Cryptography and Network Security Lab

Lab 7

AES implementation

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1. Implement AES

Code:

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

enum errorCode
{
    SUCCESS = 0,
    ERROR_AES_UNKNOWN_KEYSIZE,
    ERROR_MEMORY_ALLOCATION_FAILED,
};

unsigned char sbox[256] = {

    0x63, 0x7c, 0x77, 0x7b, 0xf2, 0x6b, 0x6f, 0xc5, 0x30, 0x01, 0x67, 0x2b,
0xfe, 0xd7, 0xab, 0x76,
    0xca, 0x82, 0xc9, 0x7d, 0xfa, 0x59, 0x47, 0xf0, 0xad, 0xd4, 0xa2, 0xaf,
0x9c, 0xa4, 0x72, 0xc0,
    0xb7, 0xfd, 0x93, 0x26, 0x36, 0x3f, 0xf7, 0xcc, 0x34, 0xa5, 0xe5, 0xf1,
0x71, 0xd8, 0x31, 0x15,
    0x04, 0xc7, 0x23, 0xc3, 0x18, 0x96, 0x05, 0x9a, 0x07, 0x12, 0x80, 0xe2,
0xeb, 0x27, 0xb2, 0x75,
    0x09, 0x83, 0x2c, 0x1a, 0x1b, 0x6e, 0x5a, 0xa0, 0x52, 0x3b, 0xd6, 0xb3,
0x29, 0xe3, 0x2f, 0x84,
    0x53, 0xd1, 0x00, 0xed, 0x20, 0xfc, 0xb1, 0x5b, 0x6a, 0xcb, 0xbe, 0x39,
0x4a, 0x4c, 0x58, 0xcf,
    0xd0, 0xef, 0xaa, 0xfb, 0x43, 0x4d, 0x33, 0x85, 0x45, 0xf9, 0x02, 0x7f,
0x50, 0x3c, 0x9f, 0xa8,
    0x51, 0xa3, 0x40, 0x8f, 0x92, 0x9d, 0x38, 0xf5, 0xbc, 0xb6, 0xda, 0x21,
0x10, 0xff, 0xf3, 0xd2,
    0xcd, 0x0c, 0x13, 0xec, 0x5f, 0x97, 0x44, 0x17, 0xc4, 0xa7, 0x7e, 0x3d,
0x64, 0x5d, 0x19, 0x73,
    0x60, 0x81, 0x4f, 0xdc, 0x22, 0x2a, 0x90, 0x88, 0x46, 0xee, 0xb8, 0x14,
0xde, 0x5e, 0x0b, 0xdb,
    0xe0, 0x32, 0x3a, 0x0a, 0x49, 0x06, 0x24, 0x5c, 0xc2, 0xd3, 0xac, 0x62,
0x91, 0x95, 0xe4, 0x79,
    0xe7, 0xc8, 0x37, 0x6d, 0x8d, 0xd5, 0x4e, 0xa9, 0x6c, 0x56, 0xf4, 0xea,
0x65, 0x7a, 0xae, 0x08,
    0xba, 0x78, 0x25, 0x2e, 0x1c, 0xa6, 0xb4, 0xc6, 0xe8, 0xdd, 0x74, 0x1f,
0x4b, 0xbd, 0x8b, 0x8a,
    0x70, 0x3e, 0xb5, 0x66, 0x48, 0x03, 0xf6, 0x0e, 0x61, 0x35, 0x57, 0xb9,
0x86, 0xc1, 0x1d, 0x9e,
    0xe1, 0xf8, 0x98, 0x11, 0x69, 0xd9, 0x8e, 0x94, 0x9b, 0x1e, 0x87, 0xe9,
0xce, 0x55, 0x28, 0xdf,
    0x8c, 0xa1, 0x89, 0x0d, 0xbf, 0xe6, 0x42, 0x68, 0x41, 0x99, 0x2d, 0x0f,
0xb0, 0x54, 0xbb, 0x16};
```

```
unsigned char rsbox[256] =
    {0x52, 0x09, 0x6a, 0xd5, 0x30, 0x36, 0xa5, 0x38, 0xbf, 0x40, 0xa3, 0x9e,
0x81, 0xf3, 0xd7, 0xfb, 0x7c, 0xe3, 0x39, 0x82, 0x9b, 0x2f, 0xff, 0x87, 0x34,
0x8e, 0x43, 0x44, 0xc4, 0xde, 0xe9, 0xcb, 0x54, 0x7b, 0x94, 0x32, 0xa6, 0xc2,
0x23, 0x3d, 0xee, 0x4c, 0x95, 0x0b, 0x42, 0xfa, 0xc3, 0x4e, 0x08, 0x2e, 0xa1,
0x66, 0x28, 0xd9, 0x24, 0xb2, 0x76, 0x5b, 0xa2, 0x49, 0x6d, 0x8b, 0xd1, 0x25,
0x72, 0xf8, 0xf6, 0x64, 0x86, 0x68, 0x98, 0x16, 0xd4, 0xa4, 0x5c, 0xcc, 0x5d,
0x65, 0xb6, 0x92, 0x6c, 0x70, 0x48, 0x50, 0xfd, 0xed, 0xb9, 0xda, 0x5e, 0x15,
0x46, 0x57, 0xa7, 0x8d, 0x9d, 0x84, 0x90, 0xd8, 0xab, 0x00, 0x8c, 0xbc, 0xd3,
0x0a, 0xf7, 0xe4, 0x58, 0x05, 0xb8, 0xb3, 0x45, 0x06, 0xd0, 0x2c, 0x1e, 0x8f,
0xca, 0x3f, 0x0f, 0x02, 0xc1, 0xaf, 0xbd, 0x03, 0x01, 0x13, 0x8a, 0x6b, 0x3a,
0x91, 0x11, 0x41, 0x4f, 0x67, 0xdc, 0xea, 0x97, 0xf2, 0xcf, 0xce, 0xf0, 0xb4,
0xe6, 0x73, 0x96, 0xac, 0x74, 0x22, 0xe7, 0xad, 0x35, 0x85, 0xe2, 0xf9, 0x37,
0xe8, 0x1c, 0x75, 0xdf, 0x6e, 0x47, 0xf1, 0x1a, 0x71, 0x1d, 0x29, 0xc5, 0x89,
0x6f, 0xb7, 0x62, 0x0e, 0xaa, 0x18, 0xbe, 0x1b, 0xfc, 0x56, 0x3e, 0x4b, 0xc6,
0xd2, 0x79, 0x20, 0x9a, 0xdb, 0xc0, 0xfe, 0x78, 0xcd, 0x5a, 0xf4, 0x1f, 0xdd,
0xa8, 0x33, 0x88, 0x07, 0xc7, 0x31, 0xb1, 0x12, 0x10, 0x59, 0x27, 0x80, 0xec,
0x5f, 0x60, 0x51, 0x7f, 0xa9, 0x19, 0xb5, 0x4a, 0x0d, 0x2d, 0xe5, 0x7a, 0x9f,
0x93, 0xc9, 0x9c, 0xef, 0xa0, 0xe0, 0x3b, 0x4d, 0xae, 0x2a, 0xf5, 0xb0, 0xc8,
0xeb, 0xbb, 0x3c, 0x83, 0x53, 0x99, 0x61, 0x17, 0x2b, 0x04, 0x7e, 0xba, 0x77,
0xd6, 0x26, 0xe1, 0x69, 0x14, 0x63, 0x55, 0x21, 0x0c, 0x7d};

unsigned char getSBoxValue(unsigned char num);
unsigned char getSBoxInvert(unsigned char num);

void rotate(unsigned char *word);

unsigned char Rcon[255] = {
    0x8d, 0x01, 0x02, 0x04, 0x08, 0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c,
0xd8,
    0xab, 0x4d, 0x9a, 0x2f, 0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a, 0xd4,
0xb3,
    0x7d, 0xfa, 0xef, 0xc5, 0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2,
0x9f,
    0x25, 0x4a, 0x94, 0x33, 0x66, 0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb,
0x8d,
    0x01, 0x02, 0x04, 0x08, 0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c, 0xd8,
0xab,
    0x4d, 0x9a, 0x2f, 0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a, 0xd4, 0xb3,
0x7d,
    0xfa, 0xef, 0xc5, 0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2, 0x9f,
0x25,
    0x4a, 0x94, 0x33, 0x66, 0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb, 0x8d,
0x01,
    0x02, 0x04, 0x08, 0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c, 0xd8, 0xab,
0x4d,
    0x9a, 0x2f, 0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a, 0xd4, 0xb3, 0x7d,
0xfa,
    0xef, 0xc5, 0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2, 0x9f, 0x25,
0x4a,
    0x94, 0x33, 0x66, 0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb, 0x8d, 0x01,
0x02,
    0x04, 0x08, 0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c, 0xd8, 0xab, 0x4d,
0x9a,
    0x2f, 0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a, 0xd4, 0xb3, 0x7d, 0xfa,
0xef,
    0xc5, 0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2, 0x9f, 0x25, 0x4a,
0x94,
    0x33, 0x66, 0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb, 0x8d, 0x01, 0x02,
0x04,
    0x08, 0x10, 0x20, 0x40, 0x80, 0x1b, 0x36, 0x6c, 0xd8, 0xab, 0x4d, 0x9a,
0x2f,
    0x5e, 0xbc, 0x63, 0xc6, 0x97, 0x35, 0x6a, 0xd4, 0xb3, 0x7d, 0xfa, 0xef,
0xc5,
    0x91, 0x39, 0x72, 0xe4, 0xd3, 0xbd, 0x61, 0xc2, 0x9f, 0x25, 0x4a, 0x94,
0x33,
    0x66, 0xcc, 0x83, 0x1d, 0x3a, 0x74, 0xe8, 0xcb};

unsigned char getRconValue(unsigned char num);

void core(unsigned char *word, int iteration);

enum keySize
{
    SIZE_16 = 16,
    SIZE_24 = 24,
    SIZE_32 = 32
};

void expandKey(unsigned char *expandedKey, unsigned char *key, enum keySize,
size_t expandedKeySize);

void subBytes(unsigned char *state);

void shiftRows(unsigned char *state);
void shiftRow(unsigned char *state, unsigned char nbr);

void addRoundKey(unsigned char *state, unsigned char *roundKey);

unsigned char galois_multiplication(unsigned char a, unsigned char b);
void mixColumns(unsigned char *state);
void mixColumn(unsigned char *column);

void aes_round(unsigned char *state, unsigned char *roundKey);

void createRoundKey(unsigned char *expandedKey, unsigned char *roundKey);
```

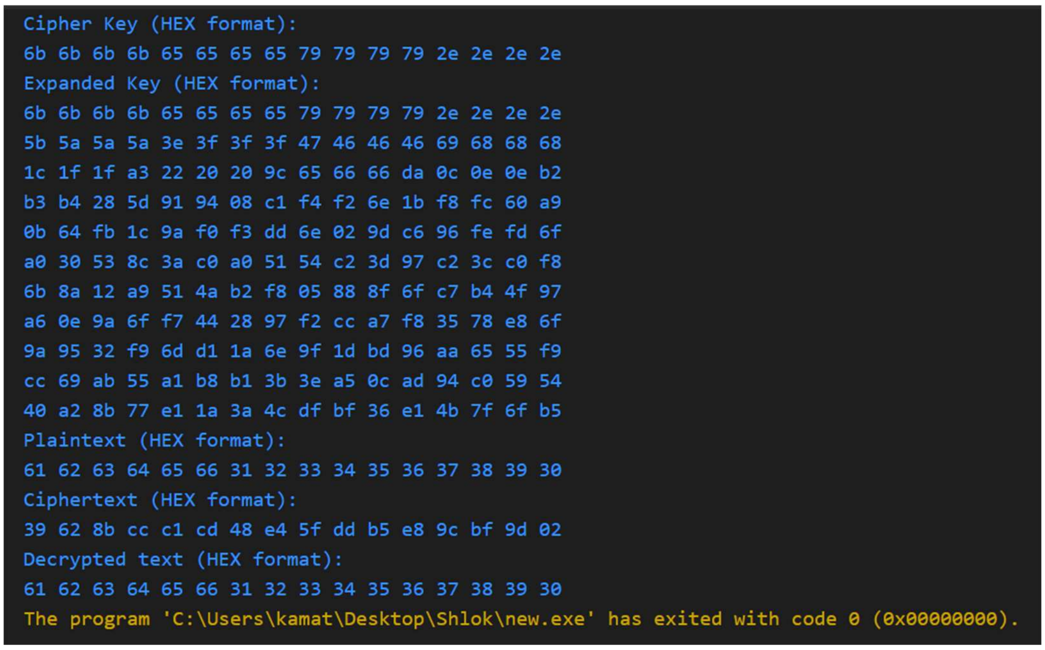
```c
void aes_main(unsigned char *state, unsigned char *expandedKey, int
nbrRounds);

char aes_encrypt(unsigned char *input, unsigned char *output, unsigned char
*key, enum keySize size);

void invSubBytes(unsigned char *state);
void invShiftRows(unsigned char *state);
void invShiftRow(unsigned char *state, unsigned char nbr);
void invMixColumns(unsigned char *state);
void invMixColumn(unsigned char *column);
void aes_invRound(unsigned char *state, unsigned char *roundKey);
void aes_invMain(unsigned char *state, unsigned char *expandedKey, int
nbrRounds);
char aes_decrypt(unsigned char *input, unsigned char *output, unsigned char
*key, enum keySize size);

int main(int argc, char *argv[])
{

    int expandedKeySize = 176;

    unsigned char expandedKey[expandedKeySize];

    unsigned char key[16] = {'k', 'k', 'k', 'k', 'e', 'e', 'e', 'e', 'y', 'y',
'y', 'y', '.', '.', '.', '.'};

    enum keySize size = SIZE_16;

    unsigned char plaintext[16] = {'a', 'b', 'c', 'd', 'e', 'f', '1', '2',
'3', '4', '5', '6', '7', '8', '9', '0'};

    unsigned char ciphertext[16];

    unsigned char decryptedtext[16];

    int i;

    printf("**************************************************\n");
    printf("*   Basic implementation of AES algorithm in C   *\n");
    printf("**************************************************\n");

    printf("\nCipher Key (HEX format):\n");

    for (i = 0; i < 16; i++)
    {

        printf("%2.2x%c", key[i], ((i + 1) % 16) ? ' ' : '\n');
    }

    expandKey(expandedKey, key, size, expandedKeySize);

    printf("\nExpanded Key (HEX format):\n");

    for (i = 0; i < expandedKeySize; i++)
    {
        printf("%2.2x%c", expandedKey[i], ((i + 1) % 16) ? ' ' : '\n');
    }

    printf("\nPlaintext (HEX format):\n");

    for (i = 0; i < 16; i++)
    {
        printf("%2.2x%c", plaintext[i], ((i + 1) % 16) ? ' ' : '\n');
    }

    aes_encrypt(plaintext, ciphertext, key, SIZE_16);

    printf("\nCiphertext (HEX format):\n");

    for (i = 0; i < 16; i++)
    {
        printf("%2.2x%c", ciphertext[i], ((i + 1) % 16) ? ' ' : '\n');
    }

    aes_decrypt(ciphertext, decryptedtext, key, SIZE_16);

    printf("\nDecrypted text (HEX format):\n");

    for (i = 0; i < 16; i++)
    {
        printf("%2.2x%c", decryptedtext[i], ((i + 1) % 16) ? ' ' : '\n');
    }

    return 0;
}

unsigned char getSBoxValue(unsigned char num)
{
    return sbox[num];
}

unsigned char getSBoxInvert(unsigned char num)
{
    return rsbox[num];
}
```

```
void rotate(unsigned char *word)
{
    unsigned char c;
    int i;

    c = word[0];
    for (i = 0; i < 3; i++)
        word[i] = word[i + 1];
    word[3] = c;
}

unsigned char getRconValue(unsigned char num)
{
    return Rcon[num];
}

void core(unsigned char *word, int iteration)
{
    int i;

    rotate(word);

    for (i = 0; i < 4; ++i)
    {
        word[i] = getSBoxValue(word[i]);
    }

    word[0] = word[0] ^ getRconValue(iteration);
}

void expandKey(unsigned char *expandedKey,
               unsigned char *key,
               enum keySize size,
               size_t expandedKeySize)
{

    int currentSize = 0;
    int rconIteration = 1;
    int i;
    unsigned char t[4] = {0};

    for (i = 0; i < size; i++)
        expandedKey[i] = key[i];
    currentSize += size;

    while (currentSize < expandedKeySize)
    {
        for (i = 0; i < 4; i++)
        {
            t[i] = expandedKey[(currentSize - 4) + i];
        }

        if (currentSize % size == 0)
        {
            core(t, rconIteration++);
        }

        if (size == SIZE_32 && ((currentSize % size) == 16))
        {
            for (i = 0; i < 4; i++)
                t[i] = getSBoxValue(t[i]);
        }

        for (i = 0; i < 4; i++)
        {
            expandedKey[currentSize] = expandedKey[currentSize - size] ^ t[i];
            currentSize++;
        }
    }
}

void subBytes(unsigned char *state)
{
    int i;

    for (i = 0; i < 16; i++)
        state[i] = getSBoxValue(state[i]);
}

void shiftRows(unsigned char *state)
{
    int i;

    for (i = 0; i < 4; i++)
        shiftRow(state + i * 4, i);
}

void shiftRow(unsigned char *state, unsigned char nbr)
{
    int i, j;
    unsigned char tmp;

    for (i = 0; i < nbr; i++)
    {
        tmp = state[0];
        for (j = 0; j < 3; j++)
            state[j] = state[j + 1];
        state[3] = tmp;
    }
}

void addRoundKey(unsigned char *state, unsigned char *roundKey)
{
    int i;
    for (i = 0; i < 16; i++)
        state[i] = state[i] ^ roundKey[i];
}

unsigned char galois_multiplication(unsigned char a, unsigned char b)
{
    unsigned char p = 0;
    unsigned char counter;
    unsigned char hi_bit_set;
    for (counter = 0; counter < 8; counter++)
    {
        if ((b & 1) == 1)
            p ^= a;
        hi_bit_set = (a & 0x80);
        a <<= 1;
        if (hi_bit_set == 0x80)
            a ^= 0x1b;
        b >>= 1;
    }
    return p;
}

void mixColumns(unsigned char *state)
{
    int i, j;
    unsigned char column[4];

    for (i = 0; i < 4; i++)
    {

        for (j = 0; j < 4; j++)
        {
            column[j] = state[(j * 4) + i];
        }

        mixColumn(column);

        for (j = 0; j < 4; j++)
        {
            state[(j * 4) + i] = column[j];
        }
    }
}

void mixColumn(unsigned char *column)
{
    unsigned char cpy[4];
    int i;
    for (i = 0; i < 4; i++)
    {
        cpy[i] = column[i];
    }
    column[0] = galois_multiplication(cpy[0], 2) ^
                galois_multiplication(cpy[3], 1) ^
                galois_multiplication(cpy[2], 1) ^
                galois_multiplication(cpy[1], 3);

    column[1] = galois_multiplication(cpy[1], 2) ^
                galois_multiplication(cpy[0], 1) ^
                galois_multiplication(cpy[3], 1) ^
                galois_multiplication(cpy[2], 3);

    column[2] = galois_multiplication(cpy[2], 2) ^
                galois_multiplication(cpy[1], 1) ^
                galois_multiplication(cpy[0], 1) ^
                galois_multiplication(cpy[3], 3);

    column[3] = galois_multiplication(cpy[3], 2) ^
                galois_multiplication(cpy[2], 1) ^
                galois_multiplication(cpy[1], 1) ^
                galois_multiplication(cpy[0], 3);
}

void aes_round(unsigned char *state, unsigned char *roundKey)
{
    subBytes(state);
    shiftRows(state);
    mixColumns(state);
    addRoundKey(state, roundKey);
}

void createRoundKey(unsigned char *expandedKey, unsigned char *roundKey)
{
    int i, j;

    for (i = 0; i < 4; i++)
    {

        for (j = 0; j < 4; j++)
            roundKey[(i + (j * 4))] = expandedKey[(i * 4) + j];
    }
}

void aes_main(unsigned char *state, unsigned char *expandedKey, int nbrRounds)
{
    int i = 0;

    unsigned char roundKey[16];

    createRoundKey(expandedKey, roundKey);
    addRoundKey(state, roundKey);

    for (i = 1; i < nbrRounds; i++)
    {
        createRoundKey(expandedKey + 16 * i, roundKey);
        aes_round(state, roundKey);
    }

    createRoundKey(expandedKey + 16 * nbrRounds, roundKey);
    subBytes(state);
    shiftRows(state);
    addRoundKey(state, roundKey);
}

char aes_encrypt(unsigned char *input,
                 unsigned char *output,
                 unsigned char *key,
                 enum keySize size)
{

    int expandedKeySize;

    int nbrRounds;

    unsigned char *expandedKey;

    unsigned char block[16];

    int i, j;

    switch (size)
    {
    case SIZE_16:
        nbrRounds = 10;
        break;
    case SIZE_24:
        nbrRounds = 12;
        break;
    case SIZE_32:
        nbrRounds = 14;
        break;
    default:
        return ERROR_AES_UNKNOWN_KEYSIZE;
        break;
    }

    expandedKeySize = (16 * (nbrRounds + 1));

    expandedKey = (unsigned char *)malloc(expandedKeySize * sizeof(unsigned
char));

    if (expandedKey == NULL)
    {
        return ERROR_MEMORY_ALLOCATION_FAILED;
    }
    else
    {

        for (i = 0; i < 4; i++)
        {

            for (j = 0; j < 4; j++)
                block[(i + (j * 4))] = input[(i * 4) + j];
        }

        expandKey(expandedKey, key, size, expandedKeySize);

        aes_main(block, expandedKey, nbrRounds);

        for (i = 0; i < 4; i++)
        {

            for (j = 0; j < 4; j++)
                output[(i * 4) + j] = block[(i + (j * 4))];
        }

        free(expandedKey);
        expandedKey = NULL;
    }

    return SUCCESS;
}
```

```
void invSubBytes(unsigned char *state)
{
    int i;

    for (i = 0; i < 16; i++)
        state[i] = getSBoxInvert(state[i]);
}

void invShiftRows(unsigned char *state)
{
    int i;

    for (i = 0; i < 4; i++)
        invShiftRow(state + i * 4, i);
}

void invShiftRow(unsigned char *state, unsigned char nbr)
{
    int i, j;
    unsigned char tmp;

    for (i = 0; i < nbr; i++)
    {
        tmp = state[3];
        for (j = 3; j > 0; j--)
            state[j] = state[j - 1];
        state[0] = tmp;
    }
}

void invMixColumns(unsigned char *state)
{
    int i, j;
    unsigned char column[4];

    for (i = 0; i < 4; i++)
    {

        for (j = 0; j < 4; j++)
        {
            column[j] = state[(j * 4) + i];
        }

        invMixColumn(column);

        for (j = 0; j < 4; j++)
        {
```

```c
            state[(j * 4) + i] = column[j];
        }
    }
}

void invMixColumn(unsigned char *column)
{
    unsigned char cpy[4];
    int i;
    for (i = 0; i < 4; i++)
    {
        cpy[i] = column[i];
    }
    column[0] = galois_multiplication(cpy[0], 14) ^
                galois_multiplication(cpy[3], 9) ^
                galois_multiplication(cpy[2], 13) ^
                galois_multiplication(cpy[1], 11);
    column[1] = galois_multiplication(cpy[1], 14) ^
                galois_multiplication(cpy[0], 9) ^
                galois_multiplication(cpy[3], 13) ^
                galois_multiplication(cpy[2], 11);
    column[2] = galois_multiplication(cpy[2], 14) ^
                galois_multiplication(cpy[1], 9) ^
                galois_multiplication(cpy[0], 13) ^
                galois_multiplication(cpy[3], 11);
    column[3] = galois_multiplication(cpy[3], 14) ^
                galois_multiplication(cpy[2], 9) ^
                galois_multiplication(cpy[1], 13) ^
                galois_multiplication(cpy[0], 11);
}

void aes_invRound(unsigned char *state, unsigned char *roundKey)
{

    invShiftRows(state);
    invSubBytes(state);
    addRoundKey(state, roundKey);
    invMixColumns(state);
}

void aes_invMain(unsigned char *state, unsigned char *expandedKey, int
nbrRounds)
{
    int i = 0;

    unsigned char roundKey[16];

    createRoundKey(expandedKey + 16 * nbrRounds, roundKey);
    addRoundKey(state, roundKey);

    for (i = nbrRounds - 1; i > 0; i--)
    {
        createRoundKey(expandedKey + 16 * i, roundKey);
        aes_invRound(state, roundKey);
    }

    createRoundKey(expandedKey, roundKey);
    invShiftRows(state);
    invSubBytes(state);
    addRoundKey(state, roundKey);
}

char aes_decrypt(unsigned char *input,
                 unsigned char *output,
                 unsigned char *key,
                 enum keySize size)
{

    int expandedKeySize;

    int nbrRounds;

    unsigned char *expandedKey;

    unsigned char block[16];

    int i, j;

    switch (size)
    {
    case SIZE_16:
        nbrRounds = 10;
        break;
    case SIZE_24:
        nbrRounds = 12;
        break;
    case SIZE_32:
        nbrRounds = 14;
        break;
    default:
        return ERROR_AES_UNKNOWN_KEYSIZE;
        break;
    }

    expandedKeySize = (16 * (nbrRounds + 1));
    expandedKey = (unsigned char *)malloc(expandedKeySize * sizeof(unsigned
char));

    if (expandedKey == NULL)
    {
        return ERROR_MEMORY_ALLOCATION_FAILED;
    }
    else
    {

        for (i = 0; i < 4; i++)
        {

            for (j = 0; j < 4; j++)
                block[(i + (j * 4))] = input[(i * 4) + j];
        }

        expandKey(expandedKey, key, size, expandedKeySize);

        aes_invMain(block, expandedKey, nbrRounds);

        for (i = 0; i < 4; i++)
        {

            for (j = 0; j < 4; j++)
                output[(i * 4) + j] = block[(i + (j * 4))];
        }

        free(expandedKey);
        expandedKey = NULL;
    }

    return SUCCESS;
}
```

OUTPUT:



```
Cipher Key (HEX format):
6b 6b 6b 6b 65 65 65 65 79 79 79 79 2e 2e 2e 2e
Expanded Key (HEX format):
6b 6b 6b 6b 65 65 65 65 79 79 79 79 2e 2e 2e 2e
5b 5a 5a 5a 3e 3f 3f 3f 47 46 46 46 69 68 68 68
1c 1f 1f a3 22 20 20 9c 65 66 66 da 0c 0e 0e b2
b3 b4 28 5d 91 94 08 c1 f4 f2 6e 1b f8 fc 60 a9
0b 64 fb 1c 9a f0 f3 dd 6e 02 9d c6 96 fe fd 6f
a0 30 53 8c 3a c0 a0 51 54 c2 3d 97 c2 3c c0 f8
6b 8a 12 a9 51 4a b2 f8 05 88 8f 6f c7 b4 4f 97
a6 0e 9a 6f f7 44 28 97 f2 cc a7 f8 35 78 e8 6f
9a 95 32 f9 6d d1 1a 6e 9f 1d bd 96 aa 65 55 f9
cc 69 ab 55 a1 b8 b1 3b 3e a5 0c ad 94 c0 59 54
40 a2 8b 77 e1 1a 3a 4c df bf 36 e1 4b 7f 6f b5
Plaintext (HEX format):
61 62 63 64 65 66 31 32 33 34 35 36 37 38 39 30
Ciphertext (HEX format):
39 62 8b cc c1 cd 48 e4 5f dd b5 e8 9c bf 9d 02
Decrypted text (HEX format):
61 62 63 64 65 66 31 32 33 34 35 36 37 38 39 30
The program 'C:\Users\kamat\Desktop\Shlok\new.exe' has exited with code 0 (0x00000000).
```