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High-Speed and Secure PRNG for Cryptographic Applications

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Abstract—Due to the fundamentally different approach underlying quantum cryptography (QC), it has not only become competitive, but also has significant advantages over traditional cryptography methods. Such significant advantage as theoretical and informational stability is achieved through the use of unique quantum particles and the inviolability of quantum physics postulates, in addition it does not depend on the intruder computational capabilities. However, even with such impressive reliability results, QC methods have some disadvantages. For instance, such promising trend as quantum secure direct communication – eliminates the problem of key distribution, since it allows to transmit information by open channel without encrypting it. However, in these protocols, each bit is confidential and should not be compromised, therefore, the requirements for protocol stability are increasing and additional security methods are needed. For a whole class of methods to ensure qutrit QC protocols stability, reliable trit generation method is required. In this paper authors have developed and studied trit generation method and software tool TriGen v.2.0 PRNG. Developed PRNG is important for various practical cryptographic applications (for example, trit QC systems, IoT and Blockchain technologies). Future research can be related with developing fully functional version of testing technique and software tool.

Index Terms—Quantum cryptography, information security, pseudorandom numbers (sequences), PRNG, evaluation, trit, quantum deterministic protocol, evaluation, trit, NIST STS.

I. Introduction

With the rapid development of information and communication technologies (ICT), most of the world is faced with the problem of supporting cybersecurity (information security). On the one hand, new powerful ICT contribute to the cybersecurity development, and on the other, they create new threats. For the past few years, number of reported cybersecurity incidents of confidential information leaks increases every month.

Today, the reliability and security of traditional cryptographic methods mostly depends on the attacker's computational power and the ability to solve a particular class of mathematical problems in polynomial time. But since the advent of such technologies as GRID computing, supercomputer and quantum computer, which perform complex calculations in minutes – companies, states and scientists have to look for new alternatives to existing security and privacy methods.

There are two major classes of methods to replace traditional cryptography – the first one is quantum cryptography (QC) [1], based on the fundamental difference, the use of the unique capabilities of quantum mechanics; the second is post-quantum cryptography (PQC) [2], based on the more complicated mathematical problems (for example, lattice-based cryptosystems, syndrome-based cryptosystems and others).

Unlike most classical cryptosystems, whose security is based on unproven mathematical assumptions, the security

of QC systems relies on fundamental laws of quantum mechanics, which, with proper implementation makes it fundamentally impossible to intercept information and breach its confidentiality. One of the most advanced QC technologies, along with quantum key distribution (QKD), is quantum secure direct communication (QSDC), which allows to transmit information through an open channel directly (without encryption, so the problem of key distribution is eliminated) [3]. Today, a large number of QSDC methods are proposed [4, 6, 8] based on various quantum technologies and can be used both for secure information transmission (using qubits or qudits) and for the cryptographic keys distribution [22, 25]. However, in deterministic QSDC protocols, every bit is confidential and should not be compromised, so the requirements for its stability are much higher than for QKD protocols. The deterministic QSDC protocols disadvantage is that they have only asymptotic resistance (security) to non-coherent attacks and, of course, require security enhancement (amplification) methods.

II. Related Works and problem Statement

In [6], the methods of enhancing the QSDC protocols security are described, and the authors proposed and theoretically substantiated method of ensuring QSDC protocols stability. The method developed in [6] requires the generation of ternary (trit) pseudorandom number generator (PRNG) [23], thus increasing the information capacity of transmission protocols. The analysis revealed a sufficient number of existing PRNG that can be used for various applications [4, 5, 7-11, 14, 16].

The ISO/IEC 18031 standard [5], which sets out conceptual models, terminology and requirements relating to the structural elements and properties of systems used to generate random bits in cryptographic applications, defines two types of PRNG: non-deterministic (random bit generation mechanism that uses an entropy source to generate a random bit stream) and deterministic (bit generation mechanism that uses deterministic mechanisms such as cryptographic algorithms on an entropy source to generate a random bit stream).

PRNG can be classified according to different distribution principles [4], but the most complete classification is presented in [7]. According to this classification, PRNG are divided into crypto-resistant and non-crypto-resistant. Crypto-resistant include: based on streaming ciphers (e.g., Dragon-128, SEAL, RC4, RC5, RC6, Grain, Yamb, Phelix), based on block ciphers (for example, GOST 28147-89, AES, ANSI X9.17, DES), based on one-way functions (for example, BBS, RSA, Dual_EC_DRBG (elliptic curves), GPSSD (linear codes), etc.) and non-crypto-resistant: based on elementary recursors (for example, linear congruent, polynomial congruent, additive Fibonacci, additive Fibonacci delayed and multiplicative Fibonacci delayed PRNG), based on operations in finite fields (for example, Genoa generators, Golman, and others) [20, 21, 24, 27].

However, all PRNG developed today are binary sequences oriented, so developing a trit PRNG is an urgent scientific task. In view of this, the authors previously proposed a new method for generating trit PRN in [12]. To verify this method appropriate software needs to be developed. In view of this, the purpose of the article is to carry out detailed experimental study of the proposed trit PRNG for its effectiveness evaluation in various cryptographic applications.

III. Theoretical Basis of the Proposed Method and PRNG Construction

The trit generation method includes the following main steps: 1) initialization of the internal state vector; 2) directly PRN generation. Consider shortly each step:

Step 1. Initialization of the internal state vector U is performed. Based on initialization vector VI and secret key K, $U \in V_p$, $VI \in V_e$, $K \in V_n$, let's consider :

$U = (x_1, x_2, x_3, x_4, x_5, x_6, y_1, y_2, y_3, y_4, k_1, k_2, k_3, k_4)$, where x_i, y_j, k_j are parts of internal state vector U ($x_i \in V_l$, $y_j \in V_l$, $k_j \in V_l$, $i \in \overline{1,6}$, $j \in \overline{1,4}$); $VI = (VI_1, VI_2, VI_3, VI_4, VI_5, VI_6, VI_7, VI_8, VI_9, VI_{10})$, where VI_o are initialization vector parts VI ($VI_o \in V_l$, $o \in \overline{1,10}$); $K = (K_1, K_2, K_3, K_4)$, where K_w are secret key parts K ($K_w \in V_l$, $w \in \overline{1,4}$).

Then, the internal vector state U is initialized this way: $x_i = VI_i$, $y_j = VI_{6+j}$, $k_j = K_j$, $i \in \overline{1,6}$, $j \in \overline{1,4}$.

Step 2. Progressive generation of the output sequence is performed $M = (M_1, ..., M_b)$, $M \in V_m$, M_q are parts of the generated sequence M, $M_q \in V_n$, $q \in \overline{1,b}$.

Sub step 2.1. To generate part of the output sequence M_q r-times the following calculations are done:

2.1.1. New values of vectors x_1, x_2, x_3;
2.1.2. New values of vectors k_1, k_2, y_1, y_2;
2.1.3. New vectors x_4, x_5, x_6;
2.1.4. New values of vectors k_3, k_4, y_3, y_4.

Sub step 2.2. Using the vector concatenation, the initial sequence is calculated M_q: $M_q = (y_1 \mid y_2 \mid y_3 \mid y_4)$.

Based on this method TriGen v.2.0 PRNG was developed. Detail algorithm of this PRNG realization is presented on Fig. 1.

TriGen v.2.0

Input: initialization vector VI, secret key K, $VI \in V_{240}$, $K \in V_{96}$, parameter b.

Output: output sequence $M = (M_1, ..., M_b)$, $M \in V_{96b}$, $M_q \in V_{96}$, $q \in \overline{1,b}$.

1. $x_i = VI_i$, $y_j = VI_{6+j}$, $k_j = K_j$, $i \in \overline{1,6}$, $j \in \overline{1,4}$.

2. *For* $q = 1; q \le b; q++$ *do*

2.1. *For* $j = 0; j < 4; j++$ *do*

2.1.1. $x_1 = (Sbox(x_1 + k_1) \oplus x_4) <<< k_4$; $x_2 = (Sbox(x_2 + k_2) + x_5) >>> k_3$;

$x_3 = Mix((x_3 + x_6) \oplus y_3) <<< x_1$;

2.1.2. $k_1 = Sbox((Sbox(x_1 \oplus k_1) + x_5) \oplus y_1)$; $k_2 = Sbox(Mix(x_2 + k_2 + x_6) \oplus y_2)$;

2.1.3. $y_1 = Sbox(((k_1 + y_1) <<< x_2) \oplus k_3)$; $y_2 = Mix(Sbox(((k_2 + y_2) >>> x_3) \oplus k_4))$;

2.1.4. $x_4 = (Sbox(x_4 + k_3) \oplus x_1) <<< k_2$; $x_5 = (Sbox(x_5 + k_4) + x_2) >>> k_1$;

$x_6 = Mix((x_6 + x_3) \oplus y_1) <<< x_4$;

2.1.5. $k_3 = Sbox((Sbox(x_4 \oplus k_3) + x_2) \oplus y_3)$; $k_4 = Sbox(Mix(x_5 + k_4 + x_3) \oplus y_4)$;

2.1.6 $y_3 = Sbox(((k_3 + y_3) <<< x_5) \oplus k_1)$; $y_4 = Mix(Sbox(((k_4 + y_4) >>> x_6) \oplus k_2))$.

2.2. $M_q = (y_1 | y_2 | y_3 | y_4)$

Fig.1. Pseudocode of TriGen v.2.0 PRNG

IV. Experimental Study of the Trit PRNG

The purpose of the experiments is to investigate the effectiveness of the developed PRNG in comparison with the known C ++ PRNG and tested its adequacy.

To achieve the experimental target, the following tasks are required:

1. To test proposed and known method of generating trit PRN using the NIST STS method.
2. To test proposed and known method of generating trit PRN using the method of evaluating the trit PRN quality described previously by authors in [13].

The input parameters: generated by the TriGen v.2.0 PRNG sequences (PRN are transformed from ternary to binary) and sequences generated by standard C ++ PRNG.

Output parameters: NIST STS passing results and TriGen v.2.0 PRNG quality assessment developed using proposed console application.

Procedure for the experiments:

1. Generate 100 sequences by PRNG (TriGen v.2.0 PRNG and standard C ++ PRNG), convert trits to bits, and then check them by NIST STS software for pseudo-randomness.
2. Generate 100 sequences by PRNG (TriGen v.2.0 PRNG and standard C ++ PRNG), and then test them for pseudo-randomness using the developed TriGen v.2.0 PRNG console application.

A. Testing PRN by the NIST STS method

Initially, the proposed method of trit PRN generating was decided to test by the NIST STS method [18] in order to check whether standard bit tests can adequately assess trit PRN. NIST STS are used to determine the qualitative and quantitative features of the sequences randomness. Three basic criteria are used to draw conclusions about passing random sequences of statistical tests [17-19] are following:

1. Criterion for decision-making based on the establishment of some threshold level.
2. Criterion based on establishing a fixed confidence interval.
3. Criterion for some appropriate statistical test probability value P-value.

The statistical test is based on the verification of null hypothesis H_0 – that the sequence under study is random [15, 18, 19]. Alternative hypothesis H_1 is also provided – the sequence under study is not random. Therefore, the generated sequence is examined by a set of tests, each of which concludes whether the hypothesis H_0 is rejected or accepted. For each test, adequate randomness statistics are selected based on which the hypothesis H_0 is further rejected or accepted. Theoretically, the distribution of statistics for the null hypothesis is calculated using mathematical methods. The critical value is then determined from such an exemplary distribution. When

performing the test, the value of the test statistic is calculated, which is compared to the critical value. In case of exceeding the test critical value over the reference, hypothesis H_1 is accepted, otherwise - hypothesis H_0.

For the experiments, the following input parameters were selected for the use of NIST STS (according to [18, 19]):

1. The length of the test sequence n=10^6 bit.
2. The number of sequences being tested m=100.
3. Significance level $\alpha = 0,01$.
4. Number of tests q=188, among them: Frequency − 1, Block Frequency − 1, Cumulative Sums − 2, Runs − 1, Longest Run − 1, Rank − 1, FFT − 1, Non Overlapping Template − 148, Overlapping Template − 1, Universal − 1, Approximate Entropy − 1, Random Excursions − 8, Random Excursions Variant − 18, Serial − 2, Linear Complexity − 1.

According to [13] a confidence interval rule was applied, the lower bound being 0.96015.

For experiments, a console software called TriGen v.2.0 was developed in C ++ programming language, which allows to generate trit sequences based on proposed algorithm TriGen v.2.0 and the standard C ++ PRNG.

The experiments were decided to conduct in accordance to standard approach [18] as follows:

1. Each generator under study (TriGen v.2.0 algorithm and standard C ++ PRNG) generated three sequences of 6×10^7 trit.
2. There was a transformation of the trit sequence into a binary number system. To do this, the trit sequence was divided into 24 trit blocks, each block being individually transformed into 40 bit sequences. The result is a binary sequence of 10^8 bits in length.
3. The binary sequence was checked by NIST STS. As a result, statistical portraits of the sequences were obtained.

Generation of trit PRN with standard C ++ PRNG was performed as shown on Fig. 2.

Input: vectors k and a, $k \in V_{32}$, $a \in V_{32}$ ($V_n = \{0,1\}^n$).

Output: output sequence $M = (M_1, ..., M_n)$, $M_q \in \{0,1,2\}^n$, $q \in \overline{1,n}$.

1. $x = k$, $y = a$;

2. $std : srand(std :: time(0))$;

2. *For* $q = 1; q \le n;$ $q{+}{+}$ *do*

2.1. *For* $j = 0;$ $j < 4;$ $j{+}{+}$ *do*

2.1.1. $b = (\text{rand}() + x) \oplus y$;

2.1.2. $c = (\text{rand}() + y) \oplus x$;

2.1.3. $y = (\text{rand}() + b) \oplus c$

2.1.4. $x = (\text{rand}() + y) \oplus b$

2.2. $M[q] = x\%3$;

Fig.2. Pseudocode for trit sequences generating procedure by standard C ++ PRNG

The trit PRN generation by the proposed algorithm TriGen v.2.0 was performed as described above. For each sequence, the initial values of the 24 trit vectors k_i,, $i \in \overline{1,4}$ were set separately, after which the sequences were generated.

Firstly, describe the study results for C++ PRNG.

Table 1. Inputs for C ++ PRNG for further NIST STS testing

C++ gen	*Initial parameters*	
Sequence 1	k = 314342312	a = 403242341
Sequence 2	k = 3834425654	a = 234525320
Sequence 3	k = 2577261391	a = 980904215

The results of the NIST STS tests, for the trit sequences generated by C ++ PRNG and transformed into binary form for further testing, are presented in Fig. 3-5.

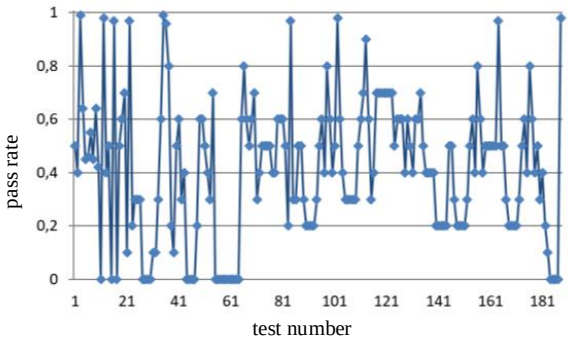


Fig.3. Statistical portrait of C ++ gen sequence 1

In the first case, the sequence was tested with only 3 test above the 99% threshold and 6 test with the 96% threshold. Conclusion: The generated sequence failed tests.

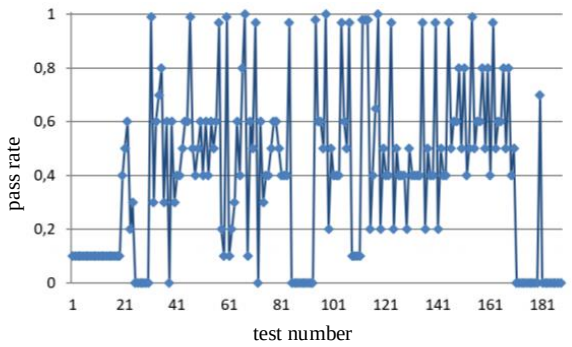


Fig.4. Statistical portrait of C ++ gen sequence 2

The results of the second experiment: 99% – passed 7 tests, the threshold 96% – 22. Which indicates that the generated sequence also failed testing.

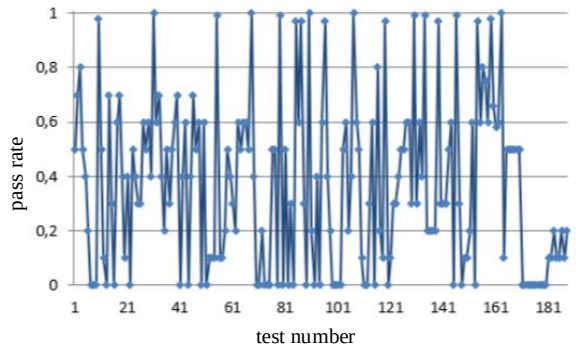


Fig.5. Statistical portrait of C ++ gen sequence 3

The third result indicates that the threshold of 99% passed – 10 tests, and the threshold of 96% passed – 18. Which means that the generated sequence also failed testing.

Let's describe results of the TriGen v.2.0 algorithm study.

Table 2. Inputs for TriGen v.2.0 algorithm for further NIST STS testing

C++ gen	*Initial parameters*
Sequence 1	k_1 = 000000 000000 000000 000000, k_2 = 000000 000000 000000 000001, k_3 = 000000 000000 000200 000000, k_4 = 000000100000 000000 000000.
Sequence 2	k_1 = 000001000000 000001011000, k_2 = 120000 000000 000210 201001, k_3 = 200100 200100 010200100001, k_4 = 201010111111 211000 002222.
Sequence 3	k_1 =102210 210120 001022 010110, k_2 = 2010010202101212101210 11, k_3 = 102021022011 120101 122102, k_4 = 120220110200102112 011012.

In Fig. 6-8 depicts statistical portraits generated by TriGen v.2.0 trit sequences during passing NIST STS tests.

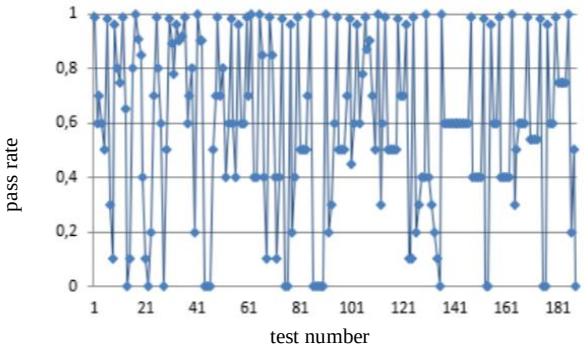


Fig.6. Statistical portrait of TriGen v.2.0 sequence 1 (NIST STS)

Sequence 1 results: the number of tests that have passed the threshold of 99% is 32, and the threshold of 96% has passed – 41, which indicates that the generated sequence by the algorithm TriGen v.2.0 also failed NIST STS testing.

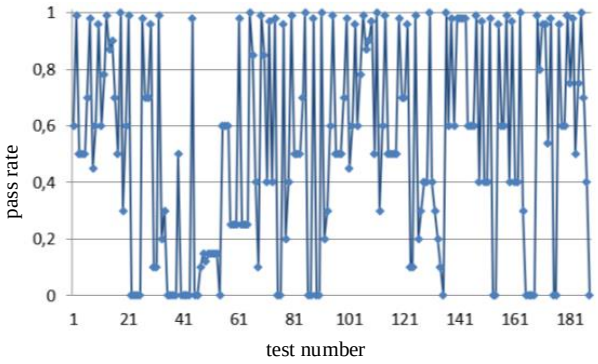


Fig.7. Statistical portrait of TriGen v.2.0 sequence 2 (NIST STS)

Sequence 2 results: the number of tests that have passed the threshold of 99% is 26, the threshold of 96% has passed – 32. The generated sequence by the algorithm TriGen v.2.0 also failed testing.

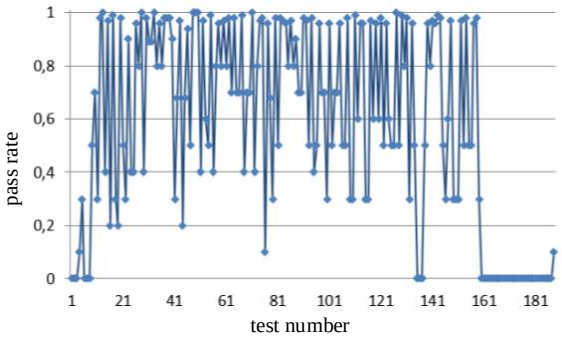


Fig.8. Statistical portrait of TriGen v.2.0 sequence 3 (NIST STS)

Sequence 3 results: the number of tests that have passed the threshold of 99% – 12, 96% passed – 48. Thus, this generated sequence by the algorithm TriGen v.2.0 also did not pass the testing.

Therefore, it can be concluded that standard bit tests cannot correctly evaluate the pseudorandom trit sequences. This can be explained by transformation sequence from trits into bits. With this transformation, the trit block (in this case 24 trits) cannot cover the fully formed bit block (in this case, 40 bits). As far as, 3^{24} = 282429536481, and 2_{40} = 1099511627776, thus, the 817082091295 bit block value will never appear in it, so the sequence is predictable.

B. Testing PRN by proposed Trit STS method

Let's describe the input parameters for Trit STS application (the parameters are chosen similar to the NIST STS tests):

1. The length of trit sequence n= 150 000 trit.
2. The number of sequences being tested m=100.

3. Significance level $\alpha = 0,01$.

4. Number of tests q=152, among them: Frequency monotrit test – 1, Frequency block trit test – 1, Trit runs test – 1, Test for the longest run in a block – 1, Trit non-overlapping template matching test – 148, Trit overlapping template matching test – 1.

Thus, the sample size under test was $N = 1.5 \times 10^7$ trit, the number of tests (q) for different lengths q = 152, so the statistical portrait of the generator contains 152 probability P-values. As for the NIST STS tests, we will apply the rule of confidence intervals, i.e. the pass rate of each test should be 0.96015%.

TritSTS 2020 (on C ++ language) console software was developed based on the proposed PRN quality assessment method and the above input parameters, which allows to evaluate the quality of Trit PRN and their suitability for use in cryptography. This tool was used in the experiments.

The experiments were carried out as follows:

1. Each PRNG under study (TriGen v.2.0 algorithm and standard C ++ PRNG) generated five sequences of length $N = 1,5 \times 10^7$ trit.

2. The resulting trit PRN was checked by the program TritSTS 2020. As a result, statistical portraits of the sequences were obtained.

Generation of trite sequences with the standard C ++ PRNG and the proposed TriGen v.2.0 algorithm is described above. Let's start pseudorandom testing from the results of the TriGen v.2.0 algorithm study.

Table 3. Inputs for TriGen v.2.0 algorithm for further TritSTS 2020 testing

C++ gen	*Initial parameters*
Sequence 1	k_1 = 102210 210120 001022 010110, k_2 = 2010010202101212101210 11, k_3 = 102021022011 120101 122102, k_4 = 120220110200102112 011012.
Sequence 2	k_1 = 000000 000000 000000 000000, k_2 = 000000 000000 000000 000001, k_3 = 000000 000000 000200 000000, k_4 = 000000100000 000000 000000.
Sequence 3	k_1 = 000000 000200 000000 001000, k_2 = 000200 000010 000000 000001, k_3 = 010000 000000 000200 000000, k_4 = 000000100000 000000 000000.
Sequence 4	k_1 = 100020102000100022 011102, k_2 = 221100 010101020202 212121, k_3 = 111002 020100 210200110202, k_4 = 120022102021022001100202.
Sequence 5	k_1 = 221020102001100022 010112, k_2 = 021222110201120001 202021, k_3 = 121110 022001112202 210201, k_4 = 102212 001021122011 201202.

In Fig. 9 depicts statistical portraits of TritSTS 2020 passage.

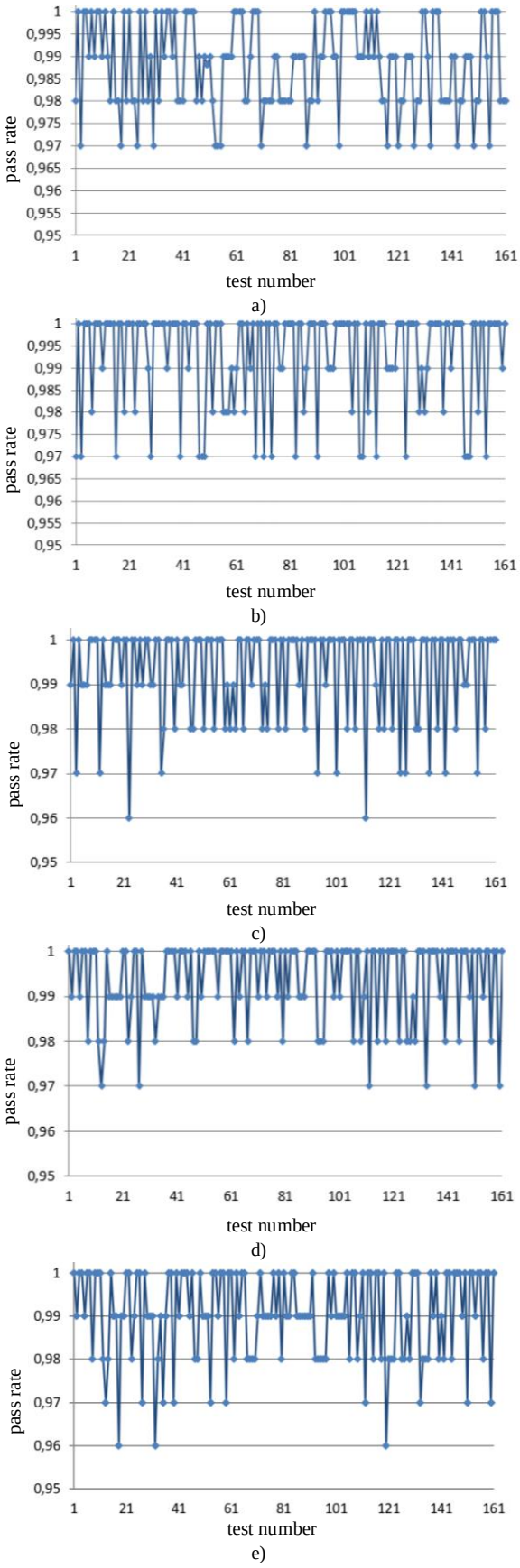


Fig.9. Statistical portraits of TriGen v.2.0 using TritSTS 2020: sequence 1 (a), sequence 2 (b), sequence 3 (c), sequence 4 (d) and sequence 5 (e)

Sequence 1 by TriGen v.2.0 results (Fig.9a): number of tests that passed the 99% threshold – 134, 96% passed – 151. $P_{value_{01}} \geq 0,01$ quantity – 150, $P_{value_{02}} \geq 0,01$ – 150, $P_{value_{12}} \geq 0,01$ – 151. These results indicate that the generated PRN has passed tests successfully.

Sequence 2 by TriGen v.2.0 results (Fig.9b): number of tests that passed the 99% threshold – 123, 96% passed – 153. $P_{value_{01}} \geq 0,01$ quantity – 152, $P_{value_{02}} \geq 0,01$ – 151, $P_{value_{12}} \geq 0,01$ – 151. These results indicate that the generated PRN has passed tests successfully.

Sequence 3 by TriGen v.2.0 results (Fig.9c): number of tests that passed the 99% threshold – 118, 96% passed – 153. $P_{value_{01}} \geq 0,01$ quantity – 152, $P_{value_{02}} \geq 0,01$ – 151, $P_{value_{12}} \geq 0,01$ – 153. PRN has passed tests successfully.

Sequence 4 by TriGen v.2.0 results (Fig.9d): number of tests that passed the 99% threshold – 120, 96% passed – 151. $P_{value_{01}} \geq 0,01$ quantity – 142, $P_{value_{02}} \geq 0,01$ – 150, $P_{value_{12}} \geq 0,01$ – 153. These results also indicate that the generated PRN has passed tests successfully.

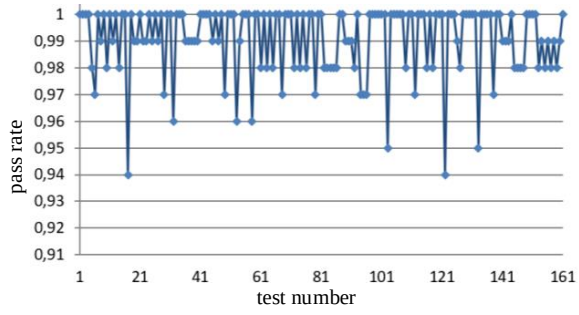
Sequence 5 by TriGen v.2.0 results (Fig.9e): number of tests that passed the 99% threshold – 114, 96% passed – 150. $P_{value_{01}} \geq 0,01$ quantity – 151, $P_{value_{02}} \geq 0,01$ – 150, $P_{value_{12}} \geq 0,01$ – 149. These results indicate that the generated PRN has not passed tests.

Let's describe the results for the standard C ++ PRNG tested by TritSTS 2020.

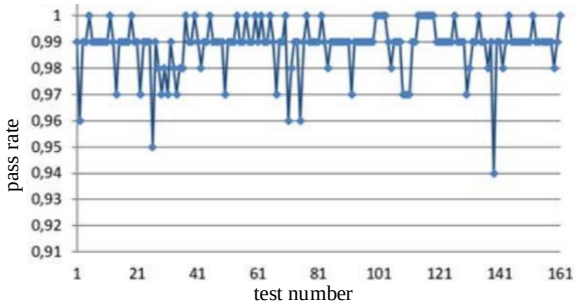
Table 4. Inputs for C ++ PRNG for further TritSTS 2020 testing

C++ gen	*Initial parameters*	
Sequence 1	k = 314342312	a = 403242341
Sequence 2	k = 3834425654	a = 234525320
Sequence 3	k = 2577261391	a = 980904215
Sequence 4	k = 5674312	a = 8476892
Sequence 5	k = 7890212	a = 34095422

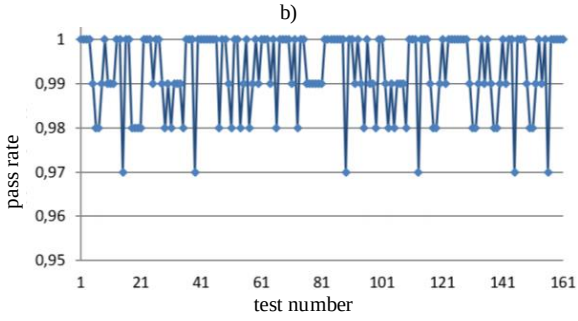
Fig. 10 shows statistical portraits for 5 different sequences using TritSTS 2020.



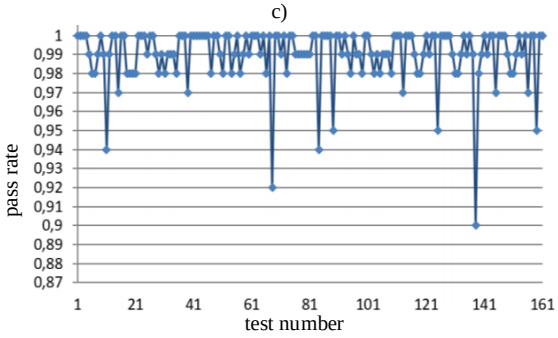
a)



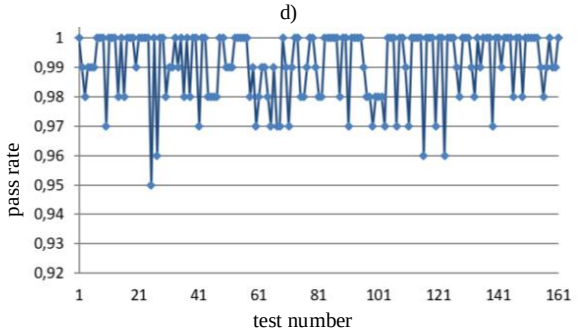
b)



c)



d)



e)

Fig.10. Statistical portrait of C++ PRNG using TritSTS 2020: sequence 1 (a), sequence 2 (b), sequence 3 (c), sequence 4 (d), sequence 5 (e)

Sequence 1 by C++ PRNG results (Fig.10a): number of tests that passed the 99% threshold – 110, 96% passed – 147. $P_{value_{01}} \geq 0,01$ quantity – 140, $P_{value_{02}} \geq 0,01$ – 143, $P_{value_{12}} \geq 0,01$ – 141. These results indicate that the generated PRN is not bad, but it did not pass the tests.

Sequence 2 by C++ PRNG results (Fig.10b): number of tests that passed the 99% threshold – 108, 96% passed – 151. $P_{value_{01}} \geq 0,01$ quantity – 144, $P_{value_{02}} \geq 0,01$ – 140, $P_{value_{12}} \geq 0,01$ – 145. These results indicate that the generated PRN is not bad, but it did not pass the tests.

Sequence 3 by C++ PRNG results (Fig.10c): number of tests that passed the 99% threshold – 121, 96% passed – 152. $P_{value_{01}} \geq 0,01$ quantity – 150, $P_{value_{02}} \geq 0,01$ – 151, $P_{value_{12}} \geq 0,01$ – 152. These results indicate that the generated PRN has passed tests successfully.

Sequence 4 by C++ PRNG results (Fig.10d): number of tests that passed the 99% threshold – 110, 96% passed – 147. $P_{value_{01}} \geq 0,01$ quantity – 140, $P_{value_{02}} \geq 0,01$ – 143, $P_{value_{12}} \geq 0,01$ – 141. These results indicate that the generated PRN is not bad, but it did not pass the tests.

Sequence 5 by C++ PRNG results (Fig.10e): number of tests that passed the 99% threshold – 116, 96% passed – 149. $P_{value_{01}} \geq 0,01$ quantity – 137, $P_{value_{02}} \geq 0,01$ – 142, $P_{value_{12}} \geq 0,01$ – 141. These results indicate that the generated PRN is not bad, but it did not pass the tests.

For clarity, the experimental results are summarized in a Table 5. According to the obtained results, the sequences generated by the proposed algorithm TriGen v.2.0 showed better results than standard C ++ PRNG.

Table 5. Test results for TritSTS 2020

Sequence	$P_{value_{01}}$	$P_{value_{02}}$	$P_{value_{12}}$	*Number of successful passing tests*	
				99%	*96%*
TritGen 1	150	150	151	134	151
TritGen 2	133	151	153	123	150
TritGen 3	152	151	153	118	153
TritGen 4	142	150	153	120	151
TritGen 5	151	150	149	114	150
C++ PRNG 1	140	143	141	110	147
C++ PRNG 2	144	140	145	108	151
C++ PRNG 3	150	151	152	121	152
C++ PRNG 4	138	133	129	109	145
C++ PRNG 5	137	142	141	116	149
TritGen average	**145,6**	**150,4**	**151,8**	**121,8**	**151**
C++PRNG average	**141,8**	**141,8**	**141,6**	**112,8**	**148,8**

Note that from five sequences generated by the standard C ++ PRNG, only one passed tests by TritSTS 2020, and four of the five sequences successfully passed tests using the TriGen v.2.0 PRNG. In average, the sequences generated by the TriGen v.2.0 algorithm are 11.6% more likely to successfully pass 99% threshold and 3.4% more likely to successfully pass 96% threshold.

V. Conclusions

In this paper high-speed and secure PRN generation method was proposed. It is important for various practical cryptographic applications (for example, trit QC systems, IoT and Blockchain technologies).

This method includes the following steps: initialization of the internal state vector and directly PRN generation. Based on this method TriGen v.2.0 PRNG was developed and studied in practice.

Therefore, analyzing the results of the study it can be conclude that NIST STS technique cannot be used to evaluate the quality of the trit sequences (this technique is oriented on bit sequences evaluation), and the developed method as well as PRNG based on it for evaluating trit sequences quality [26, 28] suitable for use in practice.

Future research study can be related with developing fully functional version of TritSTS 2020 technique and software tool.

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