



## Optimization of NTRU Cryptosystem using Genetic Algorithm

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**Abstract**— In order to achieve the security for the e-business application, generally the organizations follow the cryptographic methods. The two widely accepted and used cryptographic methods are symmetric and asymmetric. The Symmetric cryptosystem also called secret key cryptosystem, use the same key for encryption and decryption for example DES. The Asymmetric Cryptosystem also called public key cryptosystem uses two keys, a public key for encryption and a private key for decryption for example RSA and NTRU. Symmetric key ciphers are faster than the Asymmetric key ciphers. But security of Asymmetric ciphers are more than that of Symmetric ciphers. RSA is one of the oldest and the most widely used Asymmetric cryptosystem. The system works on two large prime numbers, from which the public and private keys will be generated. NTRU (Nth degree truncated polynomial ring units) is a collection of mathematical algorithms based on manipulating lists of very small integers. NTRU is the first secure public key cryptosystem not based on factorization or discrete logarithmic problems. The keys are generated by having small potent polynomials from the ring of truncated polynomials. Also NTRU is faster than RSA and uses less memory. Therefore in order to construct a highly secure speedy cryptosystem we have to optimise the NTRU Cryptosystem with respect to simulation time. In this paper we optimise NTRU using one of the advanced optimization techniques, Genetic Algorithm. We implemented this optimized NTRU in MATLAB and compared the simulation time of optimized NTRU with NTRU, DES, and RSA cryptosystems for different size of text files.

**Keywords**— NTRU, DES, RSA, Genetic Algorithm, optimization, Cryptosystem

### I. INTRODUCTION

Optimization is the act of obtaining the best result under the given circumstances. In design, construction and maintenance of any engineering systems many managerial and the technological decisions have to be taken at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Hence optimization can be defined as the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit [1] or in other words maximization or minimization of one or more functions with any possible constraints is called optimization [2].

The origin of optimization methods can be traced from 300 BC when Euclid identified the minimal distance between two points to be length of straight line joining the two. He also proved that a square has the greatest area among the rectangles with given total length of edges. Heron proved in 100 BC that light travels between two points through the path with shortest length when reflecting from a mirror. Before the invention of calculus of variations, the optimization problems like, determining optimal dimensions of wine barrel in 1615 by J. Kepler, a proof that light travels between two points in minimal time in 1657 by P. De Fermat were solved. I. Newton (1660s) and G.W. von Leibniz (1670s) created mathematical analysis that forms the basis of calculus of variation. L. Euler's publication in 1740 began the research on general theory of calculus of variations. The method of optimization for constrained problems, which involve the addition of unknown multipliers, became known by the name of its inventor, J. L. Lagrange. Cauchy made the first application of the gradient method to solve unconstrained optimization problems in 1847. G. Dantzig presented Simplex method in 1947. N. Karmarkar's polynomial time algorithm in 1984 begins a boom of interior point optimization methods. The advancement in solution techniques resulted several well defined new areas in optimization methods. The linear and non-linear constraints arising in optimization problem can be easily handled by penalty method. In this method few or more expressions are added to make objective function less optimal as the solution approaches a constraint [2].

### II. METHODOLOGY

A brief introduction of various cryptosystems implemented in this paper are as follows.

**DES:** DES is a Symmetric block cipher. It was created in 1972 by IBM, using the Data Encryption Algorithm. It was adopted by the U.S. Government as its standard encryption method for commercial and unclassified communications in 1977. DES begins the encryption process by using a 64-bit key. The NSA restricted the use of DES to a 56-bit key length, so DES discards 8-bits of the key and then uses the remaining key to encrypt data in 64-bit blocks. DES can operate in CBC, ECB, CFB, and OFB modes, giving it flexibility.

In 1998, the supercomputer DES Cracker, assisted by 100,000 distributed PCs on the Internet, cracked DES in 22 hours. The U.S. Government has not used DES since 1998[5].

**RSA:** RSA is an Asymmetric cipher. It is one of the oldest and the most widely used public key cryptographic algorithms. It was the first algorithm known to be suitable for signing as well as encryption. The system works on two large prime numbers, from which the public and private keys will be generated. RSA was developed by Ron Rivest, Adi Shamir, and Leonard Adleman, in 1977. RSA derives its name from the initials of the last name of each of its developers. It is commonly used with key strengths of 1024-bits, but its real strength relies on the prime factorization of very large numbers [5]. The RSA scheme is a block cipher in which the plaintext and the ciphertext are integers between 0 and  $n-1$  for some modulus  $n$ .

**NTRU:** NTRU is one of the public key cryptosystems. NTRU (Nth degree truncated polynomial ring units) is a collection of mathematical algorithms based on manipulating lists of very small integers. It was first introduced by Jeffrey Hoffstein, Jill Pipher and Joseph H. Silverman in 1998 [6]. NTRU is the first secure public key cryptosystem not based on factorization or discrete logarithmic problems. The keys are generated by having small potent polynomials from the ring of truncated polynomials given by  $Z[X]/(X^N - 1)$ . The security of the NTRU cryptosystem is based on the difficulty of finding short vectors in a certain lattice. The larger the parameter  $N$ , the more secure the system is. NTRU is a probabilistic cryptosystem. The encryption process includes a random element and therefore one message has several possible encryptions. The advantage of NTRU over other cryptosystems is that it is highly random in nature, Encryption and decryption are very fast, the key sizes are relatively small and the key generation is fast and easy[7,8].

### **A. Solution of Optimization Problems**

The choice of suitable optimization method depends on the type of optimization problem. Various classical methods were there to solve such problems. The major advances in optimization occurred only after the development of fast digital computers. Now days various advanced optimization techniques are used to solve the design and operation related nuclear reactor problems.

#### *1) Classical optimization techniques*

The classical optimization techniques are useful for single as well as multi dimensional optimization problems. Few popular classical optimization techniques are:

- (i) Direct methods
- (ii) Gradient methods
- (iii) Linear programming methods
- (iii) Interior point methods

#### *2) Advanced optimization techniques*

Most of the real world optimization problems involve complexities like discrete, continuous or mixed variables, multiple conflicting objectives, non-linearity, discontinuity etc. The search space may be so large that the global optimum can not be found in reasonable time. The classical methods may not be efficient to solve such problems. Various stochastic methods like hill climbing, simulated annealing or evolutionary optimization algorithms can be used in such situations. In our project we are using Evolutionary optimization algorithms. A brief description of this algorithm is as follows.

### **B. Evolutionary Optimization Algorithms**

Evolutionary algorithms (EAs) are developed to arrive at near-optimum solutions to a large scale optimization problem. The problem having very large number of decision variables and non-linear objective functions are often solved by EAs. EAs mimic the metaphor of natural biological evolution or social behavior like how ants find the shortest route to a source of food and how birds find their destination during migration. The behavior of such species is guided by learning and adaptation. The evolutionary algorithms are based on population based search procedures that incorporate random variation and selection. The first evolutionary-based optimization technique was the genetic algorithm (GA). GA was developed based on the Darwinian principle of the survival of the fittest and the natural process of evolution through reproduction. There are so many algorithms like Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Estimation of Distribution Algorithm (EDA) etc. have been introduced during the past 10 years.

EAs start from a population of possible solutions (called individuals) and move towards the optimal by incorporating generation and selection. Objects forming possible solution sets to the original problem are called phenotype and the encoding (representation) of the individuals in the EAs are called genotype. The way by which mapping of phenotype to genotype is done and the EA's operators are applied to genotype affects the computational time. An individual consist a genotype and a fitness function. Fitness represents the quality of the solution and forms the basis for selecting the individuals [2].

In our paper we optimized the NTRU cryptosystem using Genetic Algorithm. A brief description of this algorithm is as follows:

#### **Genetic Algorithm (GA)**

Genetic Algorithm (GA) works on the theory of Darwin's theory of evolution and the survival-of-the fittest [3]. Genetic algorithms guide the search through the solution space by using natural selection and genetic operators, such as crossover, mutation and the selection. GA encodes the decision variables or input parameters of the problem into solution strings of a finite length. While traditional optimization techniques work directly with the decision variables or input parameters, genetic algorithms usually work with the coding. Genetic algorithms start to search from a population of

encoded solutions instead of from a single point in the solution space. The initial population of individuals is created at random. Genetic algorithms use genetic operators to create Global optimum solutions based on the solutions in the current population. The most popular genetic operators are (1) selection (2) crossover and (3) mutation. The newly generated individuals replace the old population, and the evolution process proceeds until certain termination criteria are satisfied.

*(i) Selection*

The selection procedure implements the natural selection or the survival-of-the fittest principle and selects good individuals out of the current population for generating the next population according to the assigned fitness. The existing selection operators can be broadly classified into two classes:

- (a) proportionate schemes, such as roulette-wheel selection and stochastic universal selection and
- (b) ordinal schemes, such as tournament selection and truncation selection.

Ordinal schemes have grown more and more popular over the recent years, and one of the most popular ordinal selection operators is tournament selection. After selection, crossover and mutation recombine and alter parts of the individuals to generate new solutions.

*(ii) Crossover*

Crossover, also called the recombination operator, exchanges parts of solutions from two or more individuals, called parents, and combines these parts to generate new individuals, called children, with a crossover probability. There are a lot of ways to implement a recombination operator. The well-known crossover operators include one-point crossover. When using one-point crossover, only one crossover point is chosen at random, for example let there be two parent string A1 and A2 as:

$$\begin{aligned} A1 &= 1\ 1\ 1\ 1\ |1\ 1 \\ A2 &= 0\ 0\ 0\ 0\ |0\ 0 \end{aligned} \quad \text{Eq. 1}$$

Then, one-point crossover recombines A1 and A2 and yields two offsprings A\_1 and A\_2 as:

$$\begin{aligned} A_1 &= 1\ 1\ 1\ 1\ |1\ 1 \\ A_2 &= 0\ 0\ 0\ 0\ |1\ 1 \end{aligned} \quad \text{Eq. 2}$$

*(iii) Mutation*

Mutation usually alters some pieces of individuals to form perturbed solutions. In contrast to crossover, which operates on two or more individuals, mutation operates on a single individual. One of the most popular mutation operators is the bitwise mutation, in which each bit in a binary string is complemented with a mutation probability. For example,

$$\begin{aligned} A &= 1\ 1\ 1\ 1\ |1\ 1 \\ A_1 &= 0\ 0\ 0\ 0\ |0\ 1 \end{aligned} \quad \text{Eq. 3}$$

The step-by-step implementation of GA is explained as follows:

*Step 1:* Initialize GA parameters which are necessary for the algorithm. These parameters include population size which indicates the number of individuals, number of generations necessary for the termination criterion, crossover probability, mutation probability, number of design variables and respective ranges for the design variables. If binary version of GA is used then string length is also required as the algorithm parameter.

*Step 2:* Generate random population equal to the population size specified. Each population member contains the value of all the design variables. This value of design variable is randomly generated in between the design variable range specified. In GA, population means the group of individuals which represents the set of solutions.

*Step 3:* Obtain the values of the objective function for all the population members. The value of the objective function so obtained indicates the fitness of the individuals. If the problem is a constrained optimization problem then a specific approach such as static penalty, dynamic penalty and adaptive penalty is used to convert the constrained optimization problem into the unconstrained optimization problem.

*Step 4:* This step is for the selection procedure to form a mating pool which consists of the population made up of best individuals. The commonly used selection schemes are roulette-wheel selection, tournament selection, stochastic selection, etc. The simplest and the commonly used selection scheme is the roulette-wheel selection, where an individual is selected for the mating pool with the probability proportional to its fitness value. The individual (solution) having better fitness value will have more number of copies in the mating pool and so the chances of mating increases for the more fit individuals than the less fit ones. This step justifies the procedure for the survival of the fittest.

*Step 5:* This step is for the crossover where two individuals, known as parents, are selected randomly from the mating pool to generate two new solutions known as off-springs. The individuals from the population can go for the crossover step depending upon the crossover probability. If the crossover probability is more, then more individuals get chance to go for the crossover procedure. The simplest crossover operator is the single point crossover in which a crossover site is determined randomly from where the exchange of bits takes place. The crossover procedure is explained through Eqs. 1 and 2.

*Step 6:* After crossover, mutation step is performed on the individuals of population depending on the mutation probability. The mutation probability is generally kept low so that it does not make the algorithm unstable. In mutation, a random site is selected from the string of individuals and it is flipped as explained through Eq. 3.

*Step 7:* Best obtained results are saved using elitism. All elite members are not modified using crossover and mutation operators but can be replaced if better solutions are obtained in any iteration.

*Step 8:* Repeat the steps (from step 3) until the specified number of generations or termination criterion is reached [4].

### III. RESULT

After the implementation of optimised NTRU cryptosystem using Genetic Algorithm, we compared this algorithm with some pre-existing fast Symmetric and Asymmetric Cryptosystems. In these algorithms DES is a very fast Symmetric Cypher. RSA is the most popular oldest Asymmetric Cypher and NTRU is faster than RSA. The comparison table is as shown below :

TABLE I COMPARISON OF VARIOUS CRYPTOSYSTEMS WITH OPTIMIZED NTRU FOR DIFFERENT LENGTH OF MESSAGES WITH RESPECT TO SIMULATION TIME IN SECONDS.

Sr.No.	Cryptosystem	3 bytes	85 bytes	117 bytes	362 bytes	1432 bytes
1.	DES	0.109	0.344	0.437	1.235	7.735
2.	RSA	0.89	0.984	1.125	1.953	4.422
3.	NTRU	0.344	0.437	0.500	0.906	2.687
4.	NTRU(GA)	0.232	0.352	0.421	0.621	1.921

From the above table it is clear that when we optimize NTRU using genetic algorithm we are getting higher speed as compared to NTRU. We can also calculate the percentage increase in speed of the optimised NTRU as compared to the conventional NTRU for different length of messages as shown in the table below.

TABLE III PERCENTAGE INCREASE IN SPEED OF THE OPTIMISED NTRU AS COMPARED TO THE CONVENTIONAL NTRU FOR DIFFERENT LENGTH OF MESSAGES.

Sr.No.	Cryptosystem	3 bytes	85 bytes	117 bytes	362 bytes	1432 bytes	Average percentage increase
1.	NTRU	0.344	0.437	0.500	0.906	2.687	-
2.	NTRU(GA)	0.232	0.352	0.421	0.621	1.921	-
3.	NTRU and NTRU(GA)	32.56%	19.45%	15.8%	31.46%	28.51%	25.55%

From the above table it is clear that the average percentage increase in speed of NTRU using Genetic algorithm(GA) as compared to conventional NTRU is 25.55% .

### IV. CONCLUSIONS

In this paper we implemented some fast Symmetric and Asymmetric cryptosystems i.e. DES, RSA and NTRU in MATLAB. In order to construct a highly secure speedy cryptosystem we optimized NTRU using Genetic Algorithm and implemented it in MATLAB. After implementation we compared the simulation time of these cryptosystems for different size of text files. We found that the optimized NTRU is having the minimum simulation time. We compared the percentage increase in speed of optimized NTRU with the conventional NTRU. We found that the speed of optimized NTRU is increased by 25% on average. This comparison shows that the optimized NTRU using Genetic Algorithm is performing the best with respect to simulation time.

### REFERENCES

- [1] [http://www.nptel.ac.in/courses/105108127/pdf/Module\\_1/M1L1slides.pdf](http://www.nptel.ac.in/courses/105108127/pdf/Module_1/M1L1slides.pdf)
- [2] [http://shodhganga.inflibnet.ac.in/bitstream/10603/11449/9/09\\_chapter%204.pdf](http://shodhganga.inflibnet.ac.in/bitstream/10603/11449/9/09_chapter%204.pdf)
- [3] Holland J (1975) Adaptation in natural and artificial systems. University of Michigan Press, Ann Arbor.
- [4] <http://www.springer.com/978-1-4471-2747-5>.
- [5] An Introduction to Cryptography, and Common Electronic Cryptosystems – Part I”, EnterpriseITplanet.com
- [6] J. Hoffstein, J. Pipher and J. H. Silverman, NTRU: A Ring-Based Public Key Cryptosystem. Algorithmic Number Theory (ANTS III), Portland, OR, June 1998, J.P. Buhler (ed.), LNCS 1423, Springer-Verlag, Berlin, 267- 288, 1998.
- [7] Tommy Meskanen, ”On the NTRU CryptoSystem”, TUCS Dissertations No 63, June 2005
- [8] From Wikipedia browsed on 15.7.14.