Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/200220

Hybrid Scheme of the Laplace Transform and DNA for more Secure Cryptosystem

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Received: 2 Jan. 2026, Revised: 2 Feb. 2026, Accepted: 20 Feb. 2026
Published online: 1 Mar. 2026

Abstract: This paper presents an innovative encryption system based on incorporating the Laplace transform into DNA cryptography, leveraging the complex biological structure of DNA and the mathematical properties of the Laplace transform. This provides an additional level of protection that enhances the method's robustness against attacks in all phases of system because of the two levels of protection. The first level depends on the sample space of the DNA sequence of a cell, but the second level depends on the sample space of Laplace transforms of a function, therefore making it suitable for data transmission over insecure transmission media that require strong encryption and high reliability.

Keywords: DNA, Laplace transform, Security analysis.

1 Introduction

The field of encryption has witnessed significant advancements in recent decades, particularly with the integration of mathematical transforms into cryptographic algorithm design. In 2012, Som and Som proposed a symmetric encryption system known as DSWLT, which is characterized by its high speed and efficiency in encryption large files [1]. In 2013, Hewarikar proposed a new mathematical encryption method based on Laplace transform for encrypting plaintext, with the application of the inverse Laplace transform fir decryption, providing a high level of security in data transmission [2]. In 2017, Genço glu proposed a general attack scenario for analyzing the security of encryption systems based on the Laplace transform to enhance the security analysis of proposed algorithms [3]. In 2018, Briones presented a study that examined the conditions leading to the development of the Laplace transform – based encryption scheme and proposed a modification in the first step of the scheme using two passphrases for single iteration, enhancing encryption security [4]. In 2021, Al-Azani et al. proposed a new encryption system based on the Laplace transform using substitution boxes, where the message is encrypted over multiple rounds with the secret key introduced in each round, providing a higher level of security against various cryptographic attacks [5]. In 2022, pranajaya and Soegiarto proposed an encryption system based on the Laplace transform and maclaurin series, where the numbers derived from the series are used as coefficients to generate the key and ciphertext.

Decryption relies on the inverse Laplace transform, with the system being adaptable to different alphabets [6]. In 2023, Sharbah et al. proposed a new encryption approach based on Taylor series coefficients of the logarithmic function, which are used for encryption, while decryption relies on the Laplace transform of the logarithmic function and its inverse, leading to the development of innovative encryption and decryption formulas [7]. In 2023, Rasool and Mohan proposed an encryption method based on the Laplace equation and its inverse transform technique, where messages are converted from plaintext to ciphertext through multiple transformation rounds, ensuring information confidentiality [8]. In 2024, Abidalzahra introduced PDNA via polynomial and DNA codon [9]. In 2025, Albakaa and Yassein relied on truncated polynomials ring and DNA codons to propose the FDNA system [10]. In the next section, the mathematical construction of the proposed LT-DNA is described. In Section 3, the security analysis of the proposed system is discussed. In Section 4, an illustrative example is provided for the three phases of

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the system. Finally, the conclusions are summarized in Section 5.

2 Preliminaries

If t is positive values, then the Laplace transform of a function $f(t)$ is defined as $Lf(t)=F(s)=\int_0^\infty e^{-st}f(t)dt$ provided that the integral exists, and the parameter s is a real or complex number. The corresponding inverse Laplace transform is $L^{-1}F(s)=f(t)$ [11].

Theorem 2.1. [2] Consider standard expansion $f(t)=Gt^j\cosh rt=\sum_{i=0}^{\infty}\frac{G_i r^{2i}t^{2i+j}}{2i!}$ by writing G as a coefficient of $t^j\cosh rt$, when taking Laplace transform then G_i converted to $G_i'=q_i-26k_i$, where $q_i=G_i r^{2i}(2i+1)(2i+2)\ldots(2i+j)$ with $k_i=\frac{q_i-G_i'}{26}$ for $i=0,1,2,3\ldots$ and $r,j=1,2,3\ldots$.

Theorem 2.2. [2] Given G_i' and k_i for $i=0,1,2,3\ldots$ and taking inverse Laplace transform of $G'\left(\frac{-d^j}{ds^j}\right)\left(\frac{1}{s^2-r^2}\right)=\sum_{i=0}^{\infty}\frac{q_i}{S^{2i+j+1}}$ then G_i' converted to $G_i=\frac{26k_i+G_i'}{r^{2i}(2i+1)(2i+2)\ldots(2i+j)}$, where $q_i=G_i'+26k_i$ with $k_i=\frac{q_i-G_i'}{26}$, for $r,j=1,2,3\ldots$, and $\frac{d^j}{ds^j}$ is the j^{th} derivative with respect to s.

Theorem 2.3. [2] If $Lf_1(t)=F_1(s), Lf_2(t)=F_2(s),\ldots, Lf_n(t)=F_n(s)$ then $L\{c_1f_1(t)+c_2f_2(t)\ldots+c_nf_n(t)\}=c_1F_1(s)+c_2F(s)\ldots+c_nF_n(s)$ where $c_1,c_2,\ldots,c_n$ are constants.

2.1 DNA structure

Deoxyribonucleic acid (DNA) is a molecule responsible for storing and translating genetic information in living organisms. It is shaped like a double helix structure with two parallel opposite strands, and is composed of small units called nucleotides. Each nucleotide consists of three components:

1. Nitrogenous bases
2. Five-carbon sugar
3. Acid phosphate

DNA contains four different types of nitrogenous bases, including:

Adenine, symbolized by A, thymine, symbolized by T, cytosine, symbolized by C, and guanine, symbolized by G, where the nitrogenous bases are linked to each other in pairs. Adenine bonds with thymine (A-T), and guanine bonds with cytosine (G-C) [12].

3 LT-DNA cryptosystem

The proposed symmetric method LT-DNA (Laplace Transform DNA) is based on deoxyribonucleic acid (DNA) and the Laplace transform of special functions, and its three phases can be described as follows:

3.1 Generate of key

At this phase, two keys are chosen that are shared between the two parties: one is a DNA sequence, and the other is a function that has a Taylor series, as follows:

1. A deoxyribonucleic acid (DNA) sequence ψ is chosen as the private key from databases available at international centers specializing in genetic engineering and gene function studies, as well as from various online sources, such as GenBank (part of the International Nucleotide Sequence Database Collaboration, which comprises the European Nucleotide Archive (ENA), the DNA DataBank of Japan (DDBJ), and GenBank at National Center for Biotechnology Information (NCBI)), European Molecular Biology Laboratory (EMBL), using computer simulation techniques to generate random DNA sequences, etc.
2. The private key is selected as any function $f(t)$ that has a Taylor series expansion (for example $f(t)=t^k\cosh rt$ such that $k,r=0,1,2,\ldots$).

3.2 Encryption

This phase involves converting the original text into ciphertext through a series of transformations, where the original text is converted into codons, then into English letters, then into a Taylor series, then into a binary system, and finally back into codons, as follows:

1. We choose Tables 1, 2, and 3 to represent the encoding of plaintext characters into codons based on their position, the process of converting two nitrogenous bases into an English letter, and the encoding of nitrogenous bases in binary, respectively. For example, the letter c in the word "copy" is odd, and o is even, and p is odd, and y is even.
Table 2 shows the output of two nitrogenous bases (the first is the output of Table 1 and the second is a series of letters agreed upon by both parties) which are letters of the English language. For example to convert two nitrogenous bases TA with CC to English letters $XZ(TC\rightarrow X, AC\rightarrow Z)$. Table 3 shows the conversion of nitrogenous bases into binary system and vice versa.
2. Converting the message M into codons according to Table 1
3. By using a deoxyribonucleic acid (DNA) sequence ψ in Table 2, to obtain English letters.
4. The English letters take their sequence based on their position in the alphabetical order, where we assume these numbers represent the G_i, $i=0,1,\ldots$.
5. Taking Laplace transform of key $f(t)$.

Table 1: Coding of plaintext characters into codons according to their position

Codon	Even	Codon	Even	Codon	Odd	Codon	Odd
GACG	N	*TATG*	A	*GTAC*	N	*TTTC*	a
GCCC	O	*TGCA*	B	*GTCA*	O	*TCCA*	b
AGGA	P	*AGTT*	C	*ACGA*	P	*AATG*	c
ATTA	Q	*AACA*	D	*ACCA*	Q	*ATCC*	d
AAGA	R	*AGAG*	E	*ACAG*	R	*ATAA*	e
CGCA	S	*GACC*	F	*CACA*	S	*GTTC*	f
CTTA	T	*GAGA*	G	*CCTG*	T	*GGAC*	g
TACA	U	*TAAA*	H	*TGAA*	U	*TCAC*	h
TTGG	V	*TCGG*	I	*TAGC*	V	*TGGC*	i
TTCC	W	*CAGC*	J	*TTAC*	W	*CCAT*	j
CCCA	X	*CGAC*	K	*CAAA*	X	*CGGT*	k
CTGC	Y	*AAAA*	L	*CCGT*	y	*ATGG*	l
CTAA	Z	*AGCA*	M	*CTCA*	z	*ACTA*	m

Table 2: The procedure of converting two nitrogenous bases into an English letter

The English letter encoded the two bases	A DNA strand generated from plaintext encoding	Standard DNA strand	The English letter encoded the two bases	A DNA strand generated from plaintext encoding	Standard DNA strand
D	A	T	B	T	T
I	A	G	H	T	G
R	A	A	K	T	A
P	A	C	M	T	C
X	C	T	S	G	T
W	C	G	V	G	G
Z	C	A	Y	G	A
F	C	C	E	G	C

Table 3: Coding of nitrogenous bases in the binary system

Binary system	Nitrogenous base
00	A
01	C
10	G
11	T

6.The resulting coefficients $G_i', i = 0, 1, \ldots$ in step (5) are converted to mod 26.
7.Converting $G_i', i = 0, 1, \ldots$ to binary system.
8.Convert the binary system according to Table 3 into a sequence of nitrogenous bases, which represents the encrypted text ε.

3.3 Decryption

This phases involves converting the encrypted text back to the original text through a series of transformations, where the codons are converted to binary, then to decimal, then to inverse Laplace, then to English letters, then back to codons, and finally back to English letters, as follows:

1.Convert ε to the binary system using Table 3.
2.By taking every five digits from the binary system and converting them to the decimal system, which represents $G_i', i = 0, 1, \ldots$.
3.Taking inverse Laplace transform to function with coefficients G_i'.
4.We convert the coefficients G_i' to mod 26 to get the English letters take their sequence based on their position in the alphabetical order.
5.Using the key ψ and the Table 2, we get the codon sequence.
6.Converting the codon sequence into message M according to Table 1.

4 Implementation of the proposed method

An illustrative example is provided for the three phases of generate of key, encryption, and decryption in LT-DNA.

4.1 Generate of key

1.Select of bacteria E. Coli taken from the EBI Website, where $\psi = ATGTGCGAA\ldots$ as the DNA strand
2.Choose $f(t) = Gt^2 \cosh 3t$

4.2 Encryption

1.Take the message $M = a$.

2.Encoding message $M = a$ into codons $TTTC$, according to Table 1 since a is located in an odd position.
3.Encoding the nitrogenous bases of the two DNA chains into English letters using Table 2, as shown:

ψ	Codons	English letter	Sequenced in the alphabet
A	T	K	11
T	T	B	2
G	T	H	8
T	C	X	24

We assume that $G_0 = 11, G_1 = 2, G_2 = 8$, $G_3 = 24, G_n = 0$ for $n \geq 4$. Consider

$$\begin{aligned} f(t) &= Gt^2 \cosh 3t \\ &= t^2 \left\{ G_0.1 + G_1.\frac{3^2t^2}{2!} + G_2.\frac{3^4t^4}{4!} + G_3\frac{3^6t^6}{6!} \right\} \\ &= 11t^2 + 2.\frac{3^2t^4}{2!} + 8.\frac{3^4t^6}{4!} + 24\frac{3^6t^8}{6!} \\ &= \sum_{i=0}^{\infty} \frac{G_i\, 3^{2i} t^{2i+2}}{2i} \end{aligned}$$

4.Taking Laplace transform of $f(t)$, we have

$$\begin{aligned} L\{f(t)\} &= L\{Gt^2 \cosh(3t)\} \\ &= L\left\{ 18t^2 + 2.\frac{3^2t^4}{2!} + 22.\frac{3^4t^6}{4!} + 19\frac{3^6t^8}{6!} \right\} \\ &= 18.\frac{2!}{S^3} + 2.\frac{3^2(4!)}{(2!)S^5} + 22.\frac{3^4(6!)}{(4!)S^7} + 19.\frac{3^6(8!)}{(6!)S^9} \\ &= \sum_{i=0}^{\infty} \frac{G_i\left(3^{2i}\right)(2i+2)!}{(2i)!S^{2i+3}} \\ &= \frac{36}{S^3} + \frac{216}{S^5} + \frac{53460}{S^7} + \frac{775656}{S^9} \\ &= \sum_{i=0}^{\infty} \frac{q_i}{S^{2i+3}} \end{aligned}$$

5.E. Convert the coefficients in the last term to modulo 26 to become as follows: 22, 8, 18, 18. Assuming $G'_0 = 22, G'_1 = 8, G'_2 = 18, G'_3 = 18$.
6.Convert the resulting numbers to the binary system. 10110010001001010010.
7.Using Table 3, convert binary chain into string of nitrogenous bases GTAGAGCCAT that represents the ciphertext.
8.Compute $k_i = \frac{q_i - G'_i}{26}$ for $i = 0, 1, 2, 3 \ldots$.
In this case, the sender sends the pair (ε, k_i) to the recipien.

4.3 Decryption

1.Using 3 to convert ciphertext *GTAGAGCCAT* into the binary system chain 10110010001001010010.
2.Converting a binary system to the decimal system.

Binary system	Decimal system
10110	22
01000	8
10010	18
10010	18

$G'_0 = 22, G'_1 = 8, G'_2 = 18, G'_3 = 18$. The given key k_i for $i = 1, 2, 3 \ldots$, as 0, 8, 747, 37683. Let $q_i = 26k_i + G'_i$ for $i = 0, 1, 2, 3, \ldots$ equal to 22, 216, 19440, 979776.

$$\begin{aligned} G\left(\frac{-d^2}{ds^2}\right)\left(\frac{1}{s^2 - 3^2}\right) &= \sum_{i=0}^{\infty} \frac{q_i}{S^{2i+3}} \\ &= \frac{22}{S^3} + \frac{219}{S^5} + \frac{19440}{S^7} + \frac{979776}{S^9}. \end{aligned}$$

Taking inverse Laplace transform to get

$$\begin{aligned} G\,t^2 \cosh(3t) &= 11.\frac{2!}{S^3} + 2.\frac{3^2(4!)}{(2!)S^5} + 8.\frac{3^4(6!)}{(4!)S^7} + 24.\frac{3^6(8!)}{(6!)S^9} \\ &= 11t^2 + 2.\frac{3^2t^4}{2!} + 8.\frac{3^4t^6}{4!} + 24\frac{3^6t^8}{6!}, \end{aligned}$$

therefore, $G_0 = 11, G_1 = 2, G_2 = 8, G_3 = 24$.
3.Convert G_0, G_1, G_2, G_3 to the English letters based on their position in the alphabetical order K, B, H, X, then using the key ψ and Table 2, we get the codon sequence as follows:

ψ	English letter	Codons
A	K	T
T	B	T
G	H	T
T	X	C

4.Converting the codon sequence $TTTC$ into message (a) according to Table 1.

Now, if we take another message l with the same keys then

4.4 Encryption

1.Take the message $M = l$
2.Encoding message $M = l$ into codons ATGG, according to Table 1 since l is located in an odd position.

3.Encoding the nitrogenous bases of the two DNA chains into English letters using Table 2, as shown:

ψ	Codons	English letter	Sequenced in the alphabet
A	A	R	18
T	T	B	2
G	G	V	22
T	G	S	19

We assume that $G_0 = 18, G_1 = 2, G_2 = 22, G_3 = 19, G_n = 0$ for $n \geq 4$.
Consider

$$\begin{aligned} f(t) &= Gt^2 \cosh 3t \\ &= t^2 \left\{ G_0.1 + G_1.\frac{3^2t^2}{2!} + G_2.\frac{3^4t^4}{4!} + G_3\frac{3^6t^6}{6!} \right\} \\ &= 18t^2 + 2.\frac{3^2\, t^4}{2!} + 22.\frac{3^4t^6}{4!} + 19\frac{3^6t^8}{6!} \\ &= \sum_{i=0}^{\infty} \frac{G_i 3^{2i} t^{2i+2}}{2i\,!} \end{aligned}$$

4.Taking Laplace transform of $f(t)$, we have

$$\begin{aligned} L\{f(t)\} &= L\left\{Gt^2 \cosh(3t)\right\} \\ &= L\left\{ 18\, t^2 + 2.\frac{3^2t^4}{2!} + 22.\frac{3^4t^6}{4!} + 19\frac{3^6t^8}{6!} \right\} \\ &= 18.\frac{2!}{S^3} + 2.\frac{3^2(4!)}{(2!)\,S^5} + 22.\frac{3^4(6!)}{(4!)\,S^7} + 19.\frac{3^6(8!)}{(6!)S^9} \\ &= \sum_{i=0}^{\infty} \frac{G_i\left(3^{2i}\right)(2i+2)!}{(2i)!S^{2i+3}} \\ &= \frac{36}{S^3} + \frac{216}{S^5} + \frac{53460}{S^7} + \frac{775656}{S^9} \\ &= \sum_{i=0}^{\infty} \frac{q_i}{S^{2i+3}} \end{aligned}$$

5.Convert the coefficients in the last term to modulo 26 to become as follows: 10, 8, 4, 24. Assuming $G_0' = 10, G_1' = 8, G_2' = 4, G_3' = 24$.
6.Convert the resulting numbers to the binary system. 01010010000010011000
7.Using Table 3, convert binary chain into string of nitrogenous bases *CCAGAAGCGA* that represents the ciphertext.
8.Compute $k_i = \frac{q_i - G_i'}{26}$ for $i = 0, 1, 2, 3\ldots$.

In this case, the sender sends the pair (ε, k_i) to the recipien.

4.5 Decryption

1.Using Table 3 to convert ciphertext *GTAGAGCCAT* into the binary system chain 01010010000010011000
2.Converting a binary system to the decimal system.

Binary system	Decimal system
01010	10
01000	8
00100	4
11000	24

$G_0' = 10, G_1' = 8, G_2' = 4, G_3' = 24$.
The given key k$_i$ for i=1,2,3. . . . . , as 1, 8, 2056, 29832.
Let $q_i = 26k_i + G_i'$ for $i = 0, 1, 2, 3, \ldots$ equal to 36, 216, 53460, 775656.

$$\begin{aligned} G\left(\frac{-d^2}{ds^2}\right)\left(\frac{1}{s^2 - 3^2}\right) &= \sum_{i=0}^{\infty} \frac{q_i}{S^{2i+3}} \\ &= \frac{36}{S^3} + \frac{216}{S^5} + \frac{53460}{S^7} + \frac{775656}{S^9}. \end{aligned}$$

Taking inverse Laplace transform to get

$$\begin{aligned} Gt^2 \cosh(3t) &= 18.\frac{2!}{S^3} + 2.\frac{3^2(4!)}{(2!)\,S^5} + 22.\frac{3^4(6!)}{(4!)\,S^7} + 19.\frac{3^6(8!)}{(6!)S^9} \\ &= 18\, t^2 + 2.\frac{3^2\, t^4}{2!} + 22.\frac{3^4t^6}{4!} + 19.\frac{3^6t^8}{6!}, \end{aligned}$$

therefore, $G_0 = 18, G_1 = 2, G_2 = 22, G_3 = 19$.
3.Convert G_0, G_1, G_2, G_3 to the English letters based on their position in the alphabetical order R, B, V, S, then using the key ψ and Table 2, we get the codon sequence as follows:

ψ	English letter	Codons
A	R	A
T	B	T
G	V	G
T	S	G

4.Converting the codon sequence *ATGG* into message *l* according to Table 1.

Table 4: Implemented for encrypting the plaintexts

Message	Codons	English letters	$f(t)$	Ciphertext
a	*TTTC*	KBHX	$11t^2 + 2.\frac{3^2\, t^4}{2!} + 8.\frac{3^4t^6}{4!} + 24\frac{3^6t^8}{6!}$	*GTAGAGCCAT*
l	*ATGG*	RBVS	$18t^2 + 2.\frac{3^2\, t^4}{2!} + 22.\frac{3^4t^6}{4!} + 19\frac{3^6t^8}{6!}$	*CCAGAAGCGT*

Table 4 shows the different results that were implemented for encrypting the plaintext as various words.

5 Security of LT-DNA

The security of this system relies on combining two keys to ensure high level of protection against traditional attacks. The first key ψ is derived from a DNA sequence of length n, consisting of only the four letters T, G, C, and A ,providing a key space of 4^n. This high randomness resulting from the use of only four letters hinders statistical analysis of the ciphertext based on the relative occurrence of each of the 26 letters of the English alphabet, thus reducing the effectiveness of frequency analysis in decryption.

The second key $t^n \cosh(rt)$ is a nonlinear mathematical function subjected to the Laplace transform , adding an additional layer of complexity by mapping the data into a different mathematical domain dependent on varying parameters, making it difficult to retrieve the original information without knowing the correct key values. The security level of this key depends on the number of possible values for the parameters n and r, resulting in a large key space that resists attacks. Thus, the total security space of this system is the product of 4^n and the key space of $t^n \cosh(rt)$ making data retrieval very difficult without knowledge of both keys.

6 Conclusions

A novel encryption approach has been that combines DNA encryption with the Laplace transform to enhance data security and increase its resistance to cryptanalysis attacks such as brute-force attacks. Basically, the proposed system relies on two independent keys: one a DNA sequence and the other a hyperbolic mathematical function, adding an extra layer of security. The encryption process involves several advanced and varied mathematical operations that increase the difficulty of data recovery. Security analysis shows that this method provides a high level of protection by relying on the sample space of the DNA sequence and a function has Taylor series expansion, making it a promising option for encrypting various datasets.

Acknowledgments

The authors of this article would like to express their sincere thanks to the Department of Mathematics at the University of Kufa, College of Education for Women, for overcoming the difficulties and providing the work requirements in preparing this paper.

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