Study and Implementation of Elliptic Curve Encryption Algorithm for Azerbaijan E-ID Card

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ABSTRACT: The aim of this paper is to examine performance of elliptic curve algorithms in comparison with Rivest, Shamir and Adelman (RSA) and clarify whether the elliptic curve cryptography is better suited for e-ID cards than RSA. We study performance and security of different elliptic curves and encryption algorithm using open source toolkit implemented in framework of the Java Cryptography Architecture. It is observed that the performance and security level of algorithms based on elliptic curves is significantly better than RSA based approach. The elliptic curve approach with smaller key sizes will provide a higher security and the faster execution time even without using a crypto processor in e-ID card chip.

KEYWORDS: e-ID card; elliptic curve; prime number; cryptosystem; security; crypto resistance; RSA; key length; ECDLP.

I. INTRODUCTION

The role of electronic identity cards (e-ID) is essential in harmonization of digital markets between different countries. In order to enable secure authentication and digital signature capabilities of e-ID card a Public Key Infrastructure should be established. This will provide high security for multiple applications in virtual environment and reliable access to e-government services.

Azerbaijan is planning to launch his national electronic identity cards (e-ID) in early 2007. This project should allow citizens to widely use such e-services as online banking, declaration of taxes and signing of contracts. The e-ID chip will contain two certificates and associated keys for authentication and digital signatures. The security of electronic services is accepted to be ensured by legally binding digital certificates of the National Certificate Services Centre. In order to meet smart card security and performance requirements the investigation of Elliptic Curve and RSA cryptosystems should be done. It is well known that main benefits of using Elliptic Curve cryptography in comparison with traditional RSA based cryptosystems are related with smaller key size for higher security, possibility to implement algorithm without crypto processor and faster execution time. There are only a few e-ID card providers which use elliptic curve cryptography [1] [2] [3].
This paper is organized as follows. Section II describes the related work carried out in research fields described in the paper. In the Section III, the basic overview of Elliptic Curve Cryptography (ECC) is discussed. In Section IV, the measurement results for different algorithms are compared. Finally, Section V presents the conclusions.

II. RELATED WORK

Cryptosystems with RSA and ECC algorithms are analyzed over the years by many authors. Traditional RSA algorithm based on modular arithmetic with long operands was proposed by authors in [4]. The performance of RSA algorithm on processors with low memory and power is slow and computation time increases drastically as key size increases. In comparison with RSA algorithm, Elliptic Curve Cryptography provides higher security with less key sizes and requires significantly less computational resources which make it attractive for use in digital signature smart cards. Comparative performance of several cryptographic algorithms is studied thoroughly by implementing them in Java language [5]. Performance evaluation of cryptosystems made by authors in detail is based on time measurements for key generation, encryption and decryption algorithms. The results of study are showed many advantages of ECC over the RSA.

III. OVERVIEW OF ELLIPTIC CURVE CRYPTOGRAPHY

Elliptic curve cryptography was suggested by Victor Miller [6] and Neal Koblitz [7] as an alternative to traditional cryptography. This invention has solved the main problem of public key cryptography related with significant increase of key length to meet a high level security requirement of cryptosystem.

A standard form of an elliptic curve over the prime number field $\mathbb{Z}_p$ (where $p$ is a large prime number) is described by Weierstrass equation (1):

$$E: y^2 = x^3 + ax + b \pmod{p}$$

Two positive integers $a, b \in \mathbb{Z}_p$, less than $p$ satisfy the non-singularity condition eq. (2).

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

For the addition of two elliptic curve points $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ to produce a third point $P_3(x_3, y_3)$ on elliptic curve eq. (3) should be used:

$$x_3 = \lambda^2 - x_1 - x_2 \pmod{p}$$
$$y_3 = \lambda(x_1 - x_3) - y_1 \pmod{p}$$

where

$$\lambda = \begin{cases} 
(y_2 - y_1) / (x_2 - x_1), & \text{at } P_1 \neq P_2 \\
(3x_1^2 + a) / (2y_1), & \text{at } P_1 = P_2 
\end{cases}$$

In case of point multiplication any point $P$ on elliptic curve multiplied with a scalar $n$ gives another point $Q$ on the same curve determined by eq. (4):

$$Q = mP$$

Formally, eq. (4) represents the point $P$ added to itself $m$ times. It is easy to determine a new point $Q$ given values $n$ and $P$, but it is very difficult to calculate $n$ for known values $P$ and $Q$. This problem is called the Elliptic Curve Discrete Logarithm Problem (ECDLP). Therefore, computational solving of this problem is the basis of

For any specific elliptic curve the set of domain parameters $a, b, p, n, G$ is defined as...
In cryptography the creation of cryptosystem requires determination of three algorithms: key generation, encryption and decryption. All parties agree on above mentioned domain parameters of elliptic curve and must know them. In elliptic curve cryptography key pair is associated with domain parameters and the public key is selected as a point on the curve while a private key is a random number chosen in the range \([1, n-1]\). The public key is determined by multiplying a point generator \(G\) of the order \(n\) on a private key.

Determination of algorithms for construction of cryptosystem and comparison the results obtained for different elliptic curves is discussed in the next subsections.

IV. THE IMPLEMENTATION AND ANALYSIS

The implementation environment for the chosen algorithms is Java JDK 8 update 45 and the platform for our measurements is Windows 7 Professional 64-bit, running on Intel(R) Core i7-2630QM CPU@ 2.00 GHz and 6.00 GB of RAM. Open source implementation of the interface is based on the framework of the Java Cryptography Architecture (JCA) / Java Cryptography Extensions (JCE) and underlying algorithms are integrated with the Flexi Provider [8] toolkit developed at the Theoretical Computer Science - Cryptography and Computer Algebra Department of TU Darmstadt.

Fig.1. Program code for encryption and decryption of plaintext Elliptic Curve Cryptography algorithm.

Due to security reasons not all elliptic curves are suitable for use. Only those curves with well understandable properties shall be selected for investigation. In our implementation the following recommended NIST [9], Certicom [10] and Brainpool curves [11] are used:

- BrainpoolP160r1 - BrainpoolP512r1,
- Secp112r1 - Secp521r1,
The program code shown in Fig. 1 generates a key pair (valid public key for encryption and private key for decryption) using BrainpoolP160r1 curve and performs encryption and decryption of fixed size plaintext. Encryption and decryption scheme based on ECC is the Elliptic Curve Integrated Encryption Scheme (ECIES) described elsewhere [12]. We are compared the performance of elliptic curve encryption algorithms with RSA in terms of key generation time as a function of key sizes. The results of measurements of encryption and decryption time for different elliptic curves in comparison with the RSA are presented in Table I. As expected, the key pair generation time as well as encryption and decryption time increases about linearly with the key size, while the difference in a few orders of magnitude is observed between key pair generation time for elliptic curve and RSA algorithms.

TABLE I. Key pair generation, encryption and decryption time as a function of key sizes for different elliptic curves.

<table>
<thead>
<tr>
<th>Type of elliptical curve</th>
<th>Key length (bit)</th>
<th>Key generation time (msec)</th>
<th>Encryption time (100Kb plaintext) (msec)</th>
<th>Decryption time (100Kb plaintext) (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BrainpoolP160r1</td>
<td>160</td>
<td>5</td>
<td>22</td>
<td>32</td>
</tr>
<tr>
<td>BrainpoolP192r1</td>
<td>192</td>
<td>7</td>
<td>28</td>
<td>39</td>
</tr>
<tr>
<td>BrainpoolP224r1</td>
<td>224</td>
<td>9</td>
<td>38</td>
<td>49</td>
</tr>
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<td>BrainpoolP256r1</td>
<td>256</td>
<td>12</td>
<td>47</td>
<td>62</td>
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<tr>
<td>BrainpoolP320r1</td>
<td>320</td>
<td>19</td>
<td>72</td>
<td>94</td>
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<td>BrainpoolP384r1</td>
<td>384</td>
<td>31</td>
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<td>140</td>
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<tr>
<td>BrainpoolP512r1</td>
<td>512</td>
<td>66</td>
<td>201</td>
<td>299</td>
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<tr>
<td>NIST curves</td>
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<td></td>
</tr>
<tr>
<td>Secp112r1</td>
<td>112</td>
<td>3</td>
<td>16</td>
<td>26</td>
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<td>23</td>
<td>32</td>
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</table>
It becomes clear that elliptic curve algorithms will significantly reduce the cost of e-ID card production due to fast key generation and small memory requirements. In Fig. 2 shown comparison of time required for solving of ECDLP problem with the time required for solving Integer Factorization Problem. Complexity of the solution ECDLP problem depending on the number of bits \( n \) in the input is expressed by eq. (5).

\[
C_{\text{ECDLP}}(n) \approx 2^{n/2}
\]

eq. (5)

It is seen from Fig. 2. ECC 256-bit provides the same level of security to RSA 3072 and ECC 384-bit provides comparable security to RSA 7680-bit.

![Fig.2. Comparison of crypto resistance of algorithms based on elliptic curve and RSA](image)

The running time is computed in MIPS-year which is equal to the number of steps processed by computer for one year at one million instructions per second.

V. CONCLUSION

The measurements showed that using elliptic curve algorithms in e-ID card production will provide high efficient performance and greater security in comparison with traditional RSA algorithm. When large volumes of e-ID cards are expected to be produced, elliptic curves are better than RSA.

VI. ACKNOWLEDGMENT

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BIOGRAPHY

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