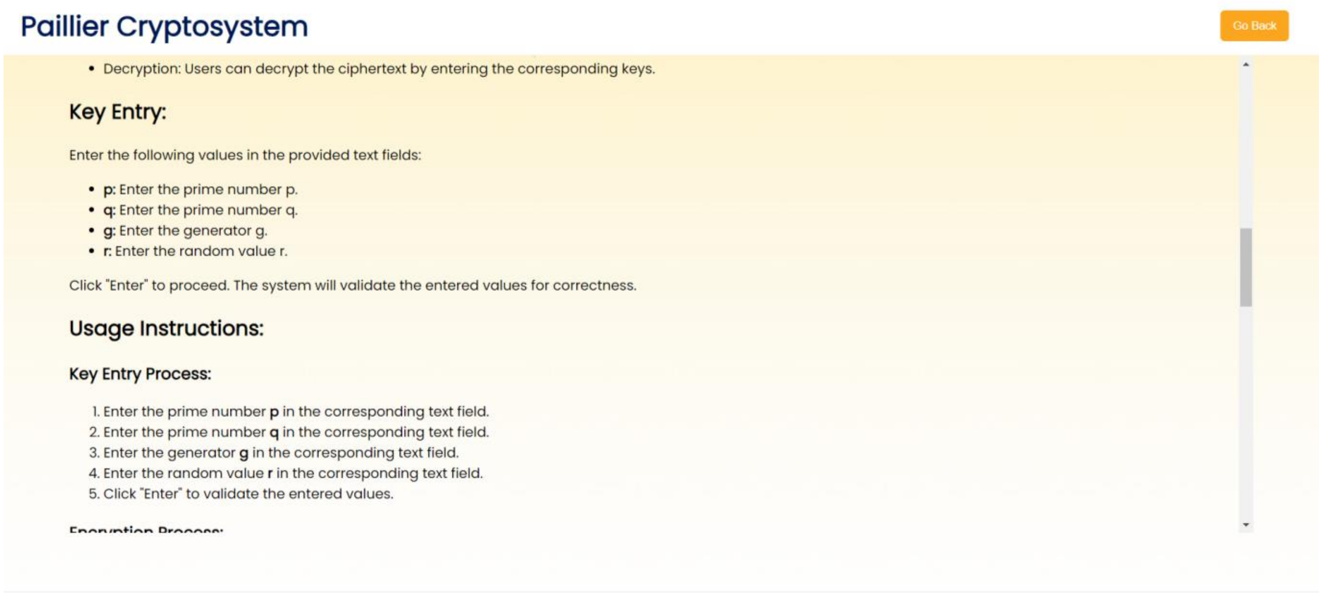
In case of errors like "Invalid input," review the validation error message and adjust the input values accordingly.

Encryption Page 2 with Manual Key Entry

Features:

- Key Entry: Users can manually input prime numbers (p, q), generator (g), and random value (r) for key generation.
- Encryption: The application encrypts the entered plaintext using the manually provided keys.

Figure 11 User – manual continued



- Decryption: Users can decrypt the ciphertext by entering the corresponding keys.

Key Entry:

Enter the following values in the provided text fields:

- **p:** Enter the prime number p.
- **q:** Enter the prime number q.
- **g:** Enter the generator g.
- **r:** Enter the random value r.

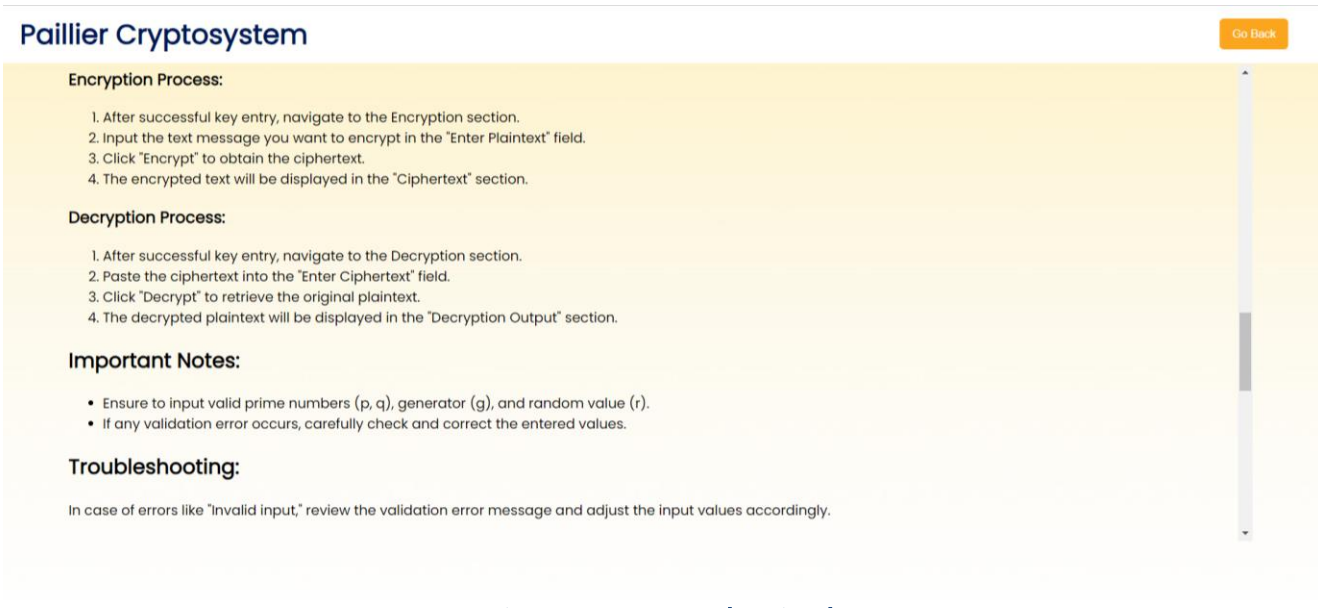
Click "Enter" to proceed. The system will validate the entered values for correctness.

Usage Instructions:

Key Entry Process:

1. Enter the prime number **p** in the corresponding text field.
2. Enter the prime number **q** in the corresponding text field.
3. Enter the generator **g** in the corresponding text field.
4. Enter the random value **r** in the corresponding text field.
5. Click "Enter" to validate the entered values.

Figure 12 User – manual continued



Encryption Process:

1. After successful key entry, navigate to the Encryption section.
2. Input the text message you want to encrypt in the "Enter Plaintext" field.
3. Click "Encrypt" to obtain the ciphertext.
4. The encrypted text will be displayed in the "Ciphertext" section.

Decryption Process:

1. After successful key entry, navigate to the Decryption section.
2. Paste the ciphertext into the "Enter Ciphertext" field.
3. Click "Decrypt" to retrieve the original plaintext.
4. The decrypted plaintext will be displayed in the "Decryption Output" section.

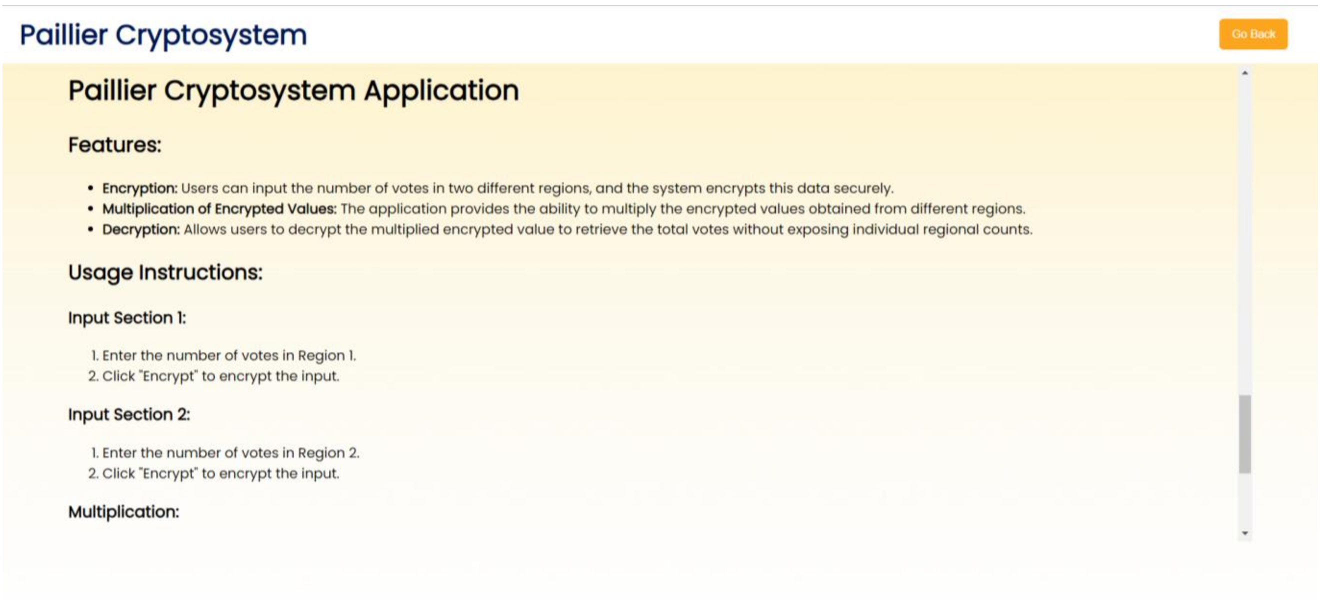
Important Notes:

- Ensure to input valid prime numbers (p, q), generator (g), and random value (r).
- If any validation error occurs, carefully check and correct the entered values.

Troubleshooting:

In case of errors like "Invalid input," review the validation error message and adjust the input values accordingly.

Figure 13 User – manual continued



Paillier Cryptosystem

Paillier Cryptosystem Application

Features:

- **Encryption:** Users can input the number of votes in two different regions, and the system encrypts this data securely.
- **Multiplication of Encrypted Values:** The application provides the ability to multiply the encrypted values obtained from different regions.
- **Decryption:** Allows users to decrypt the multiplied encrypted value to retrieve the total votes without exposing individual regional counts.

Usage Instructions:

Input Section 1:

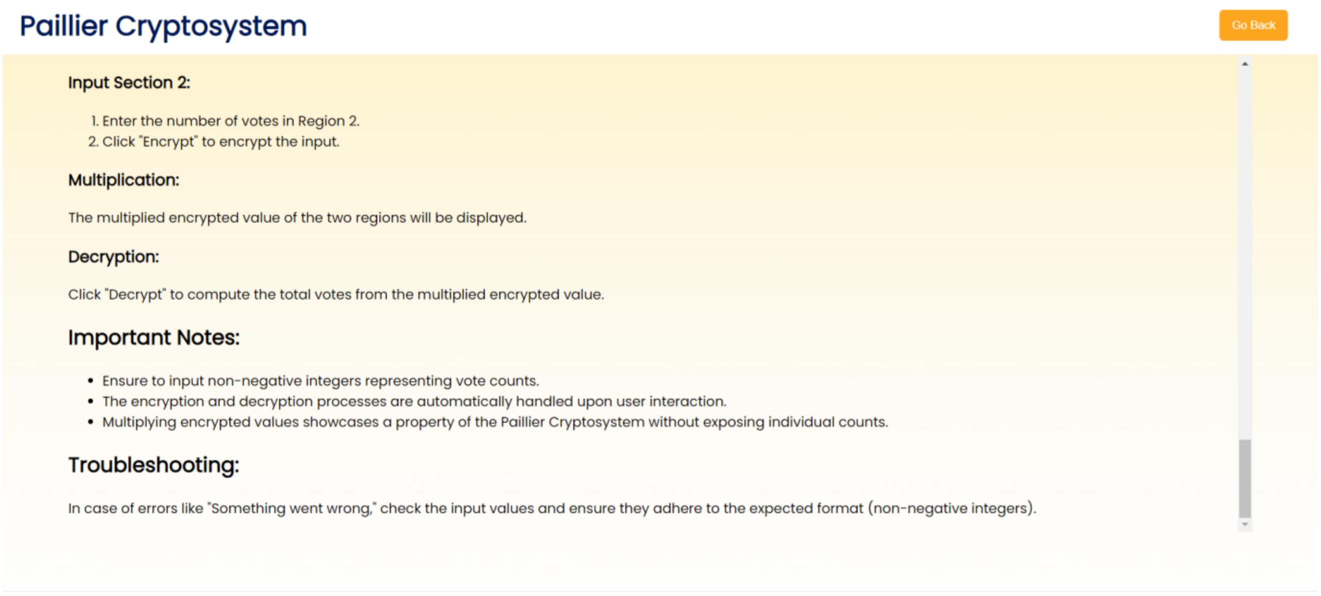
1. Enter the number of votes in Region 1.
2. Click "Encrypt" to encrypt the input.

Input Section 2:

1. Enter the number of votes in Region 2.
2. Click "Encrypt" to encrypt the input.

Multiplication:

Figure 14 User – manual continued



Paillier Cryptosystem

Input Section 2:

1. Enter the number of votes in Region 2.
2. Click "Encrypt" to encrypt the input.

Multiplication:

The multiplied encrypted value of the two regions will be displayed.

Decryption:

Click "Decrypt" to compute the total votes from the multiplied encrypted value.

Important Notes:

- Ensure to input non-negative integers representing vote counts.
- The encryption and decryption processes are automatically handled upon user interaction.
- Multiplying encrypted values showcases a property of the Paillier Cryptosystem without exposing individual counts.

Troubleshooting:

In case of errors like "Something went wrong," check the input values and ensure they adhere to the expected format (non-negative integers).

Figure 15 User – manual continued