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Implementation of Text Encryption using Elliptic Curve Cryptography

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Abstract

Elliptic Curve Cryptography has been a recent research area in the field of Cryptography. It provides higher level of security with lesser key size compared to other Cryptographic techniques. A new technique has been proposed in this paper where the classic technique of mapping the characters to affine points in the elliptic curve has been removed. The corresponding ASCII values of the plain text are paired up. The paired values serve as input for the Elliptic curve cryptography. This new technique avoids the costly operation of mapping and the need to share the common lookup table between the sender and the receiver. The algorithm is designed in such a way that it can be used to encrypt or decrypt any type of script with defined ASCII values.

1. Introduction

Cryptography is transformation of plain message to make them secure and immune from intruders. Elliptic Curve Cryptography (ECC) is a public key cryptography developed independently by Victor Miller and Neal Koblitz in the year 1985. In Elliptic Curve Cryptography we will be using the curve equation of the form

$$y^2 = x^3 + ax + b \tag{1}$$

which is known as Weierstrass equation, where a and b are the constant with

$$4a^3 + 27b^2 \neq 0 \tag{2}$$

1.1 Mathematics in elliptic curve cryptography over finite field

Cryptographic operation on elliptic curve over finite field are done using the coordinate points of the elliptic curve. Elliptic curve over finite field equation is given by:

$$y^2 = \{x^3 + ax + b\} \bmod \{p\} \tag{3}$$

Certain formula are defined for operation with the points.

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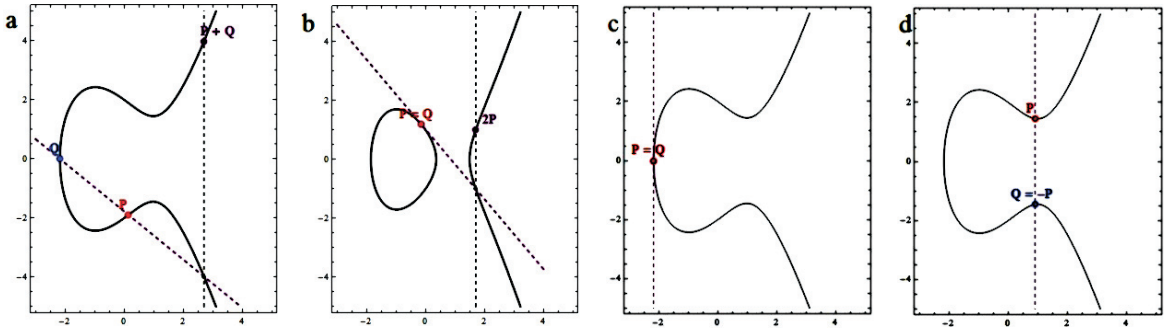*E-mail address:* [a]ldsingh.cse@gmail.com

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Fig. 1.　(a) Point addition; (b) Point doubling; (c) Point at infinity when y coordinates are both 0; (d) Point at infinity when the coordinates are mirror image of each other.

1.1.1 Point addition

The two point $P(x_1, y_1)$ and $Q(x_2, y_2)$ are distinct. $P + Q = R(x_3, y_3)$ is given by the following calculation. Figure 1(a) shows graphical representation of Point Addition operation.

$$x_3 = \{\lambda^2 - x_1 - x_2\} \bmod p \tag{4}$$

$$y_3 = \{\lambda(x_1 - x_3) - y_1\} \bmod p \tag{5}$$

where

$$\lambda = \frac{y_2 - y_1}{x_2 - x_1} \bmod p \tag{6}$$

1.1.2 Point Doubling

The two point $P(x_1, y_1)$ and $Q(x_1, y_1)$ overlap. $P + Q = R(x_3, y_3)$ is given by the following calculation. Figure 1(b) shows graphical representation of Point Doubling operation.

$$x_3 = \{\lambda^2 - 2x_1\} \bmod p \tag{7}$$

$$y_3 = \{\lambda(x_1 - x_3) - y_1\} \bmod p \tag{8}$$

where

$$\lambda = \frac{3x_1^2 + a}{2y_1} \bmod p \tag{9}$$

1.1.3 Point multiplication

Let P be any point on the elliptic curve. Multiplication operation over P is defined by the repeated addition. $kP = P + P + P + \cdots + k$ times.

1.1.4 Point at infinity

If $x_1 = x_2$ and $y_1 = y_2 = 0$ or $x_1 = x_2$ and $y_1 = -y_2$, the points is said to intersect at infinity denoted by O. Figure 1(c) and 1(d) shows graphical representation of Point at Infinity.

1.1.5 Finding Inverse Modulo

Let us consider an elliptic curve

$$y^2 = x^3 + 2x + 4 \bmod 7 \tag{10}$$

It has got the following coordinate points. $\{O, \{0, 2\}, \{0, 5\}, \{1, 0\}, \{2, 3\}, \{2, 4\}, \{3, 3\}, \{3, 4\}, \{6, 1\}, \{6, 6\}\}$. To perform point addition of two points $\{0, 5\}$ and $\{3, 4\}$, we need to find lambda.

$$\lambda = \frac{4 - 5}{3 - 0} \bmod 7 \tag{11}$$

$$\lambda = \frac{-1}{3} \bmod 7 \tag{12}$$

For finding Inverse Modulo we have used Extended Euclidean Algorithm shown in Table 1.

Table 1. Finding inverse modulo using extended euclidean algorithm.

Q	R1	R2	R	T1	T2	T
2	7	3	1	0	1	−2
3	3	1	0	1	−2	7

Where

- Q = Quotient for $R1$ divided by $R2$;
- $R1$ = Modulus value initially, followed by left shift of previous value of $R2$ in later cases.
- $R2$ = Denominator value initially, followed by left shift of value from previous R in later cases.
- R = Remainder of $R1$ divided by $R2$.
- $T1$ = 0 initially, followed by left shift of previous value from $T2$.
- $T2$ = 1 initially, followed by right shift of previous value from T.
- $T = T1 - Q * T2$.
- Continue till $R = 0$, and inverse modulo is given by the value at $T2$.

$$\lambda = -1 * -2 \bmod 7 \tag{13}$$

$$\lambda = 2 \tag{14}$$

1.2 Elliptic curve cryptography

Since ECC is a public key cryptography, we require a public key and a private key. Consider Alice and Bob are the two communicating parties. They agree upon a common Elliptic curve equation and a generator G. Let Alice and Bob private keys be nA and nB respectively. Alice and Bob public keys are given by

$$P_a = nAG \tag{15}$$

and

$$P_b = nBG \tag{16}$$

respectively. If Alice want to send a message 'Pm' to Bob, Alice uses Bob's public key to encrypt the message. The cipher text is given by

$$P_c = \{kG, P_m + kP_b\} \tag{17}$$

where 'k' is a random integer. The random 'k' make sure that even for a same message the cipher text generated is different each time. This gives a hard time for someone who is illegally trying to decrypt the message. Bob decrypts the message by subtracting the coordinate of 'kG' multiplied by nB from '$Pm + kPb$'.

$$P_m = \{P_m + kP_b - nBkG\} \tag{18}$$

Here multiplied does not mean simple multiplication that we do in algebra, rather it is multiple addition of points using the point addition method stated above in point multiplication. As the multiplier nB is the secret key of Bob, only Bob can decrypt the message sent by Alice.

2. Literature Review

Many authors have exploited the strength of ECC and came up with implementation in various tasks of public key cryptography like authentication, digital signature, key agreement and encryption. Victor S. Miller explain the use of Elliptic curves in Cryptography. He proposed an encryption scheme similar to Diffie-Hellman key exchange protocol but faster by around 20 percent[1]. Neal Koblitz explain about the elliptic curves over finite fields for public key cryptosystems. He explain that the discrete logarithm problem is harder for finite group field compared to binary field. He also gave a theorem for nonsmoothness existing in cyclic subgroup generated by a global point[2]. Neal Koblitz, Alfred Menezes and Scott Vanstone extended the idea of discrete logarithmic problem used in public key cryptography of Diffie-Hellman to elliptic curve group. It provided smaller block size, high speed and high security[3]. Darrel Hankerson, Alfred Menezes and Scott Vanstone wrote a book called Guide to Elliptic Curve Cryptography and it provide various details of elliptic curve arithmetic, cryptographic protocols and implementation issues[4]. Lawrence C. Washington wrote a book called Elliptic Curves: Number Theory and Cryptography. It provides proofs to many theorem to understand elliptic curves[5]. Jorko Teeriaho gave a very clear example implementation of ECC-DH key exchange, ECC encryption, Elliptic Curve Digital Signature using Mathematica[6]. S. Maria Celestin and K. Muneeswaran implemented text cryptography using ECC by first transforming the message in ASCII values form and mapping into affine points of Elliptic curve by performing point addition of the ASCII value times the Generator[7]. Sarvana, Suneetha and Chandrasekhar design a method to communicate with multiple parties securely, non-repudiatively in authentic way using ECC with some extra parameters[8]. Jarvinen. K, Helsinki and Skytta. J discusses parallelization of elliptic curve cryptography where the latency of point multiplication is reduced using parallel multiple field multiplier technique with Koblitz curves[9]. Amara M. and Siad A explains the network security role by ECC with smaller key size and compares ECC with RSA and conclude ECC as better choice for encryption[10]. Gopinath Ganapathy and K. Mani design an ECC system using Fuzzy Modular Arithmetic in AT89C51 microcontroller. It observed that, encryption and decryption with fuzzy modular arithmetic consumes less time compared to non-fuzzy modular arithmetic[11]. Scott A. Vansfone provides an overview of current ECC standards and its application and advantages[12]. W. Stalling has given a detailed explanation of various cryptographic technique in his book Cryptography and Network Security[14]. Loai Tawalbeh, Moad Mowafi and Walid Aljoby used ECC for performing encryption along with multimedia compression and analyzed encryption efficiency, compression efficiency, codec compliance and security[15]. Balamurugan. R, Kamalakannan. V, Rahul Ganth. D and Tamilselvan. S propose a fast mapping technique using a non singular matrix. First they map the message to points on elliptic curve and later uses ElGamal encryption method to encode the points using a non singular matrix. During decryption inverse of the non singular matrix is used[17]. Megha Kolhekar and Anita Jadhav describe a brief background of encryption/decryption and key exchange using ECC. They have used C++ to implement text encryption. They have used mapping table to map the ASCII value to Elliptic curve coordinate. Reverse mapping is used while decryption[18].

3. Motivation

Various authors who have implemented text encryption and decryption using ECC have used agreed upon table which consist of characters and ECC coordinates mapping or used the ASCII value of the characters to produce affine elliptic curve coordinates by performing point multiplication operation with generator 'G' and the corresponding ASCII value of the character. We have come up with a novel idea where use of mapping on common look up table
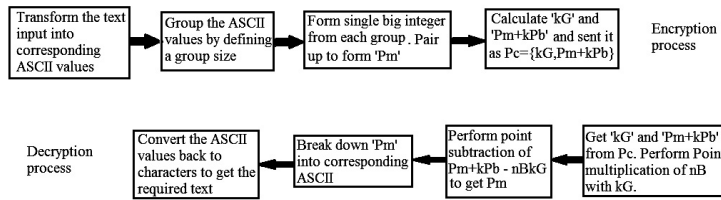
Fig. 2.   (a) Block diagram for encryption/decryption process.

between the sender and receiver has been completely removed. The proposed method is also well suited for large size data as we have designed to encrypt in terms of blocks consisting of multiple characters. Moreover, the algorithm does not limit itself just for English script but it can be used for any script with defined ASCII values.

4. Proposed Algorithm

The communicating parties agrees upon an Elliptic curve equation

$$y^2 = x^3 + ax + b \bmod p \tag{19}$$

with the generator 'G' and makes the public keys 'Pa' and 'Pb' known to all and private keys 'nA' and 'nB' are kept secret. Here, we do not map the ASCII values of the characters to affine points of the elliptic curve. We group the ASCII values of the characters and perform cryptographic operation on the group. The size of each group is given by

$$\text{group size} = \text{Length}[\text{IntegerDigits}[p, 65536]] - 1 \tag{20}$$

IntegerDigit $[n, b]$ function in Mathematica gives a list of the base b digits in the integer n. Here, we choose base as 65536 because ASCII value is defined till 65535. Length is used to count the number of elements in the given expression. The group size help us to find the maximum number of characters that can be grouped up. Each group is converted into big integer values. We pair up the big integer value and use it as 'Pm' in the ECC operation. Pairing reduces the operation of mapping to elliptic coordinates and the need to share a common look up table. The whole encryption and decryption is shown as a block diagram in Fig. 2(a).

4.1 Encryption

- Obtain the text to be send.
- Convert to its corresponding ASCII values.
- Partition the ASCII value as

$$\text{Partition}[\text{ASCII values, group size, groupsize, 1, \{\}}] \tag{21}$$

  This operation group the ASCII values with size given by group size with no overlapping and the later sub lists that have size lesser than group size are left as it is without padding.
- Each group obtained from the above step is converted into big integer values taking base as 65536.

$$\text{FromDigits}[\text{Group of ASCII values, 65536}] \tag{22}$$

- Pad with 32 to the end of the list from the above step if the count of the above list is odd, to make it even for performing complete pairing. Each single pair will be an input to the ECC system as 'Pm'. We pad with 32 because 32 represents blank space in ASCII code.
- Select random k value, $k = $ Random value with range 1 to $n-1$. Compute kG and kPb using Point multiplication operation.
- Compute $Pm + kPb$ using point addition or point doubling as required.
- Send $Pc = \{kG, Pm + kPb\}$ as cipher text to the receiver side.

4.2 Decryption

- Get the cipher text Pc.
- Get the left part kG and right part $Pm + kPb$ of the Pc separately.
- Multiply with nB to the left part and subtract it from the right part to get Pm.

$$\{P_m + kP_b\} - nBkG = Pm \tag{23}$$

since

$$P_b = nBG. \tag{24}$$

Subtraction operation can be converted to addition by multiplying with -1 to the y coordinate. This operation can be justified with point addition operation. In point addition we used to get the mirror image point over the x-axis. Example:- $\{97, 24\} = \{97, -24\}$.

- The above operation will yield the big integer value which is formed by combining group of ASCII values. Convert it back to list of ASCII values.

$$\text{IntegerDigits[big integer, 65536]} \tag{25}$$

IntegerDigits $[n, b]$ in Mathematica provides a list of the base b digits in the integer n. IntegerDigits and FromDigits function are inverse of each other, so the ASCII values are preserved during encryption and decryption.

- Convert the list of ASCII values to its corresponding characters.

5. Simulation of Text Encryption and Decryption using ECC

The simulation was performed using Mathematica version 10 on Lenovo ideapad Z510 laptop with system configuration of i7 processor @ 2.20 GHz and 8 GB Ram using 192 bit key length NIST (National Institute of Standards and Technology) recommended Elliptic curve parameter[16]. The parameters of the simulation are as follows;

a = -3;

b = 2455155546008943817740293915197451784769108058161191238065;

p = 6277101735386680763835789423207666416083908700390324961279;

nB = 2818646668928496796860388568073962675375777176687436853369;

G = {602046282375688656758213480587526111916698766368846848181, 174050332293622031404857552280219410364023488927386650641};

Pb = {2803000786541617331377384897435095499124748881890727495642, 4269718021105944287201929298168253040958383009157463900739}

5.1 Encryption process

- Input text. The text is shown in Fig. 3(a).
- Its equivalent ASCII values are: {78, 97, 116, 105, 111, 110, 97, 108, 32, 73, 110, 115, 116, 105, 116, 117, 116, 101, 32, 111, 102, 32, 84, 101, 99, 104, 110, 111, 108, 111, 103, 121, 44, 32, 77, 97, 110, 105, 112, 117, 114, 44, 32, 55, 57, 53, 48, 48, 49, 32, 40, 69, 110, 103, 108, 105, 115, 104, 41, 10, 10, 2352, 2366, 2359, 2381, 2335, 2381, 2352, 2368, 2351,..., 40, 74, 97, 112, 97, 110, 101, 115, 101, 41, 10, 10, 25216, 34899, 30740, 31350, 38498, 65292, 26364, 23612, 26222, 29246, 37030, 44, 32, 26578, 29590, 20237, 38646, 38646, 22777, 32, 32, 40, 67, 104, 105, 110, 101, 115, 101, 41, 10}
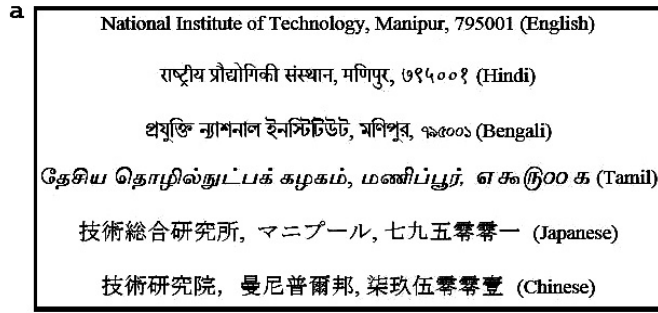
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Fig. 3. (a) Plain text in different script.

- Group the ASCII values with size calculated as Length [IntegerDigits [p, 65536]] - 1 which we get as 11. {{78, 97, 116, 105, 111, 110, 97, 108, 32, 73, 110}, {115, 116, 105, 116, 117, 116, 101, 32, 111, 102, 32}, {84, 101, 99, 104, 110, 111, 108, 111, 103, 121, 44}, ..., {25216, 34899, 30740, 31350, 38498, 65292, 26364, 23612, 26222, 29246, 37030}, {44, 32, 26578, 29590, 20237, 38646, 38646, 22777, 32, 32, 40}, {67, 104, 105, 110, 101, 115, 101, 41, 10}}

- Convert each group into big integers using FromDigits function with base 65536. {1139992909235679848531256128579078362451058502534422, 1680752752152271159881121378607785074282636351900 8,..., 64306794 7105844710730362349228912207882422992241 04, 227994585908952547218205324475788223447 14}

- Pad with 32 at the end of the above list if the number of term is odd, so that pairing can be done. Pair them up as 'Pm', which is one of the parameter used in ECC operation. {1139992909235679848531256128579078362451058502534422, 1680752752152271159881121378607785074282636351900 8,..., 64306794 7105844710730362349228912207882422992241 04, 227994585908952547218205324475788223447 14, 32}

- After calculating cipher text, $Pc = \{kG, Pm + kPb\}$ is obtained as
  $kG = \{9505840657378774338087938749375407269064020996386215 7133, 543754780728205194761539255 6992837333921930872121480709807\}$
  $Pm + kPb = \{\{5357129649847875387947498550298509562929834704857479081282, 7750014998021636504 5807699867380883020434520745864830 2309\}, \{6179418438352156963426038838668574778107168582785 759775636, 59504401840234789090842893432546121496044867877 7222099923\}, ..., \{15309672295115 14 8207238947915026472565057530630124684 09818, 266114311890734093468169472672 6146262505092101 998749657587\}, \{4467437980355690213150750580405244103471477917746833402514, 594284377872156 9318800560891052329721902975606688069237688\}\}$

- Send the cipher text Pc to the communicating party.

Every run of the program will provide different cipher text even with same input text due the random k present in the mathematical operation. We have used only one kG value to minimize the size of the cipher text.

5.2 Decryption process

- Obtain the cipher text Pc i.e kG and $Pm + kPb$.
  $kG = \{9505840657378774338087938749375407269064020996386215 7133, 543754780728205194761539255 6992837333921930872121480709807\}$
  $Pm + kPb = \{\{5357129649847875387947498550298509562929834704857479081282, 7750014998021636504 5807699867380883020434520745864830 2309\}, \{6179418438352156963426038838668574778107168582785 759775636, 59504401840234789090842893432546121496044867877 7222099923\}, ..., \{15309672295115 14 8207238947915026472565057530630124684 09818, 266114311890734093468169472672 6146262505092101 998749657587\}, \{4467437980355690213150750580405244103471477917746833402514, 594284377872156 9318800560891052329721902975606688069237688\}\}$
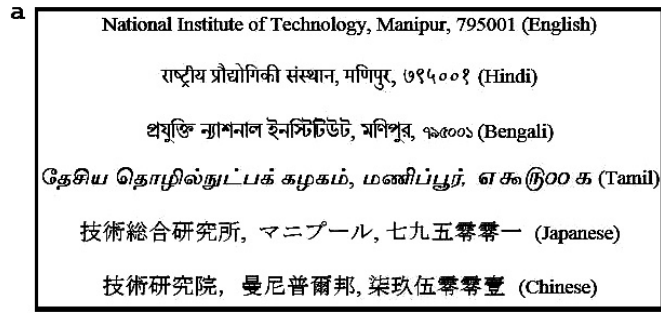
Fig. 4.   (a) Decrypted text.

- Perform Point multiplication using the private key of the receiver nB to kG as well as convert the subtraction operation to addition format.
  $nBkG$ = {31411925285028437914827984995044923033697826871736638953 77, −25448349381216678904 9 31262658721035948283301531274623 84491}
- Perform point addition operation with the above result with the $Pm+kPb$. We get {{1139992909235679848531 2 56128579078362451058502534 22, 1680752752152271159881121378607785074282636351900 8}, {122768 389944749391054080248629988098406227392397356, 46769769584977140992804375150062379259053 55 7678135},...,{3685400357110317424634750136466117899642805126001885 4, 6430679471058447107303 6 234922891220788242299224104}, {22799458590895254721820532447578822344714, 32}}
- Convert the above result to ASCII values using IntegerDigits function with base 65536.{78, 97, 116, 105, 111, 110, 97, 108, 32, 73, 110, 115, 116, 105, 116, 117, 116, 101, 32, 111, 102, 32, 84, 101, 99, 104, 110, 111, 108, 111, 103, 121, 44, 32, 77, 97, 110, 105, 112, 117, 114, 44, 32, 55,...,10, 25216, 34899, 30740, 31350, 38498, 65292, 26364, 23612, 26222, 29246, 37030, 44, 32, 26578, 29590, 20237, 38646, 38646, 22777, 32, 32, 40, 67, 104, 105, 110, 101, 115, 101, 41, 10, 32}
- Perform conversion operation of ASCII values to characters to get the required message as shown in Fig. 4(a).

5.3 Performance comparison

Table 2. Performance comparison.

Method	Words count	Encryption Time	Decryption time	Cipher Data Size	Mapping	Common look up table
Reference 18	1 word	0.20 seconds	0.30 seconds	1.146 KB	Required	Required
Reference 7	409 words	1.95 seconds	0.83 seconds	459.118 KB	Required	Required
Our method	409 words	0.093 seconds	0.14 seconds	21.017 KB	Not Required	Not required

6. Security Analysis

In this section we discuss some analysis of the implemented technique.

6.1 Key space

Security of a cryptographic technique depends a lot on the size of the key used. The algorithm will be known to all. It is always a good choice to have a big key size but we should also keep in mind the computational load when we increase the key size. ECC provides a computationally hard problem called Elliptic Curve Discrete Logarithmic Problem (ECDLP) which help in using a lesser key size compared to other cryptographic technique and still holds the security level high due to ECDLP. In our implementation we have used a 192 bit key length, which is quit good to protect against naive attack. For better security we could increase the key length used for encryption and decryption.
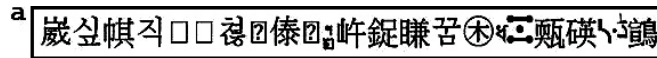
Fig. 5.   (a) Decrypted text with wrong key nB-1.

6.2 Key sensitivity

A slight change in the original key should produce a totally different recovered message. Suppose Alice sends a message "Key Sensitivity" to Bob. The original key is nB = 281864668928496796860388568073962675375771766 87436853369. The recovered message when the key changes to $nB - 1$ = 281864668928496796860388568073962675 37577176687436853368 is shown in Fig. 5(a).

6.3 Ciphertext only attack

Given that the cryptanalyst knows the encryption algorithm and the ciphertext. Until and unless, the cryptanalyst does not have the private key of the receiver the attacker can't reveal the plain text. Applying Brute Force attack would not be of much help when that key size is very large as it will take lots of time in term of years. So, even if the analyst is able to decrypt it, the value of the information will be no more at that time.

6.4 Known plaintext attack

Given that the cryptanalyst knows the encryption algorithm, ciphertext and one or more plaintext-ciphertext pairs formed with the secret key. Since, the implementation generate a different cipher text for the same message due to the random k used in the operation. Known Plaintext attack cannot do any harm.

6.5 Time complexity

The best known attack on ECC is Pollard's Rho method and Pollard Lambda method. Pollard's Rho method is expected to find the private key at most a constant time Sqrt[N] steps, where N is the cyclic order of the Elliptic curve with G as Generator. Pollard's Lambda method is similar to Pollard's Rho method but it uses many starting points to find a match. Pollard's lambda method also expects to find the private key at most a constant time Sqrt[N] steps. If implemented in parallel, the running time to find the private key can be reduced. Both these methods are probabilistic method i.e. they got a high probability but does not guarantees to finish in a constant time of Sqrt[N] steps. For a 192 bit Elliptic Curve that we have used, N value is 6277101735386680763835789423176059013767194773182842284 081.

$$\sqrt{N} \text{steps} = 7.92282 * 10^{28} \text{steps} \qquad (26)$$

Assume each step takes just 0.0000001 second, still it will take around

$$1.90148 * 10^{23} \text{ days} \qquad (27)$$

to find the private key. By this time, the value of the message will be no more and the communicating party may have used a new cryptographic technique or may have changed their keys.

7. Conclusion

In this given paper we have implemented a new technique to perform text cryptography using ECC. Here, we divide the text ASCII values into groups, where group size is determined using 'p' value of ECC parameters with a base which is greater than the maximum ASCII value present in the script. Big integers are formed using each group and the group were paired and fed as 'Pm' into ECC operation. This process helps in removing the costly operation of mapping the characters to coordinates of Elliptic curve as well as the need to share the common look up table. The proposed algorithm can be used for any script with defined ASCII value. From the performance comparison table we

can say that our proposed algorithm has got lot of positive aspect. Encryption and decryption operation is performed very swiftly even with large number of words as input, provides smaller size cipher text compared to other technique which greatly helps in saving bandwidth while sending and we don't require mapping and common look up table. ECC provide a better security with lesser key size compared to the very successful RSA. Elliptic curve discrete logarithm problem is very hard to solve, this property is used in ECC. As ECC provides equal security like other cryptographic system but with less key size, it is very suitable for devices which have power, storage and processing limitation.

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