#CNS (20CP320P)

Name: Jatin Prajapati

Roll No: 21BCP452D

Branch: Computer

Semester: 6th

Division: 5th (G-10)

PANDIT DEENDAYAL ENERGY UNIVERSITY

COMPUTER SCIENCE AND ENGINEERING DEPARTMENT

PANDIT DEENDAYAL ENERGY UNIVERSITY

A RESERVOIR OF KNOWLEDGE

CERTIFICATE

This is to certify that **Mr. JATIN RAKESHBHAI PRAJAPATI** Enrolment number **21BCP452D** of 6th Semester Degree course in **Computer Science and Engineering** has satisfactorily prepared and presented his Term Work in **Cryptography and network security lab (20CP320P)** within four walls of the laboratory of this Institute during **JANUARY 2024** to **APRIL 2024.**

Date of Submission:________________ Submitted To:________________

#INDEX

Practical 1

➢ Implementation of SDES algorithm in C language.

Keygen.h

```c
// HEADER FILE FOR KEY GENERATION

#include <stdio.h>
#include <math.h>
#include <string.h>

void permuteKey(char key[], char permutedKey[])
{
    int i;
    int permutationTable[10] = {3, 5, 2, 7, 4, 10, 1, 9, 8, 6};

    for (i = 0; i < 10; i++)
    {
        permutedKey[i] = key[permutationTable[i] - 1];
    }
}

void generateLeftRightKey(char key[], char leftKey[], char rightKey[])
{
    int i;

    for (i = 0; i < 5; i++)
    {
        leftKey[i] = key[i];
    }

    for (i = 5; i < 10; i++)
    {
        rightKey[i - 5] = key[i];
    }
}

void leftShift(char key[], int shift)
{
    int i;
    char tempKey[5];

    strcpy(tempKey, key);

    for (i = 0; i < 5; i++)
    {
        key[i] = tempKey[(i + shift) % 5];
    }
}

void p8(char key[], char key1[])
{
    int i;
    int permutationTable[8] = {6, 3, 7, 4, 8, 5, 10, 9};
    for (i = 0; i < 8; i++)
    {
        key1[i] = key[permutationTable[i] - 1];
    }

    key1[i] = '\0';
}

void generateKey1(char leftKey[], char rightKey[], char key1[])
{
    int i;
    char tempKey[10];

    leftShift(leftKey, 1);
    leftShift(rightKey, 1);

    for (i = 0; i < 5; i++)
    {
        tempKey[i] = leftKey[i];
    }

    for (i = 5; i < 10; i++)
    {
        tempKey[i] = rightKey[i - 5];
    }

    p8(tempKey, key1);
}

void generateKey2(char leftKey[], char rightKey[], char key2[])
{
    int i;
    char tempKey[10];

    leftShift(leftKey, 2);
    leftShift(rightKey, 2);

    for (i = 0; i < 5; i++)
    {
        tempKey[i] = leftKey[i];
    }

    for (i = 5; i < 10; i++)
    {
        tempKey[i] = rightKey[i - 5];
    }

    p8(tempKey, key2);
}

void generateKeys(char key[], char key1[], char key2[])
{
    char leftKey[5], rightKey[5], permutedKey[10];
    permuteKey(key, permutedKey);
    generateLeftRightKey(permutedKey, leftKey, rightKey);
    generateKey1(leftKey, rightKey, key1);
    generateKey2(leftKey, rightKey, key2);
}
```

Encrypt.h

```
// HEADER FILE FOR ENCRYPTION

#include <stdio.h>
#include <math.h>
#include <string.h>

void charToBinary(char input, char *output)
{
    int i;
    if (input == 0) {
        for (i = 0; i < 8; i++)
        {
            output[i] = '0';
        }
    }
    else {
        for (i = 8; i > 0; i--)
        {
            if (input % 2 == 0)
            {
                output[i - 1] = '0';
            }
            else
            {
                output[i - 1] = '1';
            }
            input = input / 2;
        }
    }
    output[8] = '\0';
}

void binaryToChar(char *input, char *output)
{
    int i;
    *output = 0;
    for (i = 0; i < 8; i++)
    {
        *output = *output + (input[i] - '0') * pow(2, 7 - i);
    }
}

void ip8(char *input, char *output)
{
    int i;
```

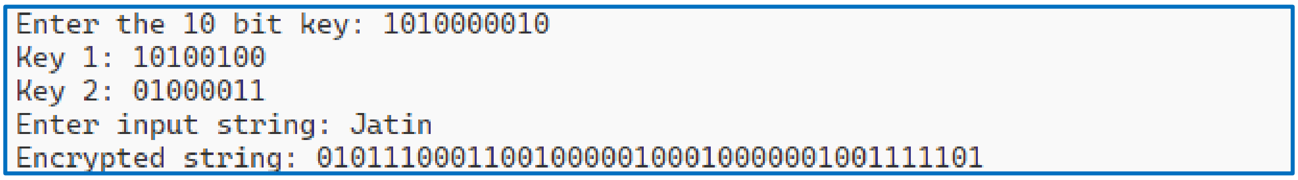
```
        int ip[] = {2, 6, 3, 1, 4, 8, 5, 7};
        for (i = 0; i < 8; i++)
        {
            output[i] = input[ip[i] - 1];
        }

        output[8] = '\0';
    }

    void devide(char *input, char *left, char *right)
    {
        int i;
        for (i = 0; i < 4; i++)
        {
            left[i] = input[i];
            right[i] = input[i + 4];
        }

        left[4] = '\0';
        right[4] = '\0';
    }

    void ep(char *input, char *output)
    {
        int i;
        int ep[] = {4, 1, 2, 3, 2, 3, 4, 1};
        for (i = 0; i < 8; i++)
        {
            output[i] = input[ep[i] - 1];
        }

        output[8] = '\0';
    }

    void xor8bit(char *input1, char *input2, char *output)
    {
        int i;
        for (i = 0; i < 8; i++)
        {
            output[i] = (input1[i] - '0') ^ (input2[i] - '0') + '0';
        }

        output[8] = '\0';
    }

    void sBox(char *input, char *output)
    {
        int s0[4][4] = {{1, 0, 3, 2},
                        {3, 2, 1, 0},
                        {0, 2, 1, 3},
                        {3, 1, 3, 2}};

        int s1[4][4] = {{0, 1, 2, 3},
                        {2, 0, 1, 3},
                        {3, 0, 1, 0},
                        {2, 1, 0, 3}};

        int i = (input[0] - '0') * 2 + (input[3] - '0');
        int j = (input[1] - '0') * 2 + (input[2] - '0');
        int k = (input[4] - '0') * 2 + (input[7] - '0');
        int l = (input[5] - '0') * 2 + (input[6] - '0');

        output[0] = s0[i][j] / 2 + '0';
        output[1] = s0[i][j] % 2 + '0';
        output[2] = s1[k][l] / 2 + '0';
        output[3] = s1[k][l] % 2 + '0';

        output[4] = '\0';
    }

    void p4(char *input, char *output)
    {
        int i;
        int p[] = {2, 4, 3, 1};
        for (i = 0; i < 4; i++)
        {
            output[i] = input[p[i] - 1];
        }

        output[4] = '\0';
    }

    void xor4bit(char *input1, char *input2, char *output)
    {
        int i;
        for (i = 0; i < 4; i++)
        {
            output[i] = (input1[i] - '0') ^ (input2[i] - '0') + '0';
        }

        output[4] = '\0';
    }

    void combine(char *input1, char *input2, char *output)
    {
        int i;
        for (i = 0; i < 4; i++)
        {
            output[i] = input1[i];
            output[i + 4] = input2[i];
        }

        output[8] = '\0';
    }

    void swap(char *input, char *output)
    {
        int i;
        char temp;
        for (i = 0; i < 4; i++)
        {
            temp = input[i];
            input[i] = output[i];
            output[i] = temp;
        }

        output[4] = '\0';
    }

    void ip8Inverse(char *input, char *output)
    {
        int i;
        int ip[] = {4, 1, 3, 5, 7, 2, 8, 6};
        for (i = 0; i < 8; i++)
        {
            output[i] = input[ip[i] - 1];
        }

        output[8] = '\0';
    }

    void encryptForK(char *bin, char *key, char *output)
    {
        // Step 2: IP8
        char ip8Output[9];
        ip8(bin, ip8Output);

        // Step 3: Devide 4n4
        char ip8Left[5], ip8Right[5];
        devide(ip8Output, ip8Left, ip8Right);

        // Step 4: EP
        char epOutput[9];
        ep(ip8Right, epOutput);

        // Step 5: XOR 8-bit
        char xorOutput[9];
        xor8bit(epOutput, key, xorOutput);

        // Step 6 and 7: S-Box
        char sBoxOutput[5];
        sBox(xorOutput, sBoxOutput);

        // Step 8: P4
        char p4Output[5];
        p4(sBoxOutput, p4Output);

        // Step 9:
        char xorOutput2[5];
        xor4bit(p4Output, ip8Right, xorOutput2);

        // Step 10: Combine S3
        char combineOutput[9];
        combine(ip8Left, xorOutput2, combineOutput);

        // Step 11: Devide 4n4
        char combineLeft[5], combineRight[5];
        devide(combineOutput, combineLeft, combineRight);

        // Step 12: Swap
        swap(combineLeft, combineRight);

        // Step 13: Combine step 12 and generate output
        char combineOutput2[9];
        combine(combineLeft, combineRight, combineOutput2);

        // Copy the combined output to the final output
        strcpy(output, combineOutput2);
    }

    void encrypt(char c, char *k1, char *k2, char *output)
    {
        // Step 1: Char to Binary
        char bin[9];
        charToBinary(c, bin);
        char output1[9], output2[9], output3[9];

        encryptForK(bin, k1, output1);
        encryptForK(output1, k2, output2);

        // Final inverse permutation
        ip8Inverse(output2, output3);

        output3[8] = '\0';

        // Copy the final output to the provided output buffer
        strcpy(output, output3);
    }
```

SDES.c

```
// SDES implementation in C
// REFERENCE: https://www.c-sharpcorner.com/article/s-des-or-simplified-data-encryption-standard/

#include <stdio.h>
#include <string.h>
#include "keygen.h"
#include "encrypt.h"

char key[10];
char key1[9];
char key2[9];

char inputString[100];
char output[9];
```

```
    char outputBits[900];


    void main()
    {
        int i;
        printf("Enter the 10 bit key: ");
        scanf("%s", &key);

        generateKeys(key, key1, key2);

        printf("Key 1: %s\n", key1);
        printf("Key 2: %s\n", key2);

        printf("Enter input string: ");
        scanf("%s", &inputString);

        int len = strlen(inputString);

        printf("Encrypted string: ");

        for (i = 0; i < len; i++)
        {
            encrypt(inputString[i], key1, key2, output);
            for (int j = 0; j < 8; j++)
            {
                outputBits[i * 8 + j] = output[j];
            }
        }

        printf("%s\n", outputBits);
    }
```

OUTPUT



```
Enter the 10 bit key: 1010000010
Key 1: 10100100
Key 2: 01000011
Enter input string: Jatin
Encrypted string: 0101110001100100000100010000001001111101
```

Practical 2

Application of Brute Force Attack on S-DES

Keygen.h

```
// HEADER FILE FOR KEY GENERATION

#include <stdio.h>
#include <math.h>
#include <string.h>

void permuteKey(char key[], char permutedKey[])
{
    int i;
    int permutationTable[10] = {3, 5, 2, 7, 4, 10, 1, 9, 8, 6};

    for (i = 0; i < 10; i++)
    {
        permutedKey[i] = key[permutationTable[i] - 1];
    }
}

void generateLeftRightKey(char key[], char leftKey[], char rightKey[])
{
    int i;

    for (i = 0; i < 5; i++)
    {
        leftKey[i] = key[i];
    }

    for (i = 5; i < 10; i++)
    {
        rightKey[i - 5] = key[i];
    }
}

void leftShift(char key[], int shift)
{
    int i;
    char tempKey[5];

    strcpy(tempKey, key);

    for (i = 0; i < 5; i++)
    {
        key[i] = tempKey[(i + shift) % 5];
    }
}

void p8(char key[], char key1[])
{
    int i;
    int permutationTable[8] = {6, 3, 7, 4, 8, 5, 10, 9};
    for (i = 0; i < 8; i++)
    {
        key1[i] = key[permutationTable[i] - 1];
    }

    key1[i] = '\0';
}

void generateKey1(char leftKey[], char rightKey[], char key1[])
{
    int i;
    char tempKey[10];

    leftShift(leftKey, 1);
    leftShift(rightKey, 1);

    for (i = 0; i < 5; i++)
    {
        tempKey[i] = leftKey[i];
    }

    for (i = 5; i < 10; i++)
    {
        tempKey[i] = rightKey[i - 5];
    }

    p8(tempKey, key1);
}

void generateKey2(char leftKey[], char rightKey[], char key2[])
{
    int i;
    char tempKey[10];

    leftShift(leftKey, 2);
    leftShift(rightKey, 2);

    for (i = 0; i < 5; i++)
    {
        tempKey[i] = leftKey[i];
    }

    for (i = 5; i < 10; i++)
    {
        tempKey[i] = rightKey[i - 5];
    }

    p8(tempKey, key2);
}

void generateKeys(char key[], char key1[], char key2[])
{
    char leftKey[5], rightKey[5], permutedKey[10];
    permuteKey(key, permutedKey);
    generateLeftRightKey(permutedKey, leftKey, rightKey);
    generateKey1(leftKey, rightKey, key1);
    generateKey2(leftKey, rightKey, key2);
}
```

Encrypt.h

```
// HEADER FILE FOR ENCRYPTION

#include <stdio.h>
#include <math.h>
#include <string.h>

void charToBinary(char input, char *output)
{
    int i;
    if (input == 0) {
        for (i = 0; i < 8; i++)
        {
            output[i] = '0';
        }
    }
    else {
        for (i = 8; i > 0; i--)
        {
            if (input % 2 == 0)
            {
                output[i - 1] = '0';
            }
            else
            {
                output[i - 1] = '1';
            }
            input = input / 2;
        }
    }
    output[8] = '\0';
}

void binaryToChar(char *input, char *output)
{
    int i;
    *output = 0;
    for (i = 0; i < 8; i++)
    {
        *output = *output + (input[i] - '0') * pow(2, 7 - i);
    }
}

void ip8(char *input, char *output)
{
    int i;
```

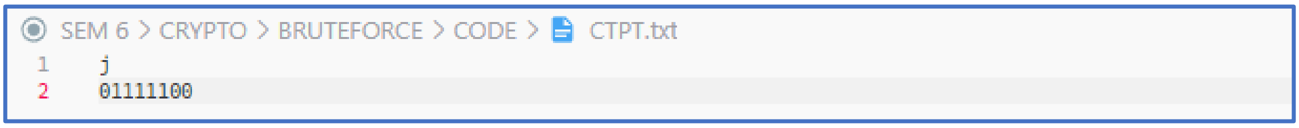
```
        int ip[] = {2, 6, 3, 1, 4, 8, 5, 7};
        for (i = 0; i < 8; i++)
        {
            output[i] = input[ip[i] - 1];
        }

        output[8] = '\0';
    }

    void devide(char *input, char *left, char *right)
    {
        int i;
        for (i = 0; i < 4; i++)
        {
            left[i] = input[i];
            right[i] = input[i + 4];
        }

        left[4] = '\0';
        right[4] = '\0';
    }

    void ep(char *input, char *output)
    {
        int i;
        int ep[] = {4, 1, 2, 3, 2, 3, 4, 1};
        for (i = 0; i < 8; i++)
        {
            output[i] = input[ep[i] - 1];
        }

        output[8] = '\0';
    }

    void xor8bit(char *input1, char *input2, char *output)
    {
        int i;
        for (i = 0; i < 8; i++)
        {
            output[i] = (input1[i] - '0') ^ (input2[i] - '0') + '0';
        }

        output[8] = '\0';
    }

    void sBox(char *input, char *output)
    {
        int s0[4][4] = {{1, 0, 3, 2},
                        {3, 2, 1, 0},
                        {0, 2, 1, 3},
                        {3, 1, 3, 2}};

        int s1[4][4] = {{0, 1, 2, 3},
                        {2, 0, 1, 3},
                        {3, 0, 1, 0},
                        {2, 1, 0, 3}};

        int i = (input[0] - '0') * 2 + (input[3] - '0');
        int j = (input[1] - '0') * 2 + (input[2] - '0');
        int k = (input[4] - '0') * 2 + (input[7] - '0');
        int l = (input[5] - '0') * 2 + (input[6] - '0');

        output[0] = s0[i][j] / 2 + '0';
        output[1] = s0[i][j] % 2 + '0';
        output[2] = s1[k][l] / 2 + '0';
        output[3] = s1[k][l] % 2 + '0';

        output[4] = '\0';
    }

    void p4(char *input, char *output)
    {
        int i;
        int p[] = {2, 4, 3, 1};
        for (i = 0; i < 4; i++)
        {
            output[i] = input[p[i] - 1];
        }

        output[4] = '\0';
    }

    void xor4bit(char *input1, char *input2, char *output)
    {
        int i;
        for (i = 0; i < 4; i++)
        {
            output[i] = (input1[i] - '0') ^ (input2[i] - '0') + '0';
        }

        output[4] = '\0';
    }

    void combine(char *input1, char *input2, char *output)
    {
        int i;
        for (i = 0; i < 4; i++)
        {
            output[i] = input1[i];
            output[i + 4] = input2[i];
        }

        output[8] = '\0';
    }

    void swap(char *input, char *output)
    {
        int i;
        char temp;
```

```c
    for (i = 0; i < 4; i++)
    {
        temp = input[i];
        input[i] = output[i];
        output[i] = temp;
    }

    output[4] = '\0';
}

void ip8Inverse(char *input, char *output)
{
    int i;
    int ip[] = {4, 1, 3, 5, 7, 2, 8, 6};
    for (i = 0; i < 8; i++)
    {
        output[i] = input[ip[i] - 1];
    }

    output[8] = '\0';
}

void encryptForK(char *bin, char *key, char *output)
{
    // Step 2: IP8
    char ip8Output[9];
    ip8(bin, ip8Output);

    // Step 3: Devide 4n4
    char ip8Left[5], ip8Right[5];
    devide(ip8Output, ip8Left, ip8Right);

    // Step 4: EP
    char epOutput[9];
    ep(ip8Right, epOutput);

    // Step 5: XOR 8-bit
    char xorOutput[9];
    xor8bit(epOutput, key, xorOutput);

    // Step 6 and 7: S-Box
    char sBoxOutput[5];
    sBox(xorOutput, sBoxOutput);

    // Step 8: P4
    char p4Output[5];
    p4(sBoxOutput, p4Output);

    // Step 9:
    char xorOutput2[5];
    xor4bit(p4Output, ip8Right, xorOutput2);

    // Step 10: Combine S3
    char combineOutput[9];
    combine(ip8Left, xorOutput2, combineOutput);

    // Step 11: Devide 4n4
    char combineLeft[5], combineRight[5];
    devide(combineOutput, combineLeft, combineRight);

    // Step 12: Swap
    swap(combineLeft, combineRight);

    // Step 13: Combine step 12 and generate output
    char combineOutput2[9];
    combine(combineLeft, combineRight, combineOutput2);

    // Copy the combined output to the final output
    strcpy(output, combineOutput2);
}

void encrypt(char c, char *k1, char *k2, char *output)
{
    // Step 1: Char to Binary
    char bin[9];
    charToBinary(c, bin);
    char output1[9], output2[9], output3[9];

    encryptForK(bin, k1, output1);
    encryptForK(output1, k2, output2);

    // Final inverse permutation
    ip8Inverse(output2, output3);

    output3[8] = '\0';

    // Copy the final output to the provided output buffer
    strcpy(output, output3);
}
```

BRUTEFORCE.c

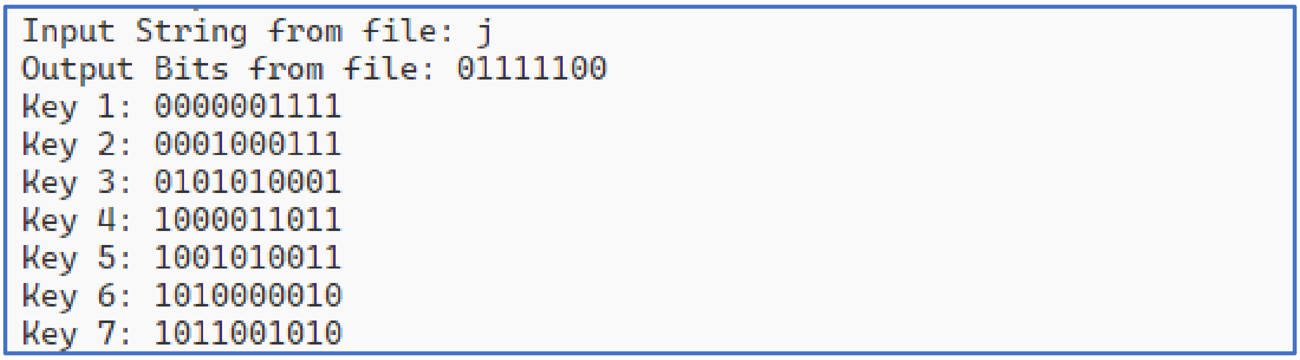
```c
// Implementation of brute force attack on the SDES algorithm

#include <stdio.h>
#include <string.h>
#include <math.h>
#include "keygen.h"
#include "encrypt.h"

void numToKey(int num, char *key)
{
    // Initialize the key with all bits set to '0'
    for (int i = 0; i < 10; i++)
    {
        key[i] = '0';
    }
    // Convert the number to binary and store it in the key
    for (int i = 9; i >= 0; i--)
    {
        key[i] = (num % 2) + '0';
        num = num / 2;
    }

    key[10] = '\0';
}

int main()
{
    FILE *filePointer;
    char inputStringFromFile[100];
    char outputBitsFromFile[900];
    char key[11], key1[9], key2[9];
    char output[8];
    char outputBits[900];

    int count = 1;

    filePointer = fopen("CTPT.txt", "r");

    if (filePointer == NULL)
    {
        printf("Error: Unable to open the file!\n");
        return 1; // Exit with error code
    }

    fscanf(filePointer, "%s", inputStringFromFile);
    fscanf(filePointer, "%s", outputBitsFromFile);

    printf("Input String from file: %s\n", inputStringFromFile);
    printf("Output Bits from file: %s\n", outputBitsFromFile);

    for (int i = 0; i < 1024; i++)
    {
        numToKey(i, key);

        generateKeys(key, key1, key2);

        int len = strlen(inputStringFromFile);

        for (int j = 0; j < len; j++)
        {
            encrypt(inputStringFromFile[j], key1, key2, output);
            for (int k = 0; k < 8; k++)
            {
                outputBits[j * 8 + k] = output[k];
            }
        }

        outputBits[len * 8] = '\0';
        if (strcmp(outputBits, outputBitsFromFile) == 0)
        {
            printf("Key %d: %s\n",count++, key);
        }
    }

    fclose(filePointer); // Don't forget to close the file

    return 0;
}
```

CTPT.txt



```
j
01111100
```

OUTPUT



```
Input String from file: j
Output Bits from file: 01111100
Key 1: 0000001111
Key 2: 0001000111
Key 3: 0101010001
Key 4: 1000011011
Key 5: 1001010011
Key 6: 1010000010
Key 7: 1011001010
```

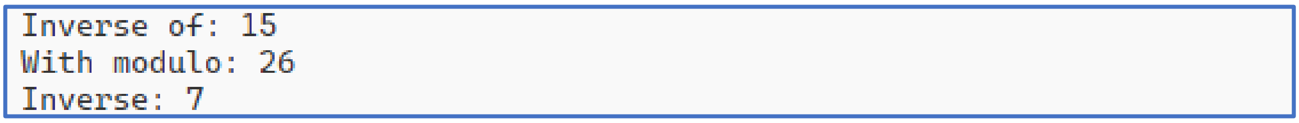
Practical 3

➢ Implementation of Extended Euclidean Algorithm

ExtendedEuclidean.c

```c
#include <stdio.h>

int t1 = 0, t2 = 1, q, r, t;

int extendedEuclidean(int a, int b)
{
    while (b != 0)
    {
        q = a / b;
        r = a % b;
        t = t1 - t2 * q;
        t1 = t2;
        t2 = t;
        a = b;
        b = r;
    }

    return a != 1 ? 0 : t1;
}

int main()
{

    int a, b, result;
    printf("Inverse of: ");
    scanf("%d", &a);
    printf("With modulo: ");
    scanf("%d", &b);

    result = extendedEuclidean(b, a);

    if (result == 0)
    {
        printf("Inverse does not exist\n");
        return 0;
    }

    else if (result < 0)
    {
        result += b;
    }

    printf("Inverse: %d\n", result);
    return 0;
}
```

OUTPUT



```
Inverse of: 15
With modulo: 26
Inverse: 7
```

Practical 4

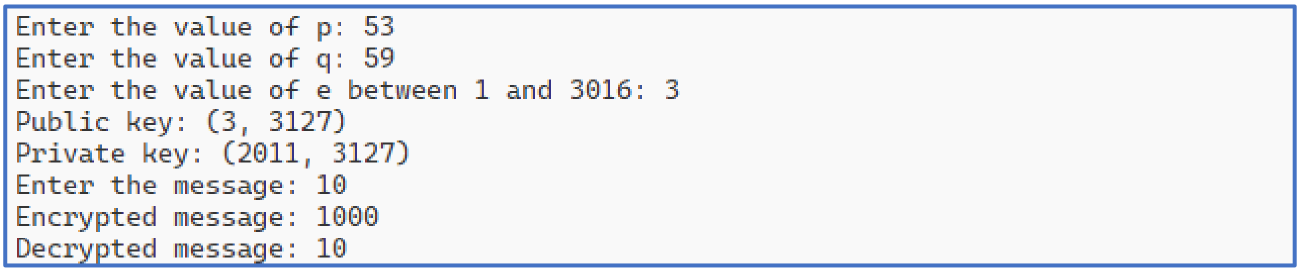
➢ Implementation of RSA with all required algorithms

rsa.c

```c
#include <stdio.h>
#include <math.h>

int isPrime(int n)
{
    int i;
    for (i = 2; i < sqrt(n); i++)
    {
        if (n % i == 0)
        {
            return 0;
        }
    }
    return 1;
}

int gcd(int a, int b)
{
    if (b == 0)
    {
        return a;
    }

    return gcd(b, a % b);
}

int extendedEuclidean(int a, int b)
{
    int t1 = 0, t2 = 1, q, r, t;
    while (b != 0)
    {
        q = a / b;
        r = a % b;
        t = t1 - t2 * q;
        t1 = t2;
        t2 = t;
        a = b;
        b = r;
    }

    return a != 1 ? 0 : t1;
}

int fastExponentiation(int a, int b, int n)
{
    int bitCount = (int)ceil(log2(b)); // Cast log2 result to int

    int aBinary[bitCount];
    int modValues[bitCount];
    int i;
    int result = 1; // Initialize result to 1

    for (i = bitCount - 1; i >= 0; i--)
    {
        aBinary[i] = b % 2;
        b = b / 2;
    }

    for (i = bitCount - 1; i >= 0; i--)
    {
        if (i == bitCount - 1) // Change i == 0 to i == bitCount - 1
        {
            modValues[i] = a % n;
        }
        else
        {
            modValues[i] = (modValues[i + 1] * modValues[i + 1]) % n; // Change i - 1 to i + 1
        }
    }

    for (i = 0; i < bitCount; i++)
    {
        if (aBinary[i] == 1)
        {
            result = (result * modValues[i]) % n; // Add modulo operation here
        }
    }
    return result;
}

int main()
{

    int p, q, e, d, n, phi;

    int m, c;

    printf("Enter the value of p: ");
    scanf("%d", &p);

    if (isPrime(p) == 0)
    {
        printf("p is not prime\n");
        return 0;
    }

    printf("Enter the value of q: ");
    scanf("%d", &q);

    if (isPrime(q) == 0)
    {
        printf("q is not prime\n");
```

```c
        return 0;
    }

    n = p * q;

    phi = (p - 1) * (q - 1);

    printf("Enter the value of e between 1 and %d: ", phi);
    scanf("%d", &e);

    if (e < 1 || e > phi)
    {
        printf("Invalid value of e\n");
        return 0;
    }

    if (gcd(e, phi) != 1)
    {
        printf("Invalid value of e\n");
        return 0;
    }

    d = extendedEuclidean(phi, e);

    if (d < 0)
    {
        d += phi;
    }

    printf("Public key: (%d, %d)\n", e, n);
    printf("Private key: (%d, %d)\n", d, n);

    printf("Enter the message: ");
    scanf("%d", &m);

    c = fastExponentiation(m, e, n);

    printf("Encrypted message: %d\n", c);

    m = fastExponentiation(c, d, n);

    printf("Decrypted message: %d\n", m);

    return 0;
}
```

OUTPUT



```
Enter the value of p: 53
Enter the value of q: 59
Enter the value of e between 1 and 3016: 3
Public key: (3, 3127)
Private key: (2011, 3127)
Enter the message: 10
Encrypted message: 1000
Decrypted message: 10
```

Practical 5

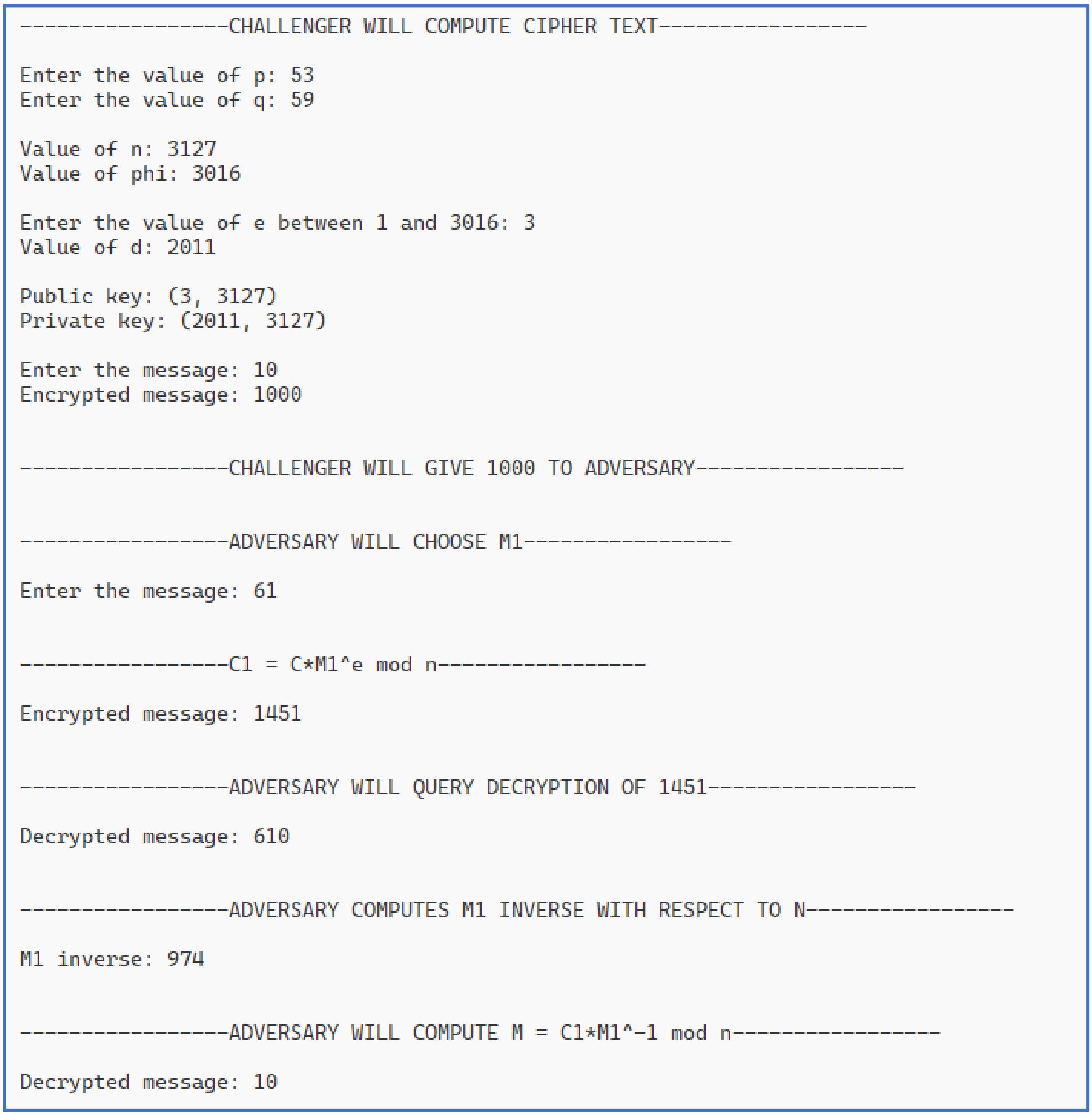
Demonstration of CCA2 attack on RSA

cca2.c

```c
// CCA2 attak on RSA

#include <stdio.h>
#include <math.h>

int isPrime(int n)
{
    int i;
    for (i = 2; i < sqrt(n); i++)
    {
        if (n % i == 0)
        {
            return 0;
        }
    }
    return 1;
}

int gcd(int a, int b)
{
    if (b == 0)
    {
        return a;
    }

    return gcd(b, a % b);
}

int extendedEuclidean(int a, int b)
{
    int t1 = 0, t2 = 1, q, r, t;
    while (b != 0)
    {
        q = a / b;
        r = a % b;
        t = t1 - t2 * q;
        t1 = t2;
        t2 = t;
        a = b;
        b = r;
    }

    return a != 1 ? 0 : t1;
}

int fastExponentiation(int a, int b, int n)
{
    int bitCount = (int)ceil(log2(b)); // Cast log2 result to int

    int aBinary[bitCount];
    int modValues[bitCount];

    int i;
    int result = 1; // Initialize result to 1

    for (i = bitCount - 1; i >= 0; i--)
    {
        aBinary[i] = b % 2;
        b = b / 2;
    }

    for (i = bitCount - 1; i >= 0; i--)
    {
        if (i == bitCount - 1) // Change i == 0 to i == bitCount - 1
        {
            modValues[i] = a % n;
        }
        else
        {
            modValues[i] = (modValues[i + 1] * modValues[i + 1]) % n; //
Change i - 1 to i + 1
        }
    }

    for (i = 0; i < bitCount; i++)
    {
        if (aBinary[i] == 1)
        {
            result = (result * modValues[i]) % n; // Add modulo operation
here
        }
    }
    return result;
}

int main()
{

    int p, q, e, d, n, phi;

    int m, c;

    int m1, c1, decOfC1, mDec;

    printf("\n-----------------CHALLENGER WILL COMPUTE CIPHER TEXT-----------
-------\n\n");

    do
    {
        printf("Enter the value of p: ");
        scanf("%d", &p);
    } while (!isPrime(p));

    do
    {
        printf("Enter the value of q: ");
        scanf("%d", &q);
    } while (!isPrime(q));

    n = p * q;

    printf("\nValue of n: %d\n", n);

    phi = (p - 1) * (q - 1);

    printf("Value of phi: %d\n", phi);

    do
    {
        printf("\nEnter the value of e between 1 and %d: ", phi);
        scanf("%d", &e);
    } while (e < 1 || e > phi || gcd(e, phi) != 1);

    d = extendedEuclidean(phi, e);

    if (d < 0)
    {
        d += phi;
    }

    printf("Value of d: %d\n", d);

    printf("\nPublic key: (%d, %d)\n", e, n);
    printf("Private key: (%d, %d)\n", d, n);

    printf("\nEnter the message: ");
    scanf("%d", &m);

    c = fastExponentiation(m, e, n);

    printf("Encrypted message: %d\n", c);

    printf("\n\n-----------------CHALLENGER WILL GIVE %d TO ADVERSARY--------
---------\n\n", c);

    printf("\n-----------------ADVERSARY WILL CHOOSE M1-----------------
\n\n");

    printf("Enter the message: ");
    scanf("%d", &m1);
    printf("\n");

    printf("\n-----------------C1 = C*M1^e mod n-----------------\n\n");

    c1 = (c * fastExponentiation(m1, e, n)) % n;

    printf("Encrypted message: %d\n", c1);

    printf("\n\n-----------------ADVERSARY WILL QUERY DECRYPTION OF %d-------
----------\n\n", c1);

    decOfC1 = fastExponentiation(c1, d, n);
```

```c
    printf("Decrypted message: %d\n", decOfC1);

    printf("\n\n-----------------ADVERSARY COMPUTES M1 INVERSE WITH RESPECT
TO N-----------------\n\n");

    int m1Inverse = extendedEuclidean(n, m1);

    if (m1Inverse < 0)
    {
        m1Inverse += n;
    }

    printf("M1 inverse: %d\n", m1Inverse);

    printf("\n\n-----------------ADVERSARY WILL COMPUTE M = C1*M1^-1 mod n---
--------------\n\n");

    mDec = (decOfC1 * m1Inverse) % n;

    printf("Decrypted message: %d\n\n", mDec);

    if (mDec == m)
    {
        printf("Adversary has successfully decrypted the message\n");
    }
    else
    {
        printf("Adversary has failed to decrypt the message\n");
    }

    return 0;
}
```

OUTPUT



```
-----------------CHALLENGER WILL COMPUTE CIPHER TEXT-----------------

Enter the value of p: 53
Enter the value of q: 59

Value of n: 3127
Value of phi: 3016

Enter the value of e between 1 and 3016: 3
Value of d: 2011

Public key: (3, 3127)
Private key: (2011, 3127)

Enter the message: 10
Encrypted message: 1000


-----------------CHALLENGER WILL GIVE 1000 TO ADVERSARY-----------------


-----------------ADVERSARY WILL CHOOSE M1-----------------

Enter the message: 61


-----------------C1 = C*M1^e mod n-----------------

Encrypted message: 1451


-----------------ADVERSARY WILL QUERY DECRYPTION OF 1451-----------------

Decrypted message: 610


-----------------ADVERSARY COMPUTES M1 INVERSE WITH RESPECT TO N-----------------

M1 inverse: 974


-----------------ADVERSARY WILL COMPUTE M = C1*M1^-1 mod n-----------------

Decrypted message: 10
```

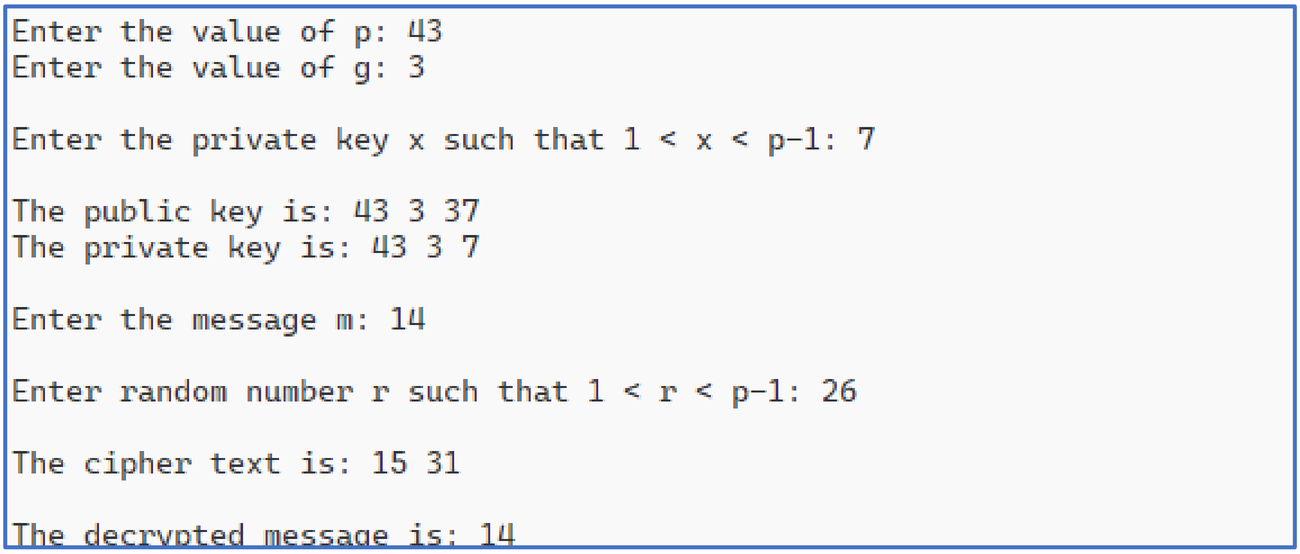
Practical 6

➢ Implementation of Elgamal Algorithm for Encryption

elgamal.c

```c
#include <stdio.h>
#include <math.h>

int fastExponentiation(int a, int b, int n)
{
    int bitCount = (int)ceil(log2(b)); // Cast log2 result to int

    int aBinary[bitCount];
    int modValues[bitCount];

    int i;
    int result = 1; // Initialize result to 1

    for (i = bitCount - 1; i >= 0; i--)
    {
        aBinary[i] = b % 2;
        b = b / 2;
    }

    for (i = bitCount - 1; i >= 0; i--)
    {
        if (i == bitCount - 1) // Change i == 0 to i == bitCount - 1
        {
            modValues[i] = a % n;
        }
        else
        {
            modValues[i] = (modValues[i + 1] * modValues[i + 1]) % n; //
Change i - 1 to i + 1
        }
    }

    for (i = 0; i < bitCount; i++)
    {
        if (aBinary[i] == 1)
        {
            result = (result * modValues[i]) % n; // Add modulo operation
here
        }
    }
    return result;
}

void main()
{
    int p, g, x, y;
    int m, r, c1, c2, dec_m;

    printf("Enter the value of p: ");
    scanf("%d", &p);
    printf("Enter the value of g: ");
    scanf("%d", &g);

    printf("\nEnter the private key x such that 1 < x < p-1: ");
    scanf("%d", &x);

    y = (int)pow(g, x) % p;

    printf("\nThe public key is: %d %d %d \n", p, g, y);
    printf("The private key is: %d %d %d \n", p, g, x);

    printf("\nEnter the message m: ");
    scanf("%d", &m);

    printf("\nEnter random number r such that 1 < r < p-1: ");
    scanf("%d", &r);

    c1 = fastExponentiation(g, r, p);
    c2 = fastExponentiation(y, r, p) * m % p;

    printf("\nThe cipher text is: %d %d \n", c1, c2);

    dec_m = c2 * fastExponentiation(c1, p - 1 - x, p) % p;

    printf("\nThe decrypted message is: %d \n", dec_m);
}
```

OUTPUT



```
Enter the value of p: 43
Enter the value of g: 3

Enter the private key x such that 1 < x < p-1: 7

The public key is: 43 3 37
The private key is: 43 3 7

Enter the message m: 14

Enter random number r such that 1 < r < p-1: 26

The cipher text is: 15 31

The decrypted message is: 14
```

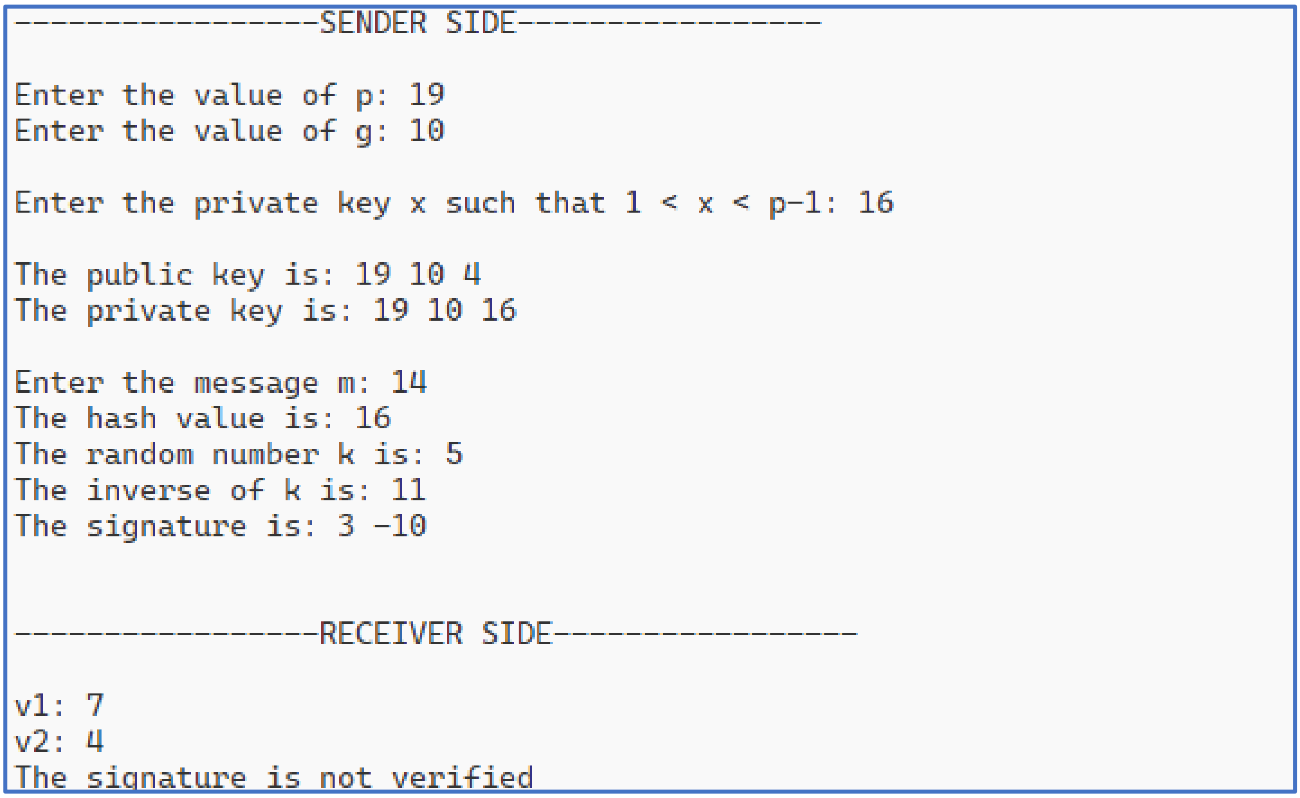
Practical 7

Implementation of Elgamal Algorithm for Digital Signature

Elgamal_digital_sign.c

```c
#include <stdio.h>
#include <math.h>

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

int gcd(int a, int b)
{
    if (b == 0)
    {
        return a;
    }

    return gcd(b, a % b);
}

int hashFunction(int m, int p)
{
    return m * m % (p - 1);
}

int randomK(int p)
{
    for (int i = 2; i < p - 1; i++)
    {
        if (gcd(i, p - 1) == 1)
        {
            return i;
        }
    }
}

int inverse(int a, int b)
{
    for (int i = 1; i < b; i++)
    {
        if ((a * i) % b == 1)
        {
            return i;
        }
    }
}

void main()
{
    int p, g, x, y;
    int m, hash, k, s1, s2, kInv;
    int v1, v2;

    printf("-----------------SENDER SIDE-----------------\n\n");

    printf("Enter the value of p: ");
    scanf("%d", &p);

    printf("Enter the value of g: ");
    scanf("%d", &g);

    printf("\nEnter the private key x such that 1 < x < p-1: ");
    scanf("%d", &x);

    y = fastExponentiation(g, x, p);

    printf("\nThe public key is: %d %d %d \n", p, g, y);
    printf("The private key is: %d %d %d \n", p, g, x);

    printf("\nEnter the message m: ");
    scanf("%d", &m);

    // hash = hashFunction(m, p);
    hash = m;

    k = randomK(p);

    printf("The hash value is: %d\n", hash);
    printf("The random number k is: %d\n", k);

    kInv = inverse(k, p - 1);

    printf("The inverse of k is: %d\n", kInv);

    s1 = fastExponentiation(g, k, p);
    s2 = kInv * (hash - x * s1) % (p - 1);

    printf("The signature is: %d %d\n", s1, s2);

    printf("\n\n-----------------RECEIVER SIDE-----------------\n\n");

    v1 = fastExponentiation(g, hash, p);
    v2 = (fastExponentiation(y, s1, p) * fastExponentiation(s1, s2, p)) % p;

    printf("v1: %d\n", v1);
    printf("v2: %d\n", v2);
    if (v1 == v2)
    {
        printf("The signature is verified\n");
    }
    else
    {
        printf("The signature is not verified\n");
    }
}
```

OUTPUT



```
-----------------SENDER SIDE-----------------

Enter the value of p: 19
Enter the value of g: 10

Enter the private key x such that 1 < x < p-1: 16

The public key is: 19 10 4
The private key is: 19 10 16

Enter the message m: 14
The hash value is: 16
The random number k is: 5
The inverse of k is: 11
The signature is: 3 -10


-----------------RECEIVER SIDE-----------------

v1: 7
v2: 4
The signature is not verified
```

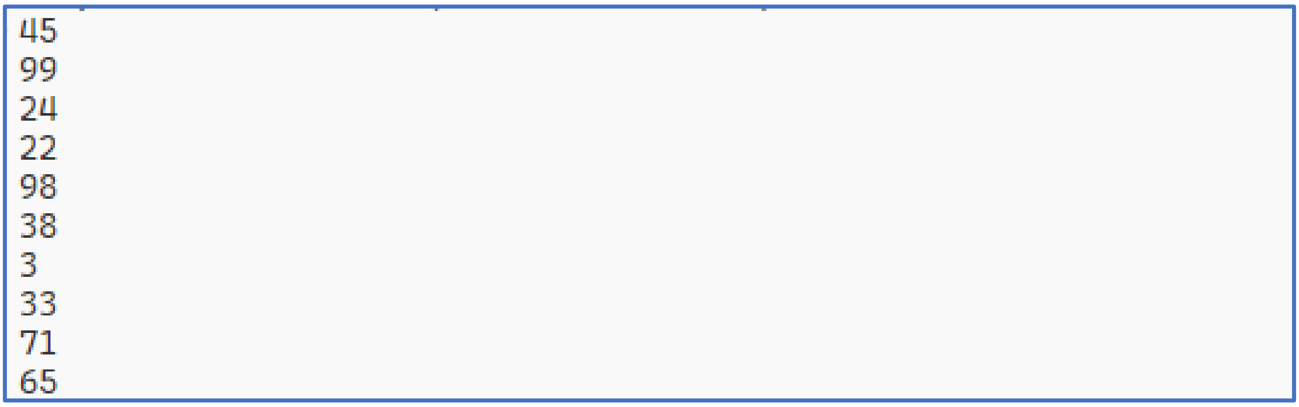
Practical 8

➢ Implementation of your own designed pseudorandom number generation

random.c

```c
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

unsigned long long int custom_rand(unsigned long long int seed)
{
    unsigned long long int multiplier = 6364136223846793005ULL;
    unsigned long long int increment = 1442695040888963407ULL;
    unsigned long long int modulus = 18446744073709551615ULL; // 2^64 - 1
(64-bit unsigned integer max value)

    // Calculate the next pseudo-random number using LCG algorithm
    seed = (multiplier * seed + increment) % modulus;

    return seed;
}

int main()
{
    unsigned long long int seed = 12345; // Initial seed value
    int i;

    int range_min = 0;
    int range_max = 100;

    // Use current time as seed for better randomness
    time_t t;
    time(&t);
    seed = t;

    // Generate and print 10 pseudo-random numbers within the specified range
    for (i = 0; i < 10; i++)
    {
        // Generate next pseudo-random number
        seed = custom_rand(seed);
        // map to the specified range
        printf("%d\n", range_min + (seed % (range_max - range_min + 1)));
    }

    return 0;
}
```

OUTPUT



```
45
99
24
22
98
38
3
33
71
65
```

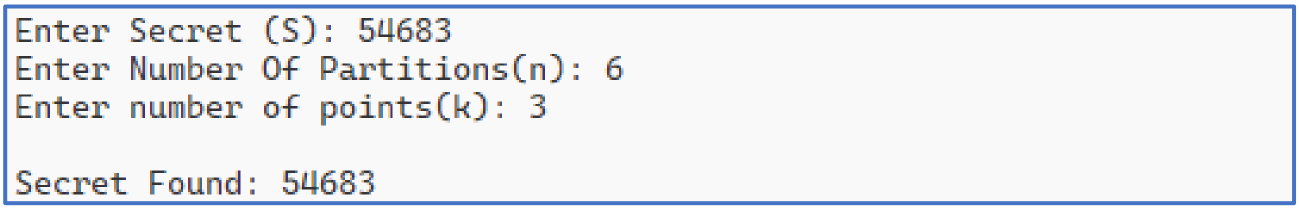
Practical 9

➢ Implement Shamir secret sharing scheme

shamir.c

```c
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <math.h>

int random_number(long x, long a, long c, int m)
{
    // Calculate the next pseudo-random number using Linear Congruential
Generator (LCG) algorithm
    long result = (x * a + c) % m;
    int res = (int)result;
    return res;
}

int main()
{

    int S, n, k;
    printf("Enter Secret (S): ");
    scanf("%d", &S);
    printf("Enter Number Of Partitions(n): ");
    scanf("%d", &n);
    printf("Enter number of points(k): ");
    scanf("%d", &k);

    // Generate a random polynomial of degree (k-1) with coefficients from
LCG algorithm
    int polynomial[k];
    polynomial[0] = S;
    for (int i = 1; i < k; i++)
    {
        polynomial[i] = random_number(time(0), 17, time(0) + 3, 967);
    }

    // Generate random points on the polynomial
    int points[n][2];
    for (int i = 1; i < n + 1; i++)
    {
        points[i - 1][0] = i;
        int sum = 0;
        for (int j = 0; j < k; j++)
        {
            sum += pow(points[i - 1][0], j) * polynomial[j];
        }
        points[i - 1][1] = sum;
    }

    // Copy random points for Lagrange interpolation
    int random_points[k][2];
    for (int i = 0; i < k; i++)
    {
        random_points[i][0] = points[i][0];
        random_points[i][1] = points[i][1];
    }

    // Lagrange Interpolation (for finding S, the term without any
polynomial)
    double l[k];
    int found_Secret = 0;
    for (int i = 0; i < k; i++)
    {
        l[i] = 1.0;
        for (int j = 0; j < k; j++)
        {
            if (j != i)
            {
                // Calculate the Lagrange interpolation coefficients
                l[i] *= (double)-1 * (random_points[j][0]) /
(random_points[i][0] - random_points[j][0]);
            }
        }
        // Calculate the secret by summing up the Lagrange coefficients
multiplied by the y-values of the points
        found_Secret += (int)(l[i]) * random_points[i][1];
    }

    printf("\nSecret Found: %d\n", found_Secret);
    return 0;
}
```

OUTPUT



```
Enter Secret (S): 54683
Enter Number Of Partitions(n): 6
Enter number of points(k): 3

Secret Found: 54683
```

Practical 10

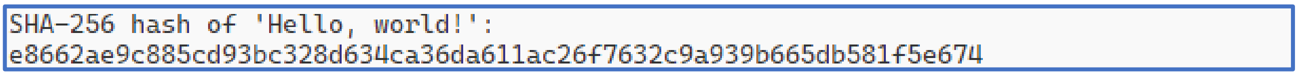
➢ Implementation of SHA 256 algorithm

Sha256.c

```c
#include <stdio.h>
#include <stdint.h>
#include <string.h>

// Rotate bits to the right
#define ROTR(x, n) (((x) >> (n)) | ((x) << (32 - (n))))

// SHA-256 Constants
const uint32_t K[64] = {
    0x428a2f98, 0x71374491, 0xb5c0fbcf, 0xe9b5dba5,
    0x3956c25b, 0x59f111f1, 0x923f82a4, 0xab1c5ed5,
    0xd807aa98, 0x12835b01, 0x243185be, 0x550c7dc3,
    0x72be5d74, 0x80deb1fe, 0x9bdc06a7, 0xc19bf174,
    0xe49b69c1, 0xefbe4786, 0x0fc19dc6, 0x240ca1cc,
    0x2de92c6f, 0x4a7484aa, 0x5cb0a9dc, 0x76f988da,
    0x983e5152, 0xa831c66d, 0xb00327c8, 0xbf597fc7,
    0xc6e00bf3, 0xd5a79147, 0x06ca6351, 0x14292967,
    0x27b70a85, 0x2e1b2138, 0x4d2c6dfc, 0x53380d13,
    0x650a7354, 0x766a0abb, 0x81c2c92e, 0x92722c85,
    0xa2bfe8a1, 0xa81a664b, 0xc24b8b70, 0xc76c51a3,
    0xd192e819, 0xd6990624, 0xf40e3585, 0x106aa070,
    0x19a4c116, 0x1e376c08, 0x2748774c, 0x34b0bcb5,
    0x391c0cb3, 0x4ed8aa4a, 0x5b9cca4f, 0x682e6ff3,
    0x748f82ee, 0x78a5636f, 0x84c87814, 0x8cc70208,
    0x90befffa, 0xa4506ceb, 0xbef9a3f7, 0xc67178f2};

// SHA-256 initial hash values
const uint32_t initial_hash[8] = {
    0x6a09e667, 0xbb67ae85, 0x3c6ef372, 0xa54ff53a,
    0x510e527f, 0x9b05688c, 0x1f83d9ab, 0x5be0cd19};

// SHA-256 Functions
#define CH(x, y, z) (((x) & (y)) ^ (~(x) & (z)))
#define MAJ(x, y, z) (((x) & (y)) ^ ((x) & (z)) ^ ((y) & (z)))
#define EP0(x) (ROTR(x, 2) ^ ROTR(x, 13) ^ ROTR(x, 22))
#define EP1(x) (ROTR(x, 6) ^ ROTR(x, 11) ^ ROTR(x, 25))
#define SIG0(x) (ROTR(x, 7) ^ ROTR(x, 18) ^ ((x) >> 3))
#define SIG1(x) (ROTR(x, 17) ^ ROTR(x, 19) ^ ((x) >> 10))

// SHA-256 Compression Function
void sha256_compress(uint32_t state[8], const uint8_t block[64])
{
    uint32_t W[64];
    uint32_t a, b, c, d, e, f, g, h;
    uint32_t T1, T2;

    // Prepare message schedule
    for (int t = 0; t < 16; ++t)
    {
        W[t] = (block[t * 4] << 24) | (block[t * 4 + 1] << 16) | (block[t * 4 + 2] << 8) | block[t * 4 + 3];
    }
    for (int t = 16; t < 64; ++t)
    {
        W[t] = SIG1(W[t - 2]) + W[t - 7] + SIG0(W[t - 15]) + W[t - 16];
    }

    // Initialize working variables
    a = state[0];
    b = state[1];
    c = state[2];
    d = state[3];
    e = state[4];
    f = state[5];
    g = state[6];
    h = state[7];

    // Compression loop
    for (int t = 0; t < 64; ++t)
    {
        T1 = h + EP1(e) + CH(e, f, g) + K[t] + W[t];
        T2 = EP0(a) + MAJ(a, b, c);
        h = g;
        g = f;
        f = e;
        e = d + T1;
        d = c;
        c = b;
        b = a;
        a = T1 + T2;
    }

    // Update hash state
    state[0] += a;
    state[1] += b;
    state[2] += c;
    state[3] += d;
    state[4] += e;
    state[5] += f;
    state[6] += g;
    state[7] += h;
}

// SHA-256 hash function
void sha256(const uint8_t *message, size_t len, uint8_t hash[32])
{
    uint32_t state[8];
    uint32_t length_bits = len * 8;
    uint8_t block[64];
    size_t i;

    // Initialize hash state
    for (i = 0; i < 8; ++i)
    {
        state[i] = initial_hash[i];
    }

    // Process message in 512-bit blocks
    while (len >= 64)
    {
        memcpy(block, message, 64);
        sha256_compress(state, block);
        message += 64;
        len -= 64;
    }

    // Append padding and length
    memset(block, 0, 64);
    memcpy(block, message, len);
    block[len] = 0x80;
    if (len < 56)
    {
        // There is enough room for padding and length in this block
        for (i = 0; i < 8; ++i)
        {
            block[56 + i] = (length_bits >> (56 - i * 8)) & 0xFF;
        }
        sha256_compress(state, block);
    }
    else
    {
        // We need an additional block to store padding and length
        sha256_compress(state, block);
        memset(block, 0, 64);
        for (i = 0; i < 8; ++i)
        {
            block[56 + i] = (length_bits >> (56 - i * 8)) & 0xFF;
        }
        sha256_compress(state, block);
    }

    // Write final hash
    for (i = 0; i < 8; ++i)
    {
        hash[i * 4] = (state[i] >> 24) & 0xFF;
        hash[i * 4 + 1] = (state[i] >> 16) & 0xFF;
        hash[i * 4 + 2] = (state[i] >> 8) & 0xFF;
        hash[i * 4 + 3] = state[i] & 0xFF;
    }
}

// Utility function to print hash in hexadecimal format
void print_hash(const uint8_t hash[32])
{
    for (int i = 0; i < 32; ++i)
    {
        printf("%02x", hash[i]);
    }
    printf("\n");
```

```
}

int main()
{
    const char *message = "Hello, world!";
    uint8_t hash[32];
    sha256((uint8_t *)message, strlen(message), hash);
    printf("SHA-256 hash of '%s':\n", message);
    print_hash(hash);
    return 0;
}
```

OUTPUT



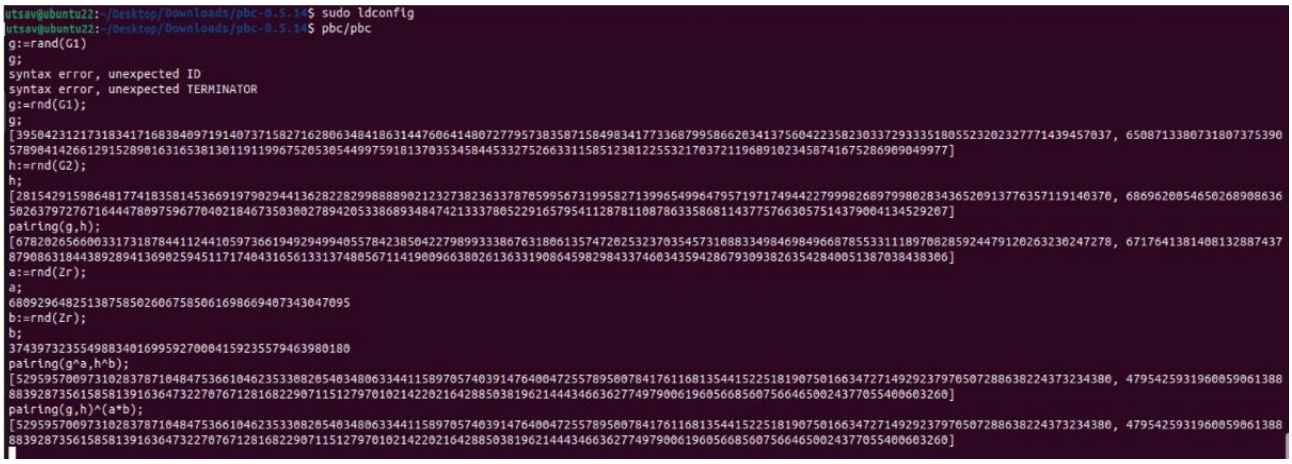
```
SHA-256 hash of 'Hello, world!':
e8662ae9c885cd93bc328d634ca36da611ac26f7632c9a939b665db581f5e674
```

Practical 11

➢ Implementation of PBC library and performing Bilinear pairing operation

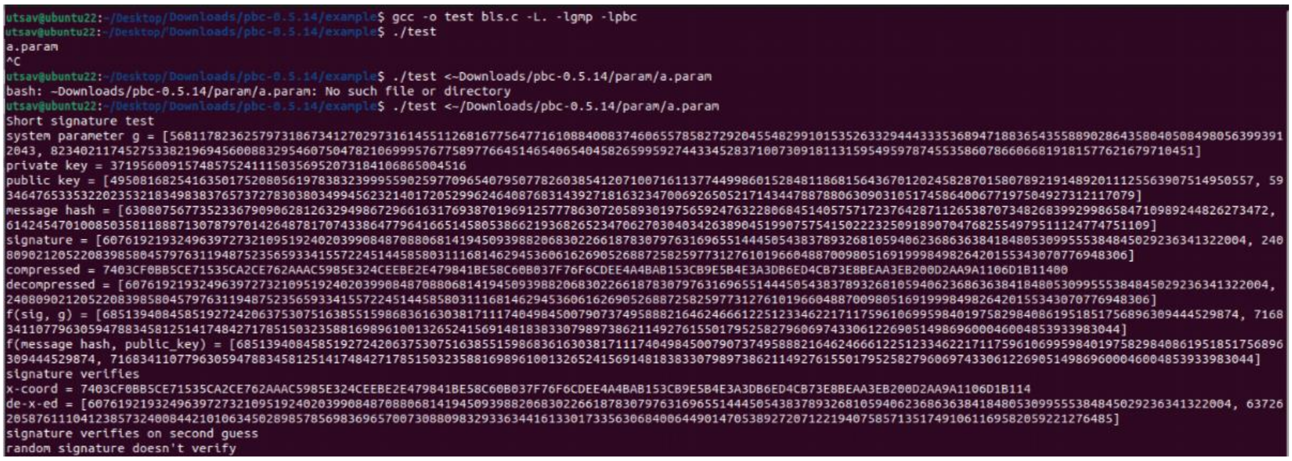
Steps:

1. Install m4, flex and bison using below commands
   - i. sudo apt-get install m4
   - ii. sudo apt-get install flex
   - iii. sudo apt-get install bison
2. Download gmp and install it using below commands
   - i. configure
   - ii. make
   - iii. sudo make install
3. After installing gmp, go to https://crypto.stanford.edu/pbc/download.html and download pbc-0.5.14.tar.gz
4. Then go to pcb-0.5.14 folder and open the terminal in that folder
5. For performing bilinear pairing follow below commands
   - i. configure
   - ii. make
   - iii. sudo make install
   - iv. sudoldconfig
   - v. pbc/pbc



```
utsav@ubuntu22:~/Desktop/Downloads/pbc-0.5.14$ sudo ldconfig
utsav@ubuntu22:~/Desktop/Downloads/pbc-0.5.14$ pbc/pbc
g:=rand(G1)
g;
syntax error, unexpected ID
syntax error, unexpected TERMINATOR
g:=rnd(G1);
g;
[3950423121731834171683840971914073715827162806348418631447606414807277957383587158498341773368799586620341375604223582303372933351805523202327771439457037, 6508713380731807375390
578904142661291528901631653813011911996752053054499759181370353458445332752663311585123812255321703721196891023458741675286909049977]
h:=rnd(G2);
h;
[2815429159864817741835814536691979029441362822829988888902123273823633787059956731995827139965499647957197174944227999826897998028343652091377635711914037 0, 6869620054650268908636
502637972767164447809759677040218467350300278942053386893484742133378052291657954112878110878633586811437757663057514379004134529207]
pairing(g,h);
[6782026566003317318784411244105973661949294994055784238504227989933386763180613574720253237035457310883349846984966878553311189708285924479120263230247278, 6717641381408132887437
879086318443892894136902594511717404316561331374805671141900966380261363319086459829843374603435942867930938263542840051387038438306]
a:=rnd(Zr);
a;
680929648251387585026067585061698669407343047095
b:=rnd(Zr);
b;
374397323554988340169959270004159235579463980180
pairing(g^a,h^b);
[5295957009731028378710484753661046235330820540348063344115897057403914764004725578950078417611681354415225181907501663472714929237970507288638224373234380, 4795425931960059061388
883928735615858139163647322707671281682290711512797010214220216428850381962144434663627749790061960566856075664650024377055400603260]
pairing(g,h)^(a*b);
[5295957009731028378710484753661046235330820540348063344115897057403914764004725578950078417611681354415225181907501663472714929237970507288638224373234380, 4795425931960059061388
883928735615858139163647322707671281682290711512797010214220216428850381962144434663627749790061960566856075664650024377055400603260]
```

6. Now for bilinear pairing go to location pcb-0.5.14/example and open terminal in that folder then write below commands
   - i. gcc -o test bls.c -L. -lgmp -lpbc
   - ii. ./test <~/Download/pbc-0.5.14/param/a.param



```
utsav@ubuntu22:~/Desktop/Downloads/pbc-0.5.14/example$ gcc -o test bls.c -L. -lgmp -lpbc
utsav@ubuntu22:~/Desktop/Downloads/pbc-0.5.14/example$ ./test
a.param
^C
utsav@ubuntu22:~/Desktop/Downloads/pbc-0.5.14/example$ ./test <~Downloads/pbc-0.5.14/param/a.param
bash: ~Downloads/pbc-0.5.14/param/a.param: No such file or directory
utsav@ubuntu22:~/Desktop/Downloads/pbc-0.5.14/example$ ./test <~/Downloads/pbc-0.5.14/param/a.param
Short signature test
system parameter g = [568117823625797318673412702973161455112681677564771610884008374606557858272920455482991015352633294443335368947188365435588902864358040508498056399391
2043, 8234021174527533821969456008832954607504782106999576775897766451465406540458265995927443345283710073091811315954959787455358607866066819181577621679710451]
private key = 371956009157485752411150356952073184106865004516
public key = [4950816825416350175208056197838323999559025977096540795077826038541207100716113774499860152848118681564367012024582870158078921914892011125563907514950557, 59
3464765335322023532183498383765737278303803499456232140172052996246408768314392718163234700692650521714344788788063090310517458640067719750492731211 7079]
message hash = [6308075677352336790906281263294986729661631769387019691257778630720589301975659247632280684514057571723764287112653870734826839929986584710989244826273472,
6142454701008503581188871307879701426487817074338647796416651458053866219368265234706270304034263890451990757541502223250918907047682554979511124774751109]
signature = [6076192193249639727321095192402039908487088068141945093988206830226618783079763169655144450543837893268105940623686363841848053099555384845029236341322004, 240
809021205220839858045797631194875235659334155722451445858031116814629453606162690526887258259773127610196604887009805169199984982642015534307077 6948306]
compressed = 7403CF0BB5CE71535CA2CE762AAAC5985E324CEEBE2E479841BE58C60B037F76F6CDEE4A4BAB153CB9E5B4E3A3DB6ED4CB73E8BEAA3EB200D2AA9A1106D1B11400
decompressed = [6076192193249639727321095192402039908487088068141945093988206830226618783079763169655144450543837893268105940623686363841848053099555384845029236341322004,
240809021205220839858045797631194875235659334155722451445858031116814629453606162690526887258259773127610196604887009805169199984982642015534307077 6948306]
f(sig, g) = [6851394084585192724206375307516385515986836163038171111740498450079073749588821646246661225123346221711175961069959840197582984086195185175689630944452 9874, 7168
341107796305947883458125141748427178515032358816989610013265241569148183833079897386211492761550179525827960697433061226905149869600046004853933983044]
f(message hash, public_key) = [68513940845851927242063753075163855159868361630381711117404984500790737495888216462466612251233462217111759610699598401975829840861951851756896
309444529874, 7168341107796305947883458125141748427178515032358816989610013265241569148183833079897386211492761550179525827960697433061226905149869600046004853933983044]
signature verifies
x-coord = 7403CF0BB5CE71535CA2CE762AAAC5985E324CEEBE2E479841BE58C60B037F76F6CDEE4A4BAB153CB9E5B4E3A3DB6ED4CB73E8BEAA3EB200D2AA9A1106D1B114
de-x-ed = [6076192193249639727321095192402039908487088068141945093988206830226618783079763169655144450543837893268105940623686363841848053099555384845029236341322004, 63726
20587611104123857324008442101063450289857856983696570073088098329336344161330173356306840064490147053892720712219407585713517491061169582059221276485]
signature verifies on second guess
random signature doesn't verify
```

➢ CODE:

```c
#include <pbc/pbc.h>
#include <pbc/pbc_test.h>

int main(int argc, char **argv)
{
    pairing_t pairing;
    element_t g, h;
    element_t public_key, sig;
    element_t secret_key;
    element_t temp1, temp2;

    pbc_demo_pairing_init(pairing, argc, argv);

    element_init_G2(g, pairing);
    element_init_G2(public_key, pairing);
    element_init_G1(h, pairing);
    element_init_G1(sig, pairing);
    element_init_GT(temp1, pairing);
    element_init_GT(temp2, pairing);
    element_init_Zr(secret_key, pairing);

    printf("Short signature test\n");

    // generate system parameters
    element_random(g);
    element_printf("system parameter g = %B\n", g);

    // generate private key
    element_random(secret_key);
    element_printf("private key = %B\n", secret_key);

    // compute corresponding public key
    element_pow_zn(public_key, g, secret_key);
    element_printf("public key = %B\n", public_key);

    // generate element from a hash
    // for toy pairings, should check that pairing(g, h) != 1
    element_from_hash(h, "hashofmessage", 13);
    element_printf("message hash = %B\n", h); // h^secret_key is the
signature // in real life: only output the first coordinate
    element_pow_zn(sig, h, secret_key);
    element_printf("signature = %B\n", sig);

    {
        int n = pairing_length_in_bytes_compressed_G1(pairing);
        // int n = element_length_in_bytes_compressed(sig);
        int i;
        unsigned char *data = pbc_malloc(n);
        element_to_bytes_compressed(data, sig);
        printf("compressed = ");
        for (i = 0; i < n; i++)
        {
            printf("%02X", data[i]);
        }
        printf("\n");
        element_from_bytes_compressed(sig, data);
        element_printf("decompressed = %B\n", sig);
        pbc_free(data);
    }

    // Verification part 1
    element_pairing(temp1, sig, g);
    element_printf("f(sig, g) = %B\n", temp1);

    // Verification part 2
    // should match above
    element_pairing(temp2, h, public_key);
    element_printf("f(message hash, public_key) = %B\n", temp2);

    if (!element_cmp(temp1, temp2))
    {
        // Signature is valid
    }
    {
        printf("signature verifies\n");
    }
    else
    {
        printf("*BUG* signature does not verify *BUG*\n");
    }

    {
        int n = pairing_length_in_bytes_x_only_G1(pairing);
        // int n = element_length_in_bytes_x_only(sig);
        int i;
        unsigned char *data = pbc_malloc(n);
        element_to_bytes_x_only(data, sig);
        printf("x-coord = ");
        for (i = 0; i < n; i++)
        {
            printf("%02X", data[i]);
        }
        printf("\n");
        element_from_bytes_x_only(sig, data);
        element_printf("de-x-ed = %B\n", sig);
        element_pairing(temp1, sig, g);
        if (!element_cmp(temp1, temp2))
        {
            printf("signature verifies on first guess\n");
        }
        else
        {
            element_invert(temp1, temp1);
            if (!element_cmp(temp1, temp2))
            {
                printf("signature verifies on second guess\n");
            }
            else
            {
                printf("*BUG* signature does not verify *BUG*\n");
            }
        }

        pbc_free(data);
    }

    // a random signature shouldn't verify
    element_random(sig);
    element_pairing(temp1, sig, g);
    if (element_cmp(temp1, temp2))
    {
        printf("random signature doesn't verify\n");
    }
    else
    {
        printf("*BUG* random signature verifies *BUG*\n");
    }

    element_clear(sig);
    element_clear(public_key);
    element_clear(secret_key);
    element_clear(g);
    element_clear(h);
    element_clear(temp1);
    element_clear(temp2);
    pairing_clear(pairing);
    return 0;
}
```

Practical 12

➢ Use Wireshark tool to view the network traffic passing across your lab computers

Wireshark:

Wireshark functions as a network protocol analyzer, capturing packets from various network connections such as those between your computer and your home office or the internet. In the context of a typical Ethernet network, a packet refers to a discrete unit of data. Wireshark stands as the most commonly utilized packet sniffer globally. Like its counterparts, Wireshark performs three primary tasks:

1. Packet Capture: Wireshark actively listens to network connections in real-time, capturing entire streams of traffic which may encompass tens of thousands of packets simultaneously.
2. Filtering: Utilizing filters, Wireshark effectively sifts through the abundance of live data, enabling users to isolate specific information of interest.
3. Visualization: Wireshark not only permits users to delve into individual network packets but also facilitates the visualization of entire conversations and network streams, offering a comprehensive understanding of network activities.

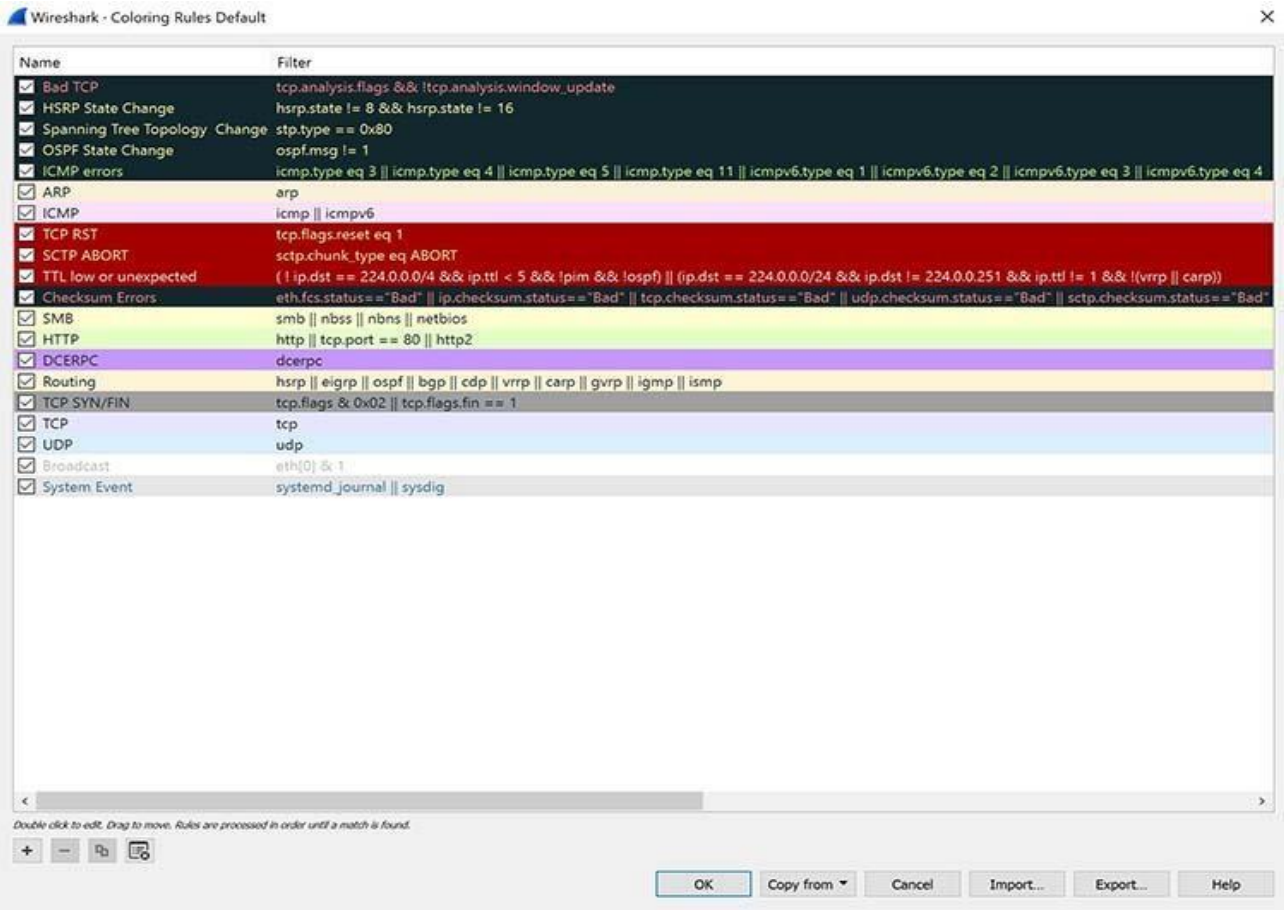
What are the Applications of Wireshark?

Wireshark serves various purposes, one of which is troubleshooting networks experiencing performance issues. Cybersecurity experts frequently employ Wireshark to track connections, inspect the contents of suspicious network transactions, and detect spikes in network traffic. It constitutes a significant component of any IT professional's arsenal – provided the professional possesses the requisite expertise to utilize it effectively.

Interpreting Color Codes in Wireshark:

Once packets are captured, understanding their significance becomes paramount. Wireshark simplifies this task by employing intuitive color coding to denote different packet types. The following table delineates the default colors assigned to major packet categories.

Color in Wireshark	Packet Type
Light purple	TCP
Light blue	UDP
Black	Packets with errors
Light green	HTTP traffic
Light yellow	Windows-specific traffic, including Server Message Blocks (SMB) and NetBIOS
Dark yellow	Routing
Dark gray	TCP SYN, FIN and ACK traffic



Wireshark - Coloring Rules Default

<table>
<tr><th>Name</th><th>Filter</th></tr>
<tr><td>☑ Bad TCP</td><td>tcp.analysis.flags && !tcp.analysis.window_update</td></tr>
<tr><td>☑ HSRP State Change</td><td>hsrp.state != 8 && hsrp.state != 16</td></tr>
<tr><td>☑ Spanning Tree Topology Change</td><td>stp.type == 0x80</td></tr>
<tr><td>☑ OSPF State Change</td><td>ospf.msg != 1</td></tr>
<tr><td>☑ ICMP errors</td><td>icmp.type eq 3 || icmp.type eq 4 || icmp.type eq 5 || icmp.type eq 11 || icmpv6.type eq 1 || icmpv6.type eq 2 || icmpv6.type eq 3 || icmpv6.type eq 4</td></tr>
<tr><td>☑ ARP</td><td>arp</td></tr>
<tr><td>☑ ICMP</td><td>icmp || icmpv6</td></tr>
<tr><td>☑ TCP RST</td><td>tcp.flags.reset eq 1</td></tr>
<tr><td>☑ SCTP ABORT</td><td>sctp.chunk_type eq ABORT</td></tr>
<tr><td>☑ TTL low or unexpected</td><td>(! ip.dst == 224.0.0.0/4 && ip.ttl < 5 && !pim && !ospf) || (ip.dst == 224.0.0.0/24 && ip.dst != 224.0.0.251 && ip.ttl != 1 && !(vrrp || carp))</td></tr>
<tr><td>☑ Checksum Errors</td><td>eth.fcs.status=="Bad" || ip.checksum.status=="Bad" || tcp.checksum.status=="Bad" || udp.checksum.status=="Bad" || sctp.checksum.status=="Bad"</td></tr>
<tr><td>☑ SMB</td><td>smb || nbss || nbns || netbios</td></tr>
<tr><td>☑ HTTP</td><td>http || tcp.port == 80 || http2</td></tr>
<tr><td>☑ DCERPC</td><td>dcerpc</td></tr>
<tr><td>☑ Routing</td><td>hsrp || eigrp || ospf || bgp || cdp || vrrp || carp || gvrp || igmp || ismp</td></tr>
<tr><td>☑ TCP SYN/FIN</td><td>tcp.flags & 0x02 || tcp.flags.fin == 1</td></tr>
<tr><td>☑ TCP</td><td>tcp</td></tr>
<tr><td>☑ UDP</td><td>udp</td></tr>
<tr><td>☑ Broadcast</td><td>eth[0] & 1</td></tr>
<tr><td>☑ System Event</td><td>systemd_journal || sysdig</td></tr>
</table>

Double click to edit. Drag to move. Rules are processed in order until a match is found.

When to Utilize Wireshark?

Wireshark serves as a reliable tool embraced by a spectrum of entities including government agencies, educational institutions, corporations, small businesses, and nonprofits for diagnosing network issues. Moreover, Wireshark doubles as an educational resource.

Novices in the realm of information security can leverage Wireshark to grasp concepts such as network traffic analysis, the dynamics of communication in the presence of specific protocols, and the identification of anomalies during troubleshooting.

However, Wireshark has its limitations. Firstly, it proves ineffective for users lacking a fundamental understanding of network protocols. Regardless of its utility, no tool can adequately substitute for comprehensive knowledge. Consequently, proficient usage of Wireshark mandates a deep comprehension of network operations, encompassing elements like the three-way TCP handshake and various protocols such as TCP, UDP, DHCP, and ICMP.

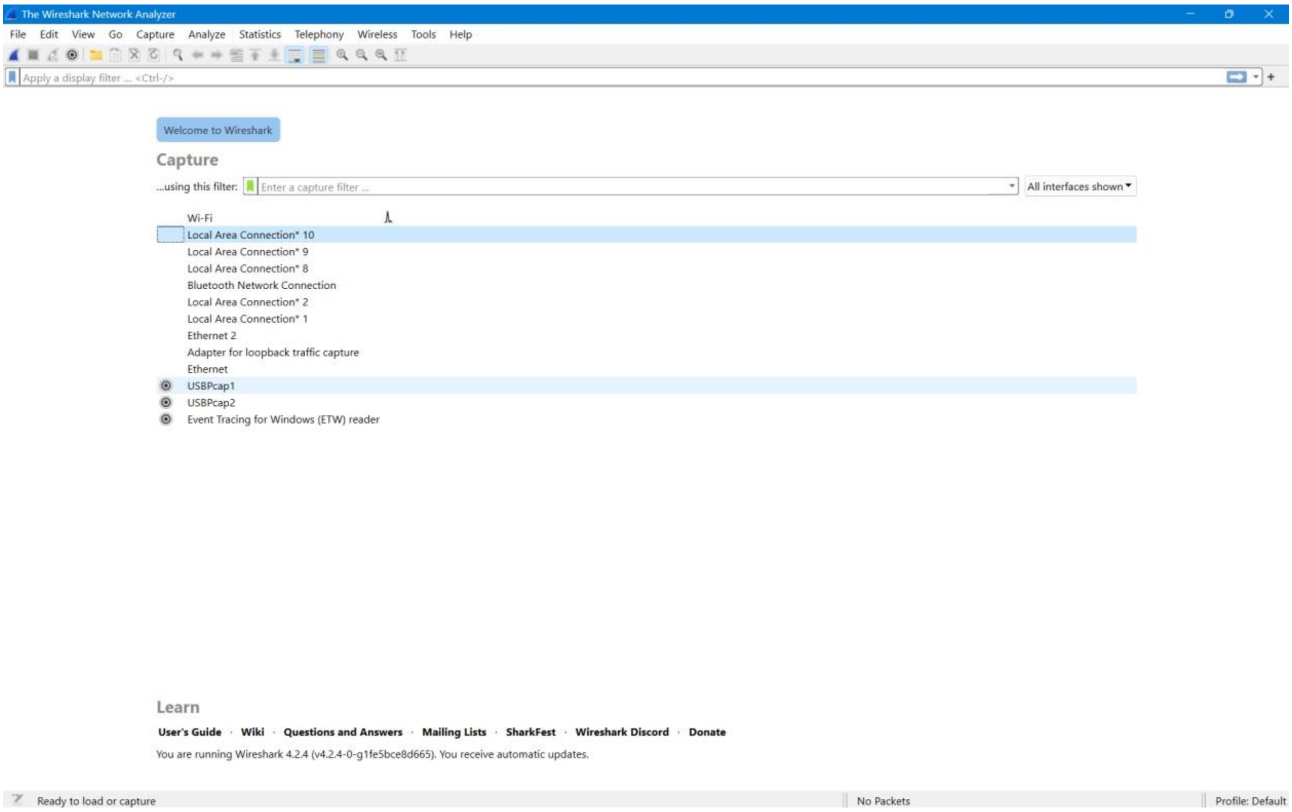
Secondly, under standard circumstances, Wireshark fails to capture traffic from all network systems. In modern network infrastructures employing switches, Wireshark, like other conventional packet-capturing tools, can only intercept traffic between the local computer and the remote system it engages with.

Thirdly, while Wireshark can detect malformed packets and implement color coding, it lacks actual alert functionalities, thus distinguishing itself from an intrusion detection system (IDS).

Fourthly, Wireshark proves ineffectual in decrypting encrypted traffic.

Lastly, Wireshark faces challenges in discerning the authenticity of IPv4 packets, particularly concerning the potential for spoofing. Differentiating between genuine and fabricated IP addresses necessitates a higher level of expertise from IT professionals and potentially supplementary software tools

EXAMPLE:


The Wireshark Network Analyzer
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter ... <Ctrl-/>
Welcome to Wireshark
All interfaces shown
User's Guide · Wiki · Questions and Answers · Mailing Lists · SharkFest · Wireshark Discord · Donate

Capture

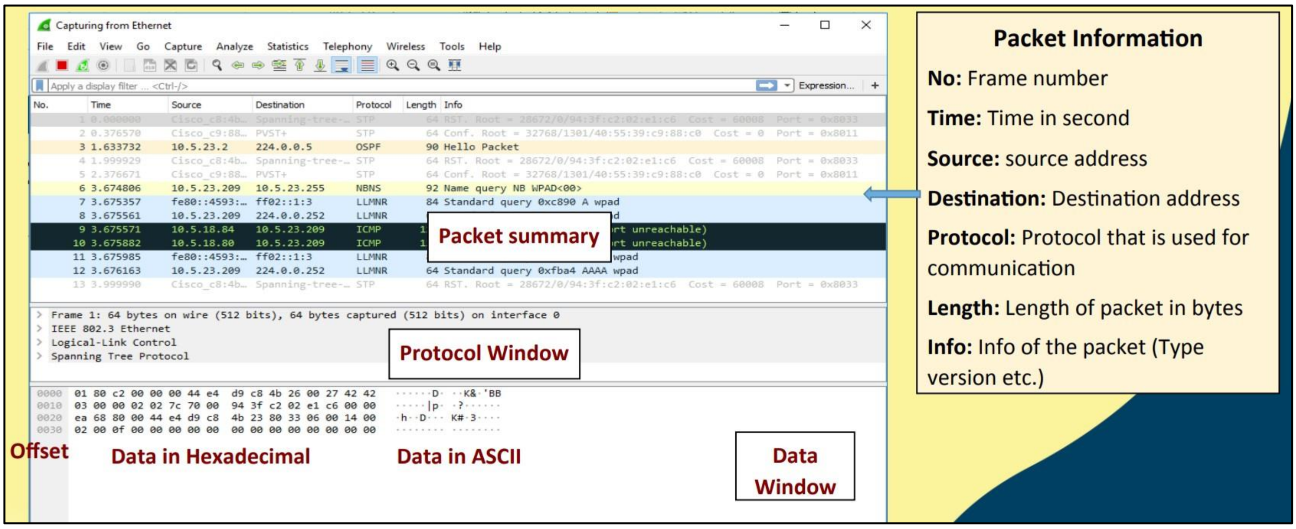
...using this filter: Enter a capture filter ...

Wi-Fi
Local Area Connection* 10
Local Area Connection* 9
Local Area Connection* 8
Bluetooth Network Connection
Local Area Connection* 2
Local Area Connection* 1
Ethernet 2
Adapter for loopback traffic capture
Ethernet
USBPcap1
USBPcap2
Event Tracing for Windows (ETW) reader

Learn

You are running Wireshark 4.2.4 (v4.2.4-0-g1fe5bce8d665). You receive automatic updates.

Ready to load or capture | No Packets | Profile: Default



```
No.  Time        Source           Destination        Protocol Length Info
   1 0.000000    Cisco_c8:4b…     Spanning-tree-…    STP      64 RST. Root = 28672/0/94:3f:c2:02:e1:c6  Cost = 60008  Port = 0x8033
   2 0.376570    Cisco_c9:88…     PVST+              STP      64 Conf. Root = 32768/1301/40:55:39:c9:88:c0  Cost = 0  Port = 0x8011
   3 1.633732    10.5.23.2        224.0.0.5          OSPF     90 Hello Packet
   4 1.999929    Cisco_c8:4b…     Spanning-tree-…    STP      64 RST. Root = 28672/0/94:3f:c2:02:e1:c6  Cost = 60008  Port = 0x8033
   5 2.376671    Cisco_c9:88…     PVST+              STP      64 Conf. Root = 32768/1301/40:55:39:c9:88:c0  Cost = 0  Port = 0x8011
   6 3.674806    10.5.23.209      10.5.23.255        NBNS     92 Name query NB WPAD<00>
   7 3.675357    fe80::4593:…     ff02::1:3          LLMNR    84 Standard query 0xc890 A wpad
   8 3.675561    10.5.23.209      224.0.0.252        LLMNR                                d
   9 3.675571    10.5.18.84       10.5.23.209        ICMP     1                           rt unreachable)
  10 3.675882    10.5.18.80       10.5.23.209        ICMP     1                           rt unreachable)
  11 3.675985    fe80::4593:…     ff02::1:3          LLMNR                                wpad
  12 3.676163    10.5.23.209      224.0.0.252        LLMNR    64 Standard query 0xfba4 AAAA wpad
  13 3.999990    Cisco_c8:4b…     Spanning-tree-…    STP      64 RST. Root = 28672/0/94:3f:c2:02:e1:c6  Cost = 60008  Port = 0x8033
```

```
> Frame 1: 64 bytes on wire (512 bits), 64 bytes captured (512 bits) on interface 0
> IEEE 802.3 Ethernet
> Logical-Link Control
> Spanning Tree Protocol
```

```
0000  01 80 c2 00 00 00 44 e4  d9 c8 4b 26 00 27 42 42   ······D· ··K&·'BB
0010  03 00 00 02 02 7c 70 00  94 3f c2 02 e1 c6 00 00   ·····|p· ·?······
0020  ea 68 80 00 44 e4 d9 c8  4b 23 80 33 06 00 14 00   ·h··D··· K#·3····
0030  02 00 0f 00 00 00 00 00  00 00 00 00 00 00 00 00   ········ ········
```

Packet Information

No: Frame number

Time: Time in second

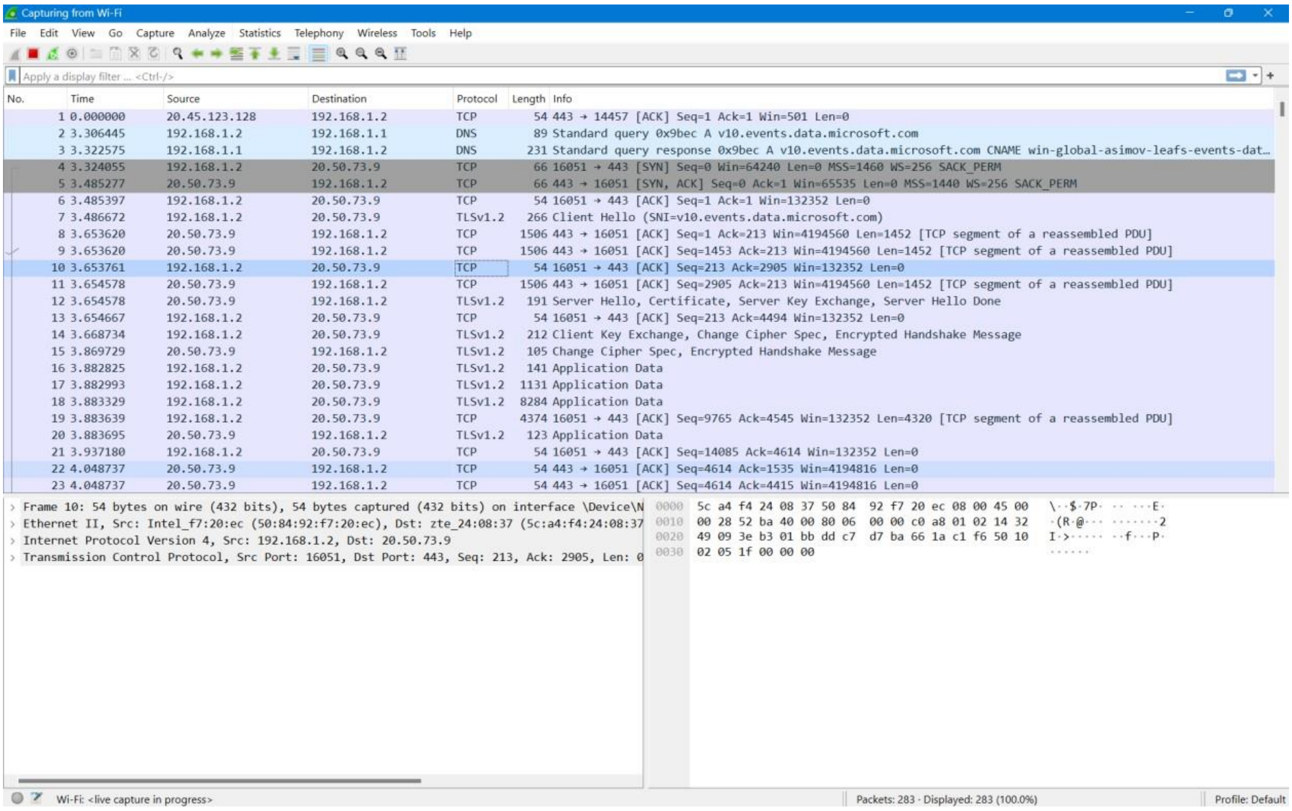
Source: source address

Destination: Destination address

Protocol: Protocol that is used for communication

Length: Length of packet in bytes

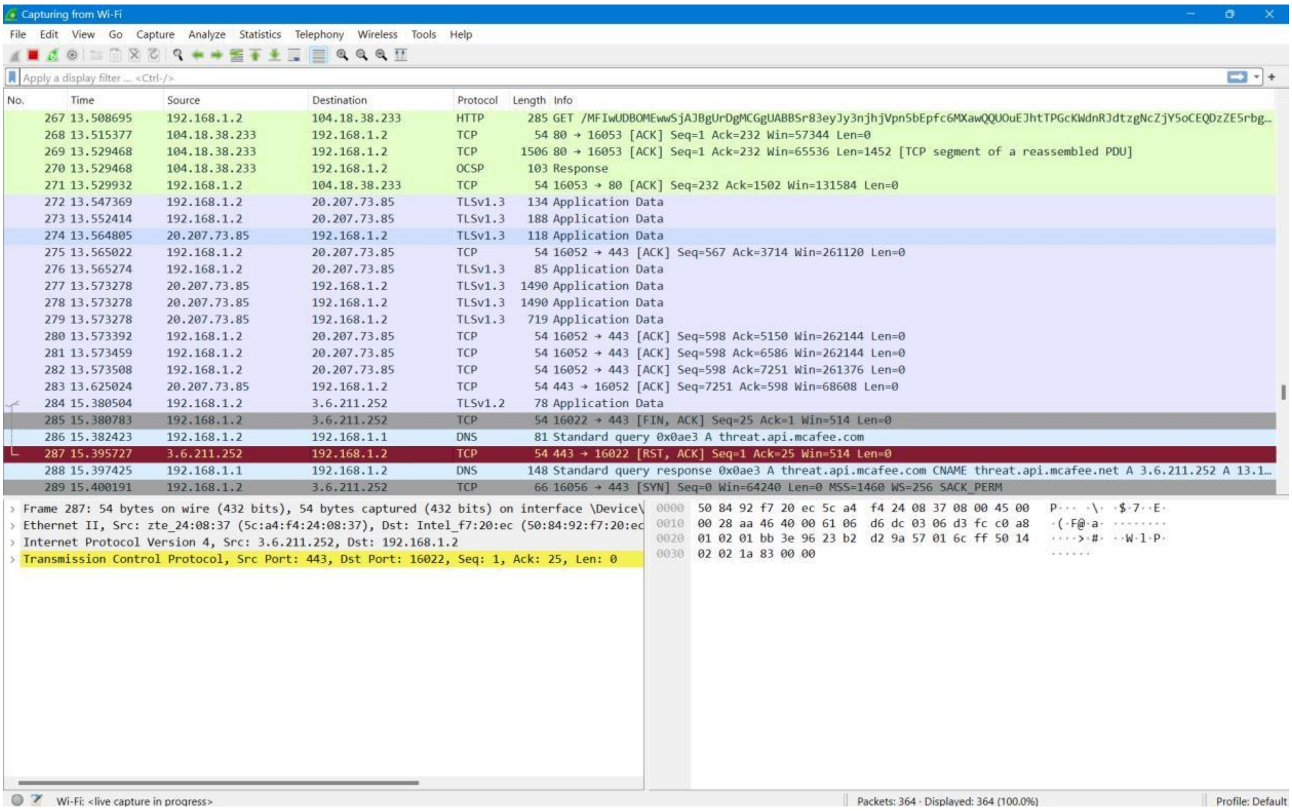
Info: Info of the packet (Type version etc.)


Capturing from Wi-Fi
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter … <Ctrl-/>
Wi-Fi: <live capture in progress>
Packets: 283 · Displayed: 283 (100.0%)
Profile: Default

```
No.  Time        Source          Destination    Protocol Length Info
   1 0.000000    20.45.123.128   192.168.1.2    TCP        54 443 → 14457 [ACK] Seq=1 Ack=1 Win=501 Len=0
   2 3.306445    192.168.1.2     192.168.1.1    DNS        89 Standard query 0x9bec A v10.events.data.microsoft.com
   3 3.322575    192.168.1.1     192.168.1.2    DNS       231 Standard query response 0x9bec A v10.events.data.microsoft.com CNAME win-global-asimov-leafs-events-dat…
   4 3.324055    192.168.1.2     20.50.73.9     TCP        66 16051 → 443 [SYN] Seq=0 Win=64240 Len=0 MSS=1460 WS=256 SACK_PERM
   5 3.485277    20.50.73.9      192.168.1.2    TCP        66 443 → 16051 [SYN, ACK] Seq=0 Ack=1 Win=65535 Len=0 MSS=1440 WS=256 SACK_PERM
   6 3.485397    192.168.1.2     20.50.73.9     TCP        54 16051 → 443 [ACK] Seq=1 Ack=1 Win=132352 Len=0
   7 3.486672    192.168.1.2     20.50.73.9     TLSv1.2   266 Client Hello (SNI=v10.events.data.microsoft.com)
   8 3.653620    20.50.73.9      192.168.1.2    TCP      1506 443 → 16051 [ACK] Seq=1 Ack=213 Win=4194560 Len=1452 [TCP segment of a reassembled PDU]
   9 3.653620    20.50.73.9      192.168.1.2    TCP      1506 443 → 16051 [ACK] Seq=1453 Ack=213 Win=4194560 Len=1452 [TCP segment of a reassembled PDU]
  10 3.653761    192.168.1.2     20.50.73.9     TCP        54 16051 → 443 [ACK] Seq=213 Ack=2905 Win=132352 Len=0
  11 3.654578    20.50.73.9      192.168.1.2    TCP      1506 443 → 16051 [ACK] Seq=2905 Ack=213 Win=4194560 Len=1452 [TCP segment of a reassembled PDU]
  12 3.654578    20.50.73.9      192.168.1.2    TLSv1.2   191 Server Hello, Certificate, Server Key Exchange, Server Hello Done
  13 3.654667    192.168.1.2     20.50.73.9     TCP        54 16051 → 443 [ACK] Seq=213 Ack=4494 Win=132352 Len=0
  14 3.668734    192.168.1.2     20.50.73.9     TLSv1.2   212 Client Key Exchange, Change Cipher Spec, Encrypted Handshake Message
  15 3.869729    20.50.73.9      192.168.1.2    TLSv1.2   105 Change Cipher Spec, Encrypted Handshake Message
  16 3.882825    192.168.1.2     20.50.73.9     TLSv1.2   141 Application Data
  17 3.882993    192.168.1.2     20.50.73.9     TLSv1.2  1131 Application Data
  18 3.883329    192.168.1.2     20.50.73.9     TLSv1.2  8284 Application Data
  19 3.883639    192.168.1.2     20.50.73.9     TCP      4374 16051 → 443 [ACK] Seq=9765 Ack=4545 Win=132352 Len=4320 [TCP segment of a reassembled PDU]
  20 3.883695    20.50.73.9      192.168.1.2    TLSv1.2   123 Application Data
  21 3.937180    192.168.1.2     20.50.73.9     TCP        54 16051 → 443 [ACK] Seq=14085 Ack=4614 Win=132352 Len=0
  22 4.048737    20.50.73.9      192.168.1.2    TCP        54 443 → 16051 [ACK] Seq=4614 Ack=1535 Win=4194816 Len=0
  23 4.048737    20.50.73.9      192.168.1.2    TCP        54 443 → 16051 [ACK] Seq=4614 Ack=4415 Win=4194816 Len=0
```

```
> Frame 10: 54 bytes on wire (432 bits), 54 bytes captured (432 bits) on interface \Device\N
> Ethernet II, Src: Intel_f7:20:ec (50:84:92:f7:20:ec), Dst: zte_24:08:37 (5c:a4:f4:24:08:37
> Internet Protocol Version 4, Src: 192.168.1.2, Dst: 20.50.73.9
> Transmission Control Protocol, Src Port: 16051, Dst Port: 443, Seq: 213, Ack: 2905, Len: 0
```

```
0000  5c a4 f4 24 08 37 50 84  92 f7 20 ec 08 00 45 00   \··$·7P· ·· ···E·
0010  00 28 52 ba 40 00 80 06  00 00 c0 a8 01 02 14 32   ·(R·@··· ·······2
0020  49 09 3e b3 01 bb dd c7  d7 ba 66 1a c1 f6 50 10   I·>····· ··f···P·
0030  02 05 1f 00 00 00                                  ······
```


Capturing from Wi-Fi
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter … <Ctrl-/>
Wi-Fi: <live capture in progress>
Packets: 364 · Displayed: 364 (100.0%)
Profile: Default

```
No.  Time        Source          Destination    Protocol Length Info
 267 13.508695   192.168.1.2     104.18.38.233  HTTP      285 GET /MFIwUDBOMEwwSjAJBgUrDgMCGgUABBSr83eyJy3njhjVpn5bEpfc6MXawQQUOuEJhtTPGcKWdnRJdtzgNcZjY5oCEQDzZE5rbg…
 268 13.515377   104.18.38.233   192.168.1.2    TCP        54 80 → 16053 [ACK] Seq=1 Ack=232 Win=57344 Len=0
 269 13.529468   104.18.38.233   192.168.1.2    TCP      1506 80 → 16053 [ACK] Seq=1 Ack=232 Win=65536 Len=1452 [TCP segment of a reassembled PDU]
 270 13.529468   104.18.38.233   192.168.1.2    OCSP      103 Response
 271 13.529932   192.168.1.2     104.18.38.233  TCP        54 16053 → 80 [ACK] Seq=232 Ack=1502 Win=131584 Len=0
 272 13.547369   192.168.1.2     20.207.73.85   TLSv1.3   134 Application Data
 273 13.552414   192.168.1.2     20.207.73.85   TLSv1.3   188 Application Data
 274 13.564805   20.207.73.85    192.168.1.2    TLSv1.3   118 Application Data
 275 13.565022   192.168.1.2     20.207.73.85   TCP        54 16052 → 443 [ACK] Seq=567 Ack=3714 Win=261120 Len=0
 276 13.565274   192.168.1.2     20.207.73.85   TLSv1.3    85 Application Data
 277 13.573278   20.207.73.85    192.168.1.2    TLSv1.3  1490 Application Data
 278 13.573278   20.207.73.85    192.168.1.2    TLSv1.3  1490 Application Data
 279 13.573278   20.207.73.85    192.168.1.2    TLSv1.3   719 Application Data
 280 13.573392   192.168.1.2     20.207.73.85   TCP        54 16052 → 443 [ACK] Seq=598 Ack=5150 Win=262144 Len=0
 281 13.573459   192.168.1.2     20.207.73.85   TCP        54 16052 → 443 [ACK] Seq=598 Ack=6586 Win=262144 Len=0
 282 13.573508   192.168.1.2     20.207.73.85   TCP        54 16052 → 443 [ACK] Seq=598 Ack=7251 Win=261376 Len=0
 283 13.625024   20.207.73.85    192.168.1.2    TCP        54 443 → 16052 [ACK] Seq=7251 Ack=598 Win=68608 Len=0
 284 15.380504   192.168.1.2     3.6.211.252    TLSv1.2    78 Application Data
 285 15.380783   192.168.1.2     3.6.211.252    TCP        54 16022 → 443 [FIN, ACK] Seq=25 Ack=1 Win=514 Len=0
 286 15.382423   192.168.1.2     192.168.1.1    DNS        81 Standard query 0x0ae3 A threat.api.mcafee.com
 287 15.395727   3.6.211.252     192.168.1.2    TCP        54 443 → 16022 [RST, ACK] Seq=1 Ack=25 Win=514 Len=0
 288 15.397425   192.168.1.1     192.168.1.2    DNS       148 Standard query response 0x0ae3 A threat.api.mcafee.com CNAME threat.api.mcafee.net A 3.6.211.252 A 13.1…
 289 15.400191   192.168.1.2     3.6.211.252    TCP        66 16056 → 443 [SYN] Seq=0 Win=64240 Len=0 MSS=1460 WS=256 SACK_PERM
```

```
> Frame 287: 54 bytes on wire (432 bits), 54 bytes captured (432 bits) on interface \Device\
> Ethernet II, Src: zte_24:08:37 (5c:a4:f4:24:08:37), Dst: Intel_f7:20:ec (50:84:92:f7:20:ec
> Internet Protocol Version 4, Src: 3.6.211.252, Dst: 192.168.1.2
> Transmission Control Protocol, Src Port: 443, Dst Port: 16022, Seq: 1, Ack: 25, Len: 0
```

```
0000  50 84 92 f7 20 ec 5c a4  f4 24 08 37 08 00 45 00   P··· ·\· ·$·7··E·
0010  00 28 aa 46 40 00 61 06  d6 dc 03 06 d3 fc c0 a8   ·(·F@·a· ········
0020  01 02 01 bb 3e 96 23 b2  d2 9a 57 01 6c ff 50 14   ····>·#· ··W·l·P·
0030  02 02 1a 83 00 00                                  ······
```