Scalalble One-Time Pad—From Information Theoretic Security to Information Conservational Security

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ABSTRACT—Whereas it is an impossible task to scale One-Time Pad (OTP) without sacrificing information theoretic security or network traffic, this project started with the attempt to develop a paradigm of Scalable One-Time Pad (S-OTP) ciphers based on information conservational computing/cryptography (ICC). This line of research, however, hits a dead-end after testing its limitation of computational precision for information conservation when long messages are transmitted. It is proven that OTP can only be partially scaled for digesting long messages on IEEE binary64, 128, and 256 standard computers associated with quantum key distribution (QKD). Significant traffic and key reduction is possible but only at the expense of information loss. It is shown that ICC enables a type of data compression to reduce or scale a long message and its cipher key length to a significantly smaller minimum with partial information conservation such as the document size, structure, and digesting. Practical applicability and limitations of the new paradigm is analysed. It leads to the proposal of a type of quantum machinery. It is concluded that, if key length requirement of OTP for information theoretic security remains an impasse, the only solution for post-quantum cryptography could be quantum teleportation. Some mysteries and challenges are discussed.

KEYWORDS: Black Hole Data Compression; Information Conservational Security; Post-Quantum Cryptography; Partially Scalable One-Time Pad; Quantum Crypto Machinery; Floor-Roof Mysteries

1. INTRODUCTION

1.1 Post-Quantum Cryptography

Cryptography is essential for the security of digital communication. However, many commonly used cryptosystems will be completely broken by a quantum algorithm for integer factorization [1] once large quantum computers are commercially applicable. Post-quantum cryptography is to counter such quantum attacks and to keep digital communication secure [2]. A key for success is to identify mathematical operations for which quantum algorithms offer little advantage in speed, and then to build cryptographic systems around them. Although progress has been made most proposed methods incur serious costs, especially in network traffic. A major challenge is to reduce encryption key length without increasing data length.

1.2 Information Theoretic Security

One-Time Pad (OTP) [3] [4] is often regarded the only cipher with proven information theoretic security (ITS) [5]. A cryptosystem with ITS derives its security purely from information theory [6]. A key concept of information theory is entropy—a measure of disorder of a system that provides a basis for unicity distance [5]. The distance can be defined as the minimum amount of ciphertext required to permit a computationally unlimited adversary to recover the unique encryption key in a brute force attack.

An information theoretically secure system cannot be broken even if the adversary has unlimited computing power. Such a cryptosystem is considered cryptanalytically unbreakable. The concept of ITS was introduced in 1949 by American mathematician Claude

Shannon, the inventor of information theory, who used it to prove that the OTP cipher was secure [5]. ITS bas been used for the most sensitive communications, such diplomatic and high-level military communications to counter the great efforts enemy governments expend toward breaking them.

OTP can now be used together with quantum key distribution (QKD)—a well-developed application of quantum cryptography. QKD uses quantum communication to establish a shared key between two parties— sender Alice and receiver Bob. The key is then shared. If a third party Eve tries to eavesdrop on the communication between Alice and Bob, the quantum communication will fail for security protection [8]. Once the key is established, it is typically used as a symmetric key for digital communication such as using OTP. Since OTP is quantum proof to quantum factorization, it is a good candidate for post-quantum cryptography [2]. Unfortunately, the key requirement of equal or greater length than the original message hinders the general application of OTP even though QKD is a well-developed partner technology. As a result, OTP is generally limited at present time to transmitting relatively short messages with high security requirement.

1.3 Information Conservational Security

History shows that, when Shannon invented OTP in 1946 [6], the first computer was not out yet. Since then, computing theory and technology have advanced beyond anyone's imagination. Although it was proven [5] that any cipher with the perfect secrecy property must use keys with effectively the same requirements as OTP keys, these proofs, however, did not take later computing theories and technological development into consideration that can conceal the meaning of a message. For instance, when entropy became a key concept in information theory, information conservational computing/cryptography (ICC) with quantum intelligence [9,10,11,12] was not incepted yet. On other hand, before the first computer was put on the drawing board, IEEE binary64, 128, and 256 double-precision floating-point format for a wide dynamic range of numeric values was unimaginable. The wide dynamic range makes equilibrium-based ICC practical.

With the new theoretical and technological advances, the information conservational approach to security attempts to incorporate holistic and set-theoretic data compression into OTP as an extension to information theoretic security. In this approach, a *partially scalable one-time pad* (S-OTP) cipher does not attempt to falsify Shannon's theorem, it bypasses the assumptions of the theorem by reducing the message length to be enciphered with black-hole-like information conservational data compression but still enable the sharing of holistic information such as document structure, size, and perhaps keywords. This type of data compression is named black hole data compression (BHDC).

Cryptosystems often compress the plaintext before encryption for added security. When properly implemented, compression greatly increases the unicity distance [5] by removing patterns that might facilitate cryptanalysis. However, many ordinary lossless compression algorithms produce headers, wrappers, or other predictable output that might instead make cryptanalysis easier. Thus, cryptosystems must utilize compression algorithms that can hide these predictable patterns. BHDC is to make this possible.

Now we have the question: *Can S-OTP really make OTP partially scalable through BHDC?*

1.4 Approach and Organization

This paper presents S-OTP based on BHDC for efficient use of QKD on a local computer. It is shown that, with ICC, BHDC can compress a large data set to a tiny minimum with partial information conservation that can then be randomized. In this way, S-OTP

makes OTP practically applicable with much shorter keys for transmitting long messages or large data sets for holistic digestive reading and browsing without increasing network traffic. It thus presents a solution to quantum-proof digital communication. Different versions of S-OTP ciphers are analyzed and compared. Partial information conservational security conditions are established. Quantum-fuzzy collective precision is proposed. Quantum machinery development of S-OTP is briefly discussed.

This paper is organized in five sections. Section II presents the theoretical basis with illustrations BHDC and S-OTP. Section III examines the applicability and optimization of the S-OTP paradigm. Section IV presents an architectural design of S-OTP quantum dream machinery. Section V draws a few conclusions and identifies a number of major theoretical challenges.

2 THEORETICAL AND METHODOLOGICAL FORMULATION WITH ILLUSTRATION

2.1 Theoretical Formulation

It is shown [3] [4] that an OTP cipher is information theoretically secure and unbreakable [5] [6] provided that the message to be ciphered is unknown to attackers, and a cipher key meets *the four conditions of OTP:* (a) truly random; (b) never reused; (c) kept secret from all possible attackers; (d) of equal or greater length than the message. Based on the four security conditions, we consider the scalability and partial scalability of OTP.

Definition 1a. *Information conservational transformation* (ICT) is referred to as a set of set-theoretic mathematical functions that forms an transformation T to transform the bit pattern of a long message in form F_1 to a significantly shorter pattern in form F_2 systematically such that there exists a reverse transformation T' that can fully recover F_1 from F_2. Formally we have: $T(F_1)$: $F_1 \rightarrow F_2$ such that $\exists T'$ and $T'(F_2)$: $F_2 \rightarrow F_1$. *Partial information conservational transformation* (PICT) is referred to as a set of set-theoretic mathematical functions that forms an transformation T to transform the bit pattern of a long message in form F_1 to a significantly shorter pattern in form F_2 systematically such that there exists a reverse transformation T' that can partially recover F_1 from F_2. Formally we have: $T(F_1)$: $F_1 \rightarrow F_2$ such that $\exists T'$ and $T'(F_2)$: $F_2 \rightarrow F_3$, where $F_1 \cap F_3$ results the partially reserved information plus document size and structure. (Note: ICT is part of PICT.)

Definition 1b. *Scalability* is referred to as using ICT once or multiple times systematically to transform a long message or large data set into one or a series of short forms such that cipher keys are reduced to practical lengths or to a minimum for enciphering the short forms as OTP pads for secure transmission. In this case, An OTP pad is called a scalable OTP (S-OTP) pad. When PICT is used an S-OTP pad is called a partially scalable. In S-OTP, a key is assumed reusable if the reuse can be concealed in another unbreakable S-OTP pad.

Based on Definitions 1a and 1b, we extend *information theoretic security* (ITS) of OTP to *information conservational security* (ICS) of S-OTP.

Definition 2a. An S-OTP cipher is said having information conservational security (ICS).

Definition 2b. Given $0<i<N$, a *minimum length form* is a message form $F_x = (X, \{x_i/X\})$ that cannot be further reduced in binary length through ICT/PICT in theory. An *absolute minimum length form* is the minimum form when N = 2.

It could be argued that S-OTP is just OTP plus data compression, and there is nothing new. The counter argument is that: (1) Information conservation or preservation has been a long sought goal in physics and information theory without a breakthrough until recently [11,12]; (2) The key length problem of OTP has been a well-known long standing impasse;

(3) ICS is essentially information theoretic in nature that qualifies to be a systematic extension to ITS [9,10].

The inception of ICS accounts for the new development in computing technology. Double precision floating-point format of IEEE binary64, 128, or 256 is used as a technological basis for analysis that was not available when information theory was initially developed [6].

Theorem 1a (Possibility Theorem). PICT for ICS is possible based upon OTP and IEEE binary64, 128, or 256. Formally, let *{x}* be the data set of a long integer *L* representing a sufficiently long message divided into sections, some set $\{x_i\}$, $0<i<N$, exists such that $(X, \{x_i/X\})$ is significantly shorter than the long integer *L*, where $X = \sum_i x_i$ is a math summation (not XOR), and $\{x_i/X\}$ a percentage distribution. However, The original message L can only be partially recovered from $(X, \{x_i/X\})$ due to the limitation of double precision.

Proof. *To show possibility, let L=16K bits divided into 32 of 512-bit sections or integers* $\{x_i\}$, $0<i<32$. *That would leads to one 64, 128, or 256-bit double floating point summation* $X=\sum_i x_i$ *and 32 of 64, 128, or 256-bit percentage distributions* $\{x_i/X\}$, *respectively, total 8K+256, 4K+128, or 2K+64 bits vs. 16K, a nearly 2-4-8-fold reduction of key length and network traffic. This could be further hierarchically scaled (reduced) to a minimum form or until the pair* $(X, \{x_i/X\})$ *is short enough to be randomized and enciphered with a significantly shorter key. Thus, ICS is achievable. However full information conservation is achievable only when the message length is in the range of the effective digits limited by double precision floating point formal of IEEE binary64, 128, or 256, but not achievable in general.* (Note: Since a possibility theorem is not an optimality theorem, a generic example is sufficient for its proof. However, the possibility opened the door to partial scalability of OTP.) ■

Theorem 1b (Minimum Length Theorem). For any message in an intermediate PICT transformation, given the number of data divisions N, *a minimum length* form $F_x = (X, \{x_i/X\})$ exists in theory where *length(X) = length*(x_i/X)*—one double precision floating point number length,* $0<i<N$. An *absolute minimum length* also exists in theory, which equals *length(three double precision floating point numbers),* that would be 192, 384, or 768 bits for IEEE binay64, 128, and 256, respectively.

Proof. *Given any PICT T, we must have a form in length* $F_x = (X, \{x_i/X\})$, $0<i<N$, *such that at certain point we must have* $T(F_x):F_x \rightarrow F_y$ *and* $length(F_y) = length(F_x)$ *because (1) given* $0<i<N$, $length(\{x_i/X\})$ *is irreducible; (2) if* $length(X) \leq$ *length(one double precision floating point number) it becomes irreducible either. Then we must have an absolute minimum length for N, where one double precision floating point number is for the summation, two are for the distribution in double precision floating point format, that would be three of them.* ■

Theorem 1c (Reachability of Minimum). Given the number of data divisions N≥2, a minimum or absolute minimum length form can be reached through a recursive PICT T(T(X)) if sufficient computational power is available.

Proof. *It follows from the proof of Theorem 1b.* ■

We name the above type of data compression *Black Hole Data Compression* (BHDC) for its ability to reach a condensed tiny minimum with holistic recursive information conservational transformation. BHDC is fundamentally different from other lossless and mathematical data compressions widely used in computer coding and zip technologies, which are based on information theoretic modeling for near optimal character coding but cannot reach a holistic condensed tiny minimum with partial information conservational transformation. Similarly, a data decompression process of BHDC can be named big bang information recovery (BBIR).

Theorem 1d (Randomization Theorem). A bit pattern *L* with a tiny minimum number of bits resulted from BHDC can always be randomized with another bit pattern *R* in limited

length for enhanced unicity distance regardless of any header, wrapper, or other predictable output in L.

Proof. *It follows from the commonsense that, if L is a tiny minimum, a small number of random bits in R can be inserted into L as paddings for enhanced unicity distance. Thus, any necessary headers, wrappers, or other predictable output can be randomized before the text is enciphered that, otherwise, would be patterns facilitating cryptanalysis by attackers in a brute force attack [5]. The paddings can be removed by a receiver based on a key (e.g. Key code 0101080302R2 stands for "Pad 1 random bit at the beginning and insert 1 random bit for every 8 bits after bit position 3, then pad 2 random bits at the end. Repeat the padding with double distance that is: Pad 1 random bits at the beginning and insert 1 random bits for every 8 bits after bit position 3 × 2 = 6, then pad 2 random bits at the end.")* ■

2.2 Method1: Add, Divide, and Conquer

The rationale of S-OTP is that, given an unsigned big integer L representing the long message or large data item D to be transmitted, L can be divided into a set of shorter long integers $\{x_i\} = x_1, x_2, .., x_i, .. x_n$ representing sectors or sections of D to be transmitted. The summation $X = x_1 + x_2 + \ ...+ x_i+...+x_n$ can be obtained which could be represented as a long integer or a floating-point decimal much shorter than L to transmit. The set of percentage distribution $\{x_i/X\}$ is a type of most primitive information conservational key that can be encrypted and transmitted together with X in ciphertext for recovering $\{x_i\}$ to L and then D in the receiver side. This leads to S-OTP-Method1—a one key cipher.

S-OTP$_1$-Method1

Assume sender Alice and receiver Bob share a private key K distributed through QKD.

Part I. Encryption

Step 1. Let math summation $X = \sum_i x_i$ (not XOR).

Step 2. Calculate percentage distribution $\{x_i/X\}$;

Step 3. Encrypt the text $U = \{X, \{x_i/X\}\}$ with one key K to ciphertext $E=K \oplus U$ where $\oplus$ is *XOR* (not math summation).

Step 4. Alice Transmits E to Bob.

Part II. Decryption

Step 1. Use K to decipher E to obtain X *and* $\{x_i/X\}$;

Step 2. Use $\{x_i/X\}$ to decrypt the summation X and recover $\{x_i\}$;

Step 3. Recover transmitted message from $\{x_i\}$ with concatenation.

2.3 Illustration of S-OTP$_1$-Mehrod1

Assuming the plaintext data D to be transmitted is represented by the big integer L = *1048549998213983988*, we divide L into the three sections *1048549, 998213, and 983988.* Assume sender Alice and receiver Bob share a private key K distributed through QKD.

Part I - Encryption

(1) Let x_1 = 1048549, x_2 = 998213, x_3 = 983988, and

(2) $X = x_1 + x_2 + x_3 = 3030750$;

(3) Calculate percentage distribution $\{x_i/X\}=\{34.5970\%, 32.9362\%, 32.4668\%\}$;

(4) Encrypt the plaintext $U=\{3030750, \{34.5970\%, 32.9362\%, 32.4668\%\}\}$ to result in ciphertext $E=K \oplus U$;

(5) Transmit E to Bob;

Part II - Decryption:

(1) Use K to recover $U=\{3030750, \{34.5970\%, 32.9362\%, 32.4668\%\}\}$;

(2) Use U to recover x_1=1048549, x_2=998213, and x_3=983988;

(3) L = concatenate(x_1, x_2, x_3) = 1048549998213983988;

(4) Recover D from L.

It can be argued that S-OTP$_1$-Mehrod1 does not reduce the key length. The counter argument is that, as a simple example the illustration is already in a minimum form. It does not really need S-OTP because a single OTP is sufficient. As proven in Theorem 1, S-OTP

does reduce key length the same way with sufficiently long dada sections. The question is the *precision problem.*

2.4 Method2—ICC with Collective Precision

Percentage distribution has its own limitation due to sequential computation. When the math summation gets huge that is usually the case, the precision of a single percentage will be a problem. The computation of such a percentage can be avoided with the massive parallel collective precision property of ICC [9,10]. In ICC a big total can be divided into many subtotals or integers representing data sections. If each subtotal is further divided into bipolar import-export values, each can be normalized by its corresponding column subtotal. A information conservational matrix can then be derived through column-major normalization for massive parallelism and collective precision without using the grand total.

ICC is made achievable with bipolar fuzzy sets [13-17]. Bipolar fuzzy set theory forms an equilibrium-based mathematical abstraction—a set theoretic or information theoretic extension to fuzzy set theory [18]. It is a generalization of truth-based computing which can still be used freely as long as equilibrium conditions are not violated. Bipolar fuzzy set theory was once rescued by Zadeh [19].

In this subsection, we show an ICC example. We then examine and explain the properties of the example in next two subsections. A key concept in ICC is an information conservational bipolar matrix *M*. With *M* an energy or information total or summation can be decrypted through equilibrium-based rebalancing to result in all the subtotals in parallel with percentage distribution built into *M*. This makes it possible to develop digital or quantum machinery with massive parallelism in collective precision that is not achievable with linearly normalized percentage distribution.

M consists of bipolar elements. The energy and/or information of a bipolar (import-export) element or variable $x = (a, b)$ is defined as the length of a bipolar interval where a is negative and b positive.

Energy of x: $\varepsilon|x| = \varepsilon|(a, b)| = b - a = |a| + |b|.$ (1)

For instance, $\varepsilon|(-2.5, 3.5)| = 3.5 - 2.5 = 2.5 + 3.5 = 6.$

A 3-partner US-China-EU trade example is used to illustrate the basic idea of ICC with collective precision. First, the 3-parners' bipolar import-export data for 2014 are shown in **Fig. 1a** as a cognitive map (CM) in million Euros. The total energy/information in the trade scenario is characterized by the total import/export

$\varepsilon|(-3030750, +0)| = \varepsilon|(-0, +3030750)| = 3030750.$

Using collective bipolar interaction in ICC, accurate calculation can be carried out with the bipolar quantum cellular automaton (BQCA) $E(t+1) = M \times E(t)$ based on a column-major normalized bipolar cognitive map matrix *M* that does not need the calculation of percentage distribution. (Note: The illustrations in this paper are in fix-point format for readability. In real computing, they are in floating-point format.)

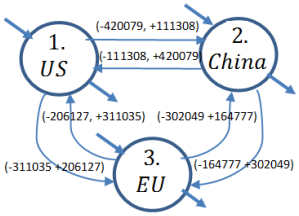
In this ICC example $E(1)$ is the transpose of the initial bipolar column vector with certain total energy/information. A cognitive map (CM) *C* is referred to as a bipolar or unipolar conceptual graph or an import/export network. *M* is obtained with column-major normalization of an i/o-consistent interactive CM in which all elements are directly or indirectly interrelated. In this example,

$$C(t) = \begin{bmatrix} (0,0) & (-420{,}079, +111{,}308) & (-311{,}035, +206{,}127) \\ (-111{,}308, +420{,}079) & (0,0) & (-164{,}777, +302{,}049) \\ (-206{,}127, +311{,}035) & (-302{,}049, +164{,}777) & (0,0) \end{bmatrix}.$$

$$M = normalize(C^T(t)) = \begin{bmatrix} (0.000\ 0.000) & (-0.112\ 0.421) & (-0.209\ 0.316) \\ (-0.401\ 0.106) & (0.000\ 0.000) & (-0.307\ 0.167) \\ (-0.297\ 0.197) & (-0.165\ 0.303) & (0.000\ 0.000) \end{bmatrix}.$$

Equilibrium-based rebalancing is illustrated in **Fig. 1b** and curved in **Fig. 1c**. **Fig. 1d** verifies such rebalancing with sequential computing. **Fig. 1e** shows 200% is balanced to a perfect percentage distribution built in *M*. Thus, matrix *M* can be deemed the encryption of a percentage distribution.

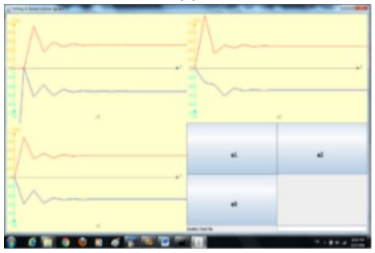
While sequential computing does not support parallel processing, equilibrium-based rebalancing can balance a total to a perfectly equilibrium state with percentage distribution coded in *M* in an iterative and massively parallel process without the need for individual percentages. Although a perfect equilibrium-state may be neither practical nor desirable in economics, equilibrium-based rebalancing provides a new approach to post-quantum cryptography. Most importantly, it finds a way for quantum-fuzzy collective precision.



(a)

t	E(t+1) = M(t) × E(t) e1	e2	e3
1	(-3030750.000, 0.000)	(-0.000, 0.000)	(-0.000, 0.000)
2	(0.000, 0.000)	(-321727.188, 1214205.875)	(-595794.188, 899022.625)
3	(-647442.250, 955835.875)	(-375738.375, 333436.250)	(-297782.688, 420514.375)
4	(-377520.813, 377520.813)	(-630613.250, 522677.375)	(-579544.938, 542872.625)
5	(-620577.625, 583280.625)	(-455013.250, 460129.250)	(-463296.094, 448453.000)
6	(-483180.125, 483180.125)	(-514797.813, 527851.500)	(-508852.563, 513087.688)
7	(-543767.625, 548278.250)	(-487545.188, 486926.438)	(-481218.563, 483013.688)
8	(-512763.688, 512763.688)	(-506231.313, 504652.594)	(-497437.406, 496901.063)
9	(-530639.875, 530094.375)	(-495690.813, 495765.688)	(-489388.063, 489170.938)
10	(-521049.438, 521049.469)	(-500810.844, 501001.781)	(-493386.656, 493451.531)
11	(-525948.625, 526014.563)	(-498152.719, 498143.656)	(-491231.906, 491258.156)
12	(-523370.719, 523370.719)	(-499627.813, 499604.750)	(-492391.719, 492383.844)
13	(-524756.813, 524748.875)	(-498834.719, 498835.813)	(-491788.219, 491785.063)
14	(-524021.125, 524021.125)	(-499249.156, 499251.906)	(-492102.594, 492103.531)
..	..	..	..
29	(-524274.313, 524274.313)	(-499106.281, 499106.281)	(-491993.781, 491993.781)
30	(-524274.250, 524274.250)	(-499106.281, 499106.281)	(-491993.781, 491993.781)
31	(-524274.250, 524274.250)	(-499106.250, 499106.250)	(-491993.750, 491993.750)
32	(-524274.250, 524274.250)	(-499106.250, 499106.250)	(-491993.750, 491993.750)

(b)



(c)

Partner	Import-Export of 2014	Total Volumes	Percentage (%)
US	(-731114 +317435)	1048549	1048549/3030750 = 34.5970%
China	(-276085 +722128)	998213	998213/3030750 = 32.9362%
EU	(-508176 +475812)	983988	983988/3030750 = 32.4668%
Total	(-1515375 +1515375)	3030750	100.0000%

(d)

t	E(t+1) = M(t) × E(t) Rebalancing 100 Percentage to Actual Distribution US	China	EU
1	(-100.0000, 100.0000)	(-0.0000, 0.0000)	(-0.0000, 0.0000)
2	(0.0000, 0.0000)	(-50.6783, 50.6783)	(-49.3217, 49.3217)
3	(-52.9004, 52.9004)	(-23.3993, 23.3993)	(-23.7003, 23.7003)
4	(-24.9127, 24.9127)	(-38.0530, 38.0530)	(-37.0343, 37.0343)
5	(-39.7215, 39.7215)	(-30.1952, 30.1952)	(-30.0833, 30.0833)
6	(-31.8852, 31.8852)	(-34.4024, 34.4024)	(-33.7125, 33.7125)
7	(-36.0322, 36.0322)	(-32.1528, 32.1528)	(-31.8150, 31.8150)
..	..	..	..
22	(-34.5969, 34.5969)	(-32.9362, 32.9362)	(-32.4669, 32.4669)
23	(-34.5971, 34.5971)	(-32.9361, 32.9361)	(-32.4668, 32.4668)
24	(-34.5970, 34.5970)	(-32.9362, 32.9362)	(-32.4668, 32.4668)
25	(-34.5970, 34.5970)	(-32.9362, 32.9362)	(-32.4668, 32.4668)

(e)

Figure 1. (a) Bipolar CM of 2014 US-China-EU trade (in Million Euros); (b) Rebalancing of total import/export to an equilibrium state; (c) Curves of the rebalancing; (d) Digital computing; (e) Quantum-fuzzy rebalancing of 200%

S-OTP$_1$-Method2

Assume key K_1 is shared by sender Alice and receiver Bob through QKD.

Part I. Encryption

Step 1. Data Transformation. *Given binary data D to be transmitted, let the unsigned integer number set $\{d_i\} = \{d_1, d_2, .., d_i, .., d_n\}$, represent the data sections of D. Let the sum $X=d_1+d_2+...+d_i ...+ d_n$.*

Step 2. Bipolar Cognitive Mapping. *Construct an i/o-consistent BCM C based on $\{d_i\}$ such that $\{d_i\}$ is decomposed into an unbalanced relational data set $\{e_{ij}\} = \{(e_{ij}^-, e_{ij}^+)\}$ where each bipolar link weight $e_{ij} = (e_{ij}^-, e_{ij}^+)$ and $|d_i| \equiv \sum_j |\varepsilon| e_{ij}$ (energy/information of row i) with ratio $|e_{ij}^-|/|e_{ij}^+| > l$, a threshold for non-zero bipolar elements. Thus, $\{e_{ij}\}$ forms a BCM C with total information $X=\sum |d_i|$. (Note: C is not unique – an area of further research where bipolar linguistic fuzzy sets can be used for the optimization of l and C.)*

Step 3. Bipolar Energy/Information Normalization. *Normalize C^T (transpose of C) to an information conservational matrix M (a bipolar quantum-fuzzy logic gate (BQFLG) or a bipolar quantum-fuzzy cognitive map (BQFCM)) under the conditions of Eq. (3) such that the BQCA $E(t+1)=M \times E(t)$ is asymptotic to an equilibrium state [10,11].*

Step 4. Data Encryption. *Use K_1 to encipher $U=\{X,M\}$ to $E=U \oplus K_1 = \{X,M\}'$.*

Step 5. Transmit the pair E=*$\{X,M\}'$.*

Part II. Decryption

Step 1. *Use K_1 to decrypt E to $\{X,M\}$; use K_2.*

Step 2*. Use M to decipher and depolarize X to recover $\{d_i\}$;*

Step 3*. Recover D from $\{d_i\}$ with concatenation.*

Applying S-OTP$_1$-Method2 we have the decryption example in **Fig. 1**. The total information of the last row of **Fig. 1b** approximate to exactly the same result as that of S-OTP$_1$-Mehrod1:

$d_1=|\varepsilon|(-731114, +317435)=1048549$;

$d_2=|\varepsilon|(-276085, +722128)=998213$;

$d_3=|\varepsilon|(-508176, +475812)=983988$

$D=Concatenate(d_1, d_2, d_3)=1048549998213983988$.

2.5 Quantum Nature of Information Conservation

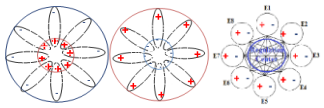
Given an $n \times n$ square bipolar interactive matrix M and an $n \times 1$ column bipolar vector $E(t)$ such that $E(t+1)=M \times E(t)$, if $\forall j$, the absolute energy/information subtotal $|\varepsilon_{col}|M_{*j}(t)$ of each column j of M (but not necessarily each row) equals 1.0, or $|\varepsilon_{col}|M_{*j}(t) \equiv 1.0$, M is defined as an information conservational bipolar quantum logic gate (BQLG) matrix or a bipolar quantum-fuzzy cognitive map (BQFCM) [9,16], and we must have the bipolar quantum cellular automata (BQCA):

$$|\varepsilon|E(t+1) = |\varepsilon|(M \times E(t)) \equiv |\varepsilon|E(t). \qquad (2)$$

Eq. (2) leads to a general-purpose BQCA theory – an equilibrium-based unification of matter and antimatter for ICC. Computationally, a BQCA can be regulated to achieve information conservation, regeneration, degeneration and oscillation. BQCA is thus a type of quantum-cellular model (**Fig. 2**). This leads to Method2 and the theory of ICC.

The transpose $C^T(t)$ is used to obtain its column-major normalized BQLG matrix M for ICC. The normalization follows Eq. (3). An i/o-consistent CM can always be designed and normalized to M for a BQCA to be asymptotic to a bipolar equilibrium state even though some link weights are weaker and need more iterations (t) to be balanced. This property provides a basis for quantum and post-quantum cryptography.

$$M(i,j) = (C^T(i,j))/|\varepsilon_{col}|(C^T_{*j}). \qquad (3)$$



(a) (b) (c)

Figure 2. A BQCA unification of matter and antimatter atoms (adapted from [11])

In Eq. (3), the denominator $|\varepsilon_{col}|(C^T_{*j})$ denotes the absolute energy/information subtotal of column j in C^T. But the notation $|\varepsilon_{col}|(M_{*j})$ denotes the normalized absolute energy/information subtotal of column j of matrix M.

2.6 Digital Nature of S-OTP-Method2

Notably, S-OTP-Method2 is based on bipolar equilibrium-based rebalancing**.** Bipolarity is a quantum feature that form the bipolar reality of negative-positive particles. The bipolar property, however, can be depolarized for digital cryptography.

A unipolar CM can be revealed from a bipolar one with depolarization. Since a bipolar representation is a generalization of unipolar representation and subsumes unipolar cases, all the elements of a polarized map can simply have zero negative energy/information which leads to the simplified CM as in **Fig. 3** coded as a unipolar matrix *C(t)*—a positive relation that does not distinguish import and export with symmetrical subtotals.

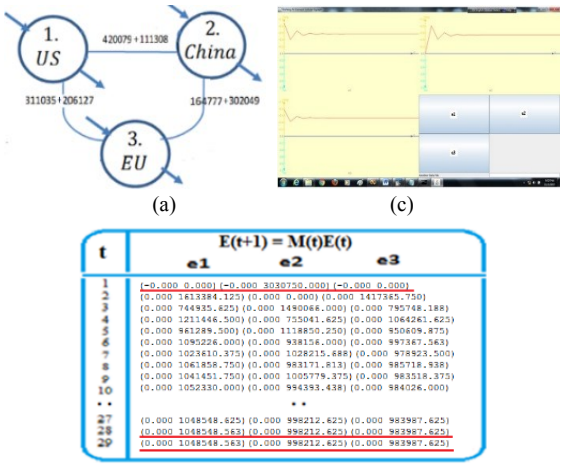
Depolarization leads to a unipolar cipher named S-OTP$_{1R1}$-Method2 that is basically the same as S-OTP$_1$-Method2 except using a positive *CM* and a positive matrix *M*. **Fig. 3** shows a decryption example using S-OTP$_{1R1}$-Method2 where in the last row we have the same result as for the bipolar case.

$d_1 = |\varepsilon|(-0, +1048549) = 1048549$;

$d_2 = |\varepsilon|(-0, +998213) = 998213$;

$d_3 = |\varepsilon|(-0, +983988) = 983988$;

$D = Concatenate(d_1, d_2, d_3) = 1048549998213983988$.



(a) (c)

(b)

Figure 3. Information-conservational unipolar rebalancing: (a) depolarized CM; (b) Positive distribution; (c) Positive curve (scaled)

2.7 Two Puzzles Explained

(A) How can matrix C(t) in symmetry (C(t)(i,j)= C(t)(j,i)) be used in cryptography? The answer is that, although matrix *C(t)* is symmetrical, a column-major normalized *M* can

be non-linear and asymmetrical because the normalization is by dividing its column subtotal of $C^T(t)$ (data section subtotal), but not by the global total (corresponding to the overall summation). For instance,

$$C(t) = \begin{bmatrix} 0 & 531587 & 517162 \\ 531587 & 0 & 466826 \\ 517162 & 466826 & 0 \end{bmatrix}; \quad M = \begin{matrix} 0 \\ 1 \\ 2 \end{matrix} \begin{bmatrix} 0.000 & 0.532 & 0.526 \\ 0.507 & 0.000 & 0.474 \\ 0.493 & 0.468 & 0.000 \end{bmatrix};$$

where C is symmetrical but M is not. The non-linear asymmetrical property of M can be characterized with a set of linear equations. Let the three subtotals (or data sections) be x, y, and z, respectively, for the 3×3 matrix M we have $m_{10}\times x - m_{01}\times y = 0$; $m_{20}\times x - m_{02}\times z = 0$; and $m_{21}\times y - m_{12}\times z = 0$; and $m_{ij} \neq m_{ji}$. The set of equations have infinite number of solutions because all column coefficients of M correlate non-linearly with each other due to non-linear normalization based on different local column subtotals. This is fundamentally different from percentage distribution where all percentages are normalized with a global total and linearly independent.

(B) If a unipolar positive matrix is sufficient, why do we need a bipolar equilibrium-based matrix in cryptography? There are three top answers to this question: (1) The universe consists of negative-positive particles. Without bipolarity, there would be no bipolar information conservation and bipolar quantum computing [9,10]. Thus, bipolarity leads to a quantum model compatible to digital computing (further discussed later). (2) A bipolar matrix avoids large denominators, doubles the number of elements in a unipolar matrix, doubles the parallel computing power, and doubles collective precision with equilibrium-based rebalancing (further discussed later). (3) Bipolarity is set-theoretically different from bilinearity or bijection [12]. One defines a 2-to-2 mapping of equilibrium-based non-linear bipolar dynamic entanglement with logically definable causality, another defines a 1-to-1 mapping without non-linearity, entanglement, and definable causality.

2.8 On the Security of Method1 and Method2

Method1 is based on percentage distribution. It provides a basis for both theoretical analysis and practical development. The goal is to search for secure information conservational S-OTP ciphers by analyzing different approaches that may or may not be secure.

Theorem 2a. Under the conditions of Definition 2, S-OTP$_1$-Method1 is information conservationally not secure.

Proof. *It follows from that the transmitted message consists of numerical meta data with fixed format. Such knowledge could potentially weaken the ITS of OTP.* ■

Based on the Randomization Theorem (Theorem 5d), The above problem can be resolved by adding random bits to the metadata as paddings before the text being enciphered. The paddings can be removed when being decrypted by receiver. This is made possible with BHDC that can compress a long message to a tiny minimum such that sufficient random padding bits can be used for the randomization.

Theorem 2b. Under the conditions of Definition 2, S-OTP$_1$-Method1 would be information conservationally secure provided that a sufficient number of random bits are inserted as paddings to the metadata to be enciphered and removed when being decrypted by the receiver.

Proof*. With the provision, the conditions of S-OTP as defined in Definition 2 remain intact.* ■

The one key version (S-OTP$_1$) suggests that, two different keys (S-OTP$_2$) might be considered for an information conservational solution.

S-OTP$_2$-Method1 and Its Revised Versions

(1) S-OTP$_2$-Mehrod1: Use key K_1 to encipher the summation $X = \sum_i x_i$ to X'; Use key K_2 to encipher the text of $\{x_i/X\}$ to $\{x_i/X\}$'; Transmit the packaged pair $\{X', \{x_i/X\}'\}$ without key reuse;

(2) S-OTP$_{2\text{-}2}$-Mehrod1: First, use a random number of bits specified in key K_1 as random paddings for altering the numerical format of {X, {x_i/X}} to {X, {x_i/X}}' (See Theorem 1d.); Then, use K_2 as a key to encipher {X, {x_i/X}}' to {X, {x_i/X}}''; Transmit {X, {x_i/X}}''.

Theorem 3a. Under the conditions of Definition 2, S-OTP$_2$-Mehrod1 is information conservationally not secure.

Proof. *It follows the proof of S-OTP$_1$-Mehrod1.* ■

Theorem 3b. Under the conditions of Definition 2, S-OTP$_{2\text{-}2}$-Mehrod1 is information conservationally secure but only preserve partial information.

Proof. *With sufficient random bits as paddings specified by the first key and a regular second key, the message and its format are randomized and concealed in an unbreakable pad that does not weaken the security of OTP. However, the message only partially preserve original information.* ■

Evidently, if a percentage distribution *{x_i/X}* is replaced with an information conservational matrix *M* we will have different 1-key or 2-key versions of S-OTP-Mehrod2 with similar security conditions as that of S-OTP-Mehrod1.

3 ANALYSIS AND OPTIMIZATION—TOWARD SECURE POST-QUANTUM CRYPTOGRAPHY

3.1 Minimal BQCA Theorem

Theorem 4. Mehtod1 is the minimal case of Method2.

Proof. *Mehtod2 entails an N×N square matrix multiplied by a column vector in an information conservational BQCA. When N×N is reduced to N×1, the matrix becomes a column vector of percentage distributions w_i = {x_i/X} summing up to 1.0, the single number must be the summation X of N sections, such that the column vector multiplied by a single element matrix results in a column vector energy/information distribution {x_i}. The Matrix multiplication can be deemed the minimal BQCA which requires a final equilibrium state be reached in a single step with high precision such as* $\begin{pmatrix} w_0 \\ w_1 \\ w_{i+1} \\ w_n \end{pmatrix}[X] = \begin{pmatrix} x_0 \\ x_1 \\ x_{i+1} \\ x_n \end{pmatrix}$. ■

Theorem 4 proves that Method1 is suitable for reducing network traffic, and Method2 can be used for computational precision. Theorems 1-4 provide a basis for applicability and efficiency analysis of a new crypto paradigm using either Method1 (percentage distribution) or Method2 (information conservational matrix) or a combination of the two. Based on IEEE binary64-128-256 standard, double precision floating-point format provides us an upper limit for long messages. Major considerations are on the key length for enciphering both the math summation and the percentage distribution. According to IEEE binary64 standard, exponents range from −1022 to +1023 that allows the representation of numbers between 10^{-308} and 10^{308}, with full 15–17 decimal digits precision. By compromising precision, it allows even smaller values up to about 5×10^{-324}. Using IEEE binary128 or 256, a significantly larger portion of the information can be preserved.

3.2 Applicability and Efficiency of Method1

Using S-OTP$_{2\text{-}2}$-Method1, the percentage distribution {x_i/X} needs to be enciphered, where each double precision floating-point number x_i/X requires 64 bits for IEEE binary64. While a 1M = 2^{20} bits message needs an impractical same length OTP key, if the 1M-bit message is divided into 512-bit sections, the division leads to N = $2^{20}/2^9 = 2^{11}$ data sections with a math summation less than 512+11 = 523 bits. N = 2^{11} double precision floating-point numbers are needed for the percentage distribution {x_i/X} that entails $2^{11}2^6 = 2^{17}$=128k-bit key length. A 128k+523-bit key is a nearly 8-fold reduction in key length compared with the message length. The upper limit of the exponent is +1023 for signed integers based on IEEE binary64. At the limit, the key length saving approaches 16-fold. It seems to be a clean solusion. But, there are still unsolved problems. First, 128K+523 bits

data plus K_1 for random paddings is still too long to be a practical key length. Second, when the grand total is huge, the percentage distribution will have a precision problem because a percentage is normalized by the grand total as the denominator.

3.3 Applicability and Efficiency of Method2

While for 1M-bit long messages the key length requirement for OTP is not practical, it is much less a problem with percentage distribution using Method1, but still a problem with Method2. A 1M-bit message divided into 2K 512-bit sections would need a $2^{11}\times2^{11}$ sparsely populated information conservational matrix M. Assuming each column has an average of no more than 8 non-zero elements in 64-bit double precision floating-point format plus one index that leads to $8\times64=2^3\times2^6$ bits per column. A total of $8\times64\times2^{11}=2^{20}$ bits plus a 513-bit summation need to be transmitted in ciphertext—more than the original 1M bits.

While Method2 is inefficient and impractical, its information conservational property is still quite attractive. In terms of digital computing, its column-major normalization does not use the grand total but a much smaller section subtotal as the denominator and a much smaller sender designated percentage of a subtotal as the numerator. Remarkably, it can divide-and-conquer the high precision requirement into lower precision requirement. On the quantum side, its equilibrium-based rebalancing property reflects the bipolar reality of particle-antiparticle coexistence [9-12].

3.4 Hierarchical Optimization

Without entirely enciphering both a summation and its percentage distribution or matrix M, Method1 and Method2 cannot achieve ICS. Since enciphering matrix M does not reduce key length, S-OTP$_{2\text{-}2}$-Method1 is a candidate for hierarchical scalability as in **Fig. 4** based on IEEE binary64.

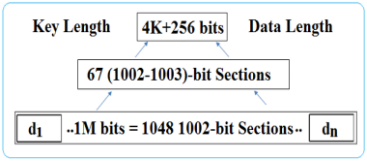


Figure 4. A 3-Level Hierarchy of S-OTP$_H$ for 1M bits

First, we assume that 1M = 1048576 bits data divided into 1048 1000-bit sections. We would have a maximum of 1012-bit summation X associated with a $1048\times64 = (2^{10} + 24) \times 2^6 = 2^{16} + (24 \times 2^6) = 64K + (16+8) \times 2^6 = 64K + 1K + 512$ bits percentage distribution D. The summation can be converted to a 64-bit double precision floating-point number. The pair {X, D} would consists of 64K + 1K + 576 bits = 67136 bits. Second, the 67136 bits can be divided into 67 of 1002-1003-bit sections. That leads to 67 of 64-bit double precision floating-point numbers for the percentage distribution plus a maximum of 1008-bit summation. Again, the summation can be converted to a 64-bit double precision floating-point number. The 67+1 double precision numbers need $68\times64 = 2^{12} + 256 = 4K + 256$ bits. Third, 4K + 256 bits can be further scaled to 1K-bits plus K_1 as a less than1K-bit randomizer to result in a 2K-bit key K_2. Evidently, due to the short length the two keys are no longer a drawback. Formally, we have S-OTP$_H$-Method1. Similarly, 1 Gaga bits = 1K Mega bits that entails a larger hierarchy.

S-OTP$_H$-Method1

For every 1M bits of data to be transferred, assume sender Alice and receiver Bob share two private keys K_1 and K_2 distributed through QKD.

Part I – Encryption: Use BHDC to achieve S-OTP

(1) L=1; if the data length is short enough for an OTP cipher key, print message "Please use OTP without hierarchy";

(2) L=L+1; determine summation $X = \{\sum_i x_i\}$ *and derive the percentage distribution* $D = \{x_i/X\}$;

(3) If the data is too long for an OTP cipher key and its length is reducible (>minimum), go to Step (2);

(4) If the data is too long for an OTP cipher key and its length is unreducible, stop and restart with different number of scalable pads;

(5) Apply S-OTP$_{2\text{-}2}$-Method1 to encipher {X,D,L} to {X,D,L}'' with key K_1 for sufficient random paddings and K_2 as a cipher key;

(6) Transmit the ciphertext {X,D,L}'' to the receiver.

Part II – Decryption: Use BBIR to recover the message

(1) Decipher {X,D,L}'' to {X,D,L} with K_2 and K_1;

(2) Use X and D to find next layer {{x_i}, D}, L = L-1, if L>1, repeat step (2) until L = 1;

(3) Cast {x_i} to string format {d_i};

(4) Recover the original message or data set D by concatenating {d_i}.

Theorem 5. Under the conditions of Definition 2, S-OTP$_H$-Method1 is information conservationally secure.

Proof. *It follows from the proofs of Theorem 1d, 2b and the information conservational security of S-OTP$_{2\text{-}2}$-Method1.* ■

3.5 Collective Precision

While Method1 uses percentage distribution, Method2 uses information conservational encryption. In Method1 each data section depends on a single percentage resulted from linear normalization by a grand total. When the data length is long, Method1 will have a precision problem. In Method2, each data section depends on all columns of matrix *M* resulted from column-major normalization by much smaller subtotals where percentage distribution is not directly calculated using the grant total. If each column has an average of $n > 2$ non-zero numbers, the precision requirement is *n*-times smaller. The larger the number *n* the more parallelism in high precision decryption. When *n* equals *N*, Method2 reaches maximum parallelism with *N*-fold precision enforcement for a positive matrix *M* and *2N*-fold for a bipolar matrix *M.* This observation leads to the inception of information conservational *collective precision*.

Observation 1: Asymptoticity. If *M* is information conservational, BQCA $E(t+1) = M \times E(t)$ is asymptotic to an equilibrium state determined by *M* [9,10].

Observation 2: Information Conservational Computing and Cryptography. If an original message *D* is converted to an energy/information total *E* through a BQCA transformation, the information conservational matrix *M* of the BQCA can serve as a key to decode the total information to the original message D in the receiver side [9]. However, to encrypt and transmit matrix *M* will cost more than to encrypt and transmit the original message. Thus, Method1 is more efficient than Method2 for encryption and transmission, but only Method2 can enable collective precision and efficient decryption.

Theorem 6. If *M* is information conservational, BQCA $E(t+1) = M \times E(t)$ can be used to derive the percentage distribution in an equilibrium state determined by the BQCA.

Proof. *Given 100 (percent), Theorem 6 follows the asymptoticity theorem [9] directly (see example in Fig. 1e).* ■

Theorem 7. A percentage distribution of N divisions can be converted to an $N\times N$ (unipolar or bipolar) information conservational matrix M for collective precision with maximum parallelism such that M is information conservational and BQCA $E(t+1) = M \times E(t)$ is asymptotic to an equilibrium state.

Proof. *Notice that M is normalized and information conservational but not unique. Theorem 7 follows from* $\begin{pmatrix} w_0 \\ w_1 \\ w_{i+1} \\ w_n \end{pmatrix}[E] = \begin{pmatrix} w_0E \\ w_1E \\ w_{(i+1)}E \\ w_nE \end{pmatrix}$ *because* $\begin{pmatrix} w_0 \\ w_1 \\ w_{i+1} \\ w_n \end{pmatrix}$ *is strictly proportional to* $\begin{pmatrix} w_0E \\ w_1E \\ w_{i+1}E \\ w_nE \end{pmatrix}$. *That is, M can be derived from either of them* ■

Based on the above findings we can conclude that, on the sender side, matrix M can be used for determining the percentage distribution with *N-2N fold* reduction of precision requirement due to column-major normalization (Re. Eq. (3)). On the receiver side, M can be used to decrypt a big total to subtotals (or data sections) with collective precision in a reverse way (**Fig. 1b** and **Fig. 3b**). Thus, Method1 and Method2 can be used in a combination. Method2 focuses on collective precision with ICC; Method1 focuses on secure and efficient data transmission, that lead to the block diagram design in Fig. 5 impact factor followed by an optimized algorithm that combines the advantages of Method1 and Method2 while eliminating their drawbacks.

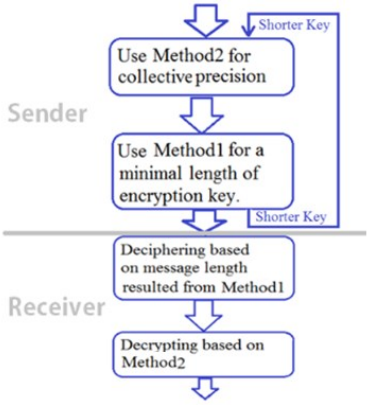


Figure 4. Sender and Receiver

S-OTP$_H$-Method1+2

For every 1M bits of data to be transferred, **a**ssume sender Alice and receiver Bob share two private keys K_1 and K_2 distributed through QKD.

Part I – Sender Side: Use BHDC to achieve S-OTP

(1) L=1; if the data length is short enough for an OTP cipher key, print message "Please use OTP" without hierarchy;

(2) L=L+1, compute summation X =$\{\sum_i x_i\}$*, derive information conservational matrix M, and determine percentage distribution D=*$\{x_i/X\}$ *with BQCA E(t+1) = M×E(t) (see **Fig. 1e**);*

(3) If the data is too long for an OTP cipher key and its length is reducible (>minimum), go to Step (2);

(4) If the data is too long for an OTP cipher key and its length is unreducible, go to Step (2) with a smaller N such that 0<i<N and N≥2;

(5) Apply S-OTP$_{2\text{-}2}$-Method1 to encipher {X,D,L} to {X,D,L}'' with key K_1 for sufficient random paddings and K_2 as a cipher key;

(6) Transmit the ciphertext {X,D,L}'' to the receiver.

Part II – Receiver Side: Use BBIR to recover the message

(1) Decipher {X,D,L}'' to {X,D,L} with K_2 and K_1;

(2) Construct information conservational matrix M from D;

(3) Use X and M in a BQCA to find next layer {$\{x_i\}$*,M}, L=L-1;*
if L>1, repeat step (3) until L=1;

(4) Cast $\{x_i\}$ to string format $\{d_i\}$;
(5) Recover the original message or data set D by concatenating $\{d_i\}$.

Theorem 8. Under the conditions of Definition 2, S-OTP$_H$-Method1+2 is information conservationally secure.

Proof. *Since Method2 is only used for collective precision on the sender side and parallel decryption on the receiver side, the theorem follows from the proof of Theorem 1d, 2b and the security of S-OTP$_H$-Method1.* ■

3.6 Transmitting Large Dada Sets

With S-OTP$_H$-Method1+2 a large data set can be serialized as a number of Mega bits S-OTP pads, and each Mega bits can be securely transmitted with a 2K-4K bit short key that is practical with QKD while a 1M bit key with the same length as the message is obviously not practical.

Furthermore, noticing that **S-OTP$_H$-Method1** and **S-OTP$_H$-Method1+2** are defined for every Mega bits of data. The data, however, can be original message or intermediate compressed data toward a tiny minimum. Thus, the methods can be hierarchically extended to work for every Gaga or every Tega bits of data.

Theorem 9. A significantly larger data set does not necessarily require a significantly longer key for ICS with partial information conservation.

Proof. *It follows the Reachability of Minimum Theorem with BHDC.* ■

3.7 A Consequence of Collective Precision

Collective precision adds a number of new features to hierarchical S-OTP. On the sender side, it can be used for testing everything efficiently and precisely to guarantee that the receiver side will get the correct message or partial message. On the receiver side it can be used to decrypt a summation efficiently with collective precision and in massive parallelism colluding with the sender side through public protocols based on data length and number of divisions N. These are necessary auxiliary functions.

It can be observed that the percentage distribution $\{x_i/X\}$ is a major contributor to the key length requirement of S-OTP. If it does not have to be enciphered but transmitted in plaintext, we only need to cipher a short summation with a much shorter key. If 1Gaga bits divided into 1K mega divisions, each 1Mega division results in a 64-bit double precision summation, 1G bits with 1K such summations would only need 64K bits to be ciphered. Of course, the summations can be hierarchically scaled further to a minimum.

Now, with collective precision, we have the challenging question: *Can the percentage distribution $\{x_i/X\}$ be securely transmitted in plaintext if $\{x_i\}$ are double precision floating-point numbers due to the reuse of a double precision floating-point key in multiplication or division operation instead of XOR?*

Whereas this paper has assumed that a transmitted message as a long binary integer L is divided into smaller integers $\{x_i\}$, and their summation is also an integer $X = \sum_i x_i$. Evidently, X can be guessed by attackers with a trial-error method to break S-OTP if an integer key is reused for $\{x_i\}$ without encrypting the percentage distribution $\{x_i/X\}$. Now with collective precision, floating point decimals can be used instead of integers.

Collective precision makes it possible to use double precision floating-point decimals as a reusable key for non-linear multiplication, division, addition, and/or subtraction. Such non-linear operations lead to decimal precision that cannot be guessed without knowing the reusable key—a double precision floating-point decimal. The summation of these decimals results in another double precision floating-point decimal that can be encrypted as an S-OTP pad. In this case, the percentage distribution $\{x_i/X\}$ could be misleading to attackers,

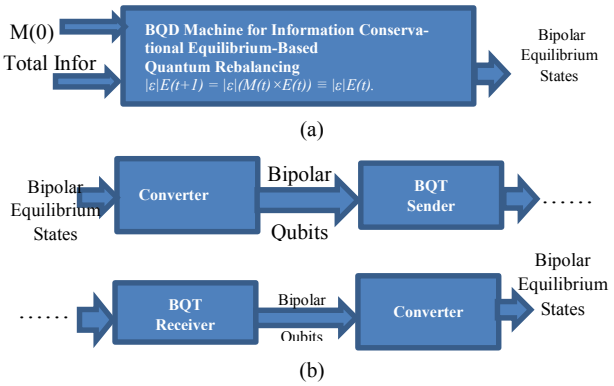
and the final summation could be unguessable with a trail-error method due to floating point decimal precision and non-linear operation with a decimal key. This leads to the hypothesis for future research.

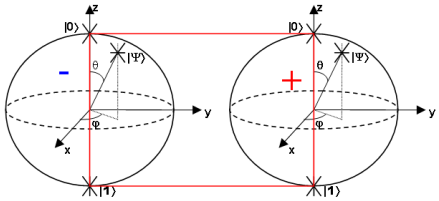
Hypothesis: *With double precision floating-point decimals for collective precision, the percentage distribution {x_i/X} in S-OTP can be securely transmitted in plaintext provided that (a) {x_i/X} is not the actual percentage distribution but a misleading to attackers; (b) the summation $X = \sum_i x_i$ is enciphered as an unbreakable summation of double precision floating point decimal numbers.* (Remark: This hypothesis could close a loophole in the proof of Theorem 8 of ref. [9]. However, it may not reduce network traffic.)

4. QUANTUM CRYPTO MACHINERY

While we so far only assumed partial information conservation, collective precision suggests that Method2 is suitable for research/development of bipolar quantum-digital machinery for fully information conservation without the limitation of double precision floating point format due to computational speed. While unipolar values are preferred by digital machines, the bipolar nature of S-OTP-Mehtod2 makes it suitable for developing quantum machinery with equilibrium-based bipolar quantum rebalancing and information conservation (**Fig. 6**). Encryption would be unnecessary for quantum computing and communication [8]. The quantum machine in **Fig. 6(a)** can be used, theoretically, in decryption for digital communication. Each column of an N×N matrix *M* may have a maximum of N non-zero bipolar elements for maximum parallelism. If N=1K or 2K, a math distribution among N sectors can be determined in one procedure on the sender side; or an information total can be quantum rebalanced to N subtotals in parallel without using percentage distribution.

While the bipolar quantum crypto machine seems to be "far-fetched" in terms of quantum-digital compatibility, a newly reported discovery of a class of subatomic particles (fermions) [20] named Angel Particles injected new life into this line of research. The new discovery is a family of particles that are their own antiparticles. These family of particles are expected to make quantum computing more practical and powerful. It strengthens the ontological basis of equilibrium-based bipolar quantum rebalancing. **Fig. 6(a)** shows the draft of a bipolar quantum-digital crypto machine. **Fig. 6(b)** shows bipolar quantum teleportation. **Fig. 6(c)** shows a bipolar qubit register. The dream machinery forms a quantum intelligence paradigm or S-OTP$_Q$ for further research.





(c)

Figure 6. (a) Bipolar quantum-digital (BQD) computing; (b) Bipolar quantum teleportation (BQT); (c) Bipolar qubit register [15,21]

5 CONCLUSIONS

S-OTP has been presented based on ICC and BHDC. Security conditions have been established. Collective precision has been proposed. It has been shown that

(1) BHDC can reduce key and data length to a tiny minmum with partial information conservation.

(2) S-OTP makes it possible for transmitting long messages or large data sets with ICS with partial information conservation.

(3) Math summation without using big primes makes S-OTP quantum proof to quantum factorization (cf. [1, 9, 22-27]).

(4) ICC can be massively parallel, accurate, efficient, and suitable for developing quantum-digital compatible machinery with collective precision for full information conservation.

Whereas OTP is prevented from being widely used by its key length requirement, S-OTP gets around the problem through ICC for some limited applications without compromising OTP security and network traffic. Thus, the S-OTP paradigm qualifies itself as a unique extension from ITS to ICS for post-quantum cryptography (Fig. 7) with minimal partial information conservation. Its significance lies in the opening of a different approach to a difficult problem.

Floor-roof mysteries. According to the floor-roof theory of science [17], ITS of OTP is developed based on information theory rooted in probability and statistics—a floor of modern science; ICS of S-OTP is a set-theoretic development rooted in bipolar fuzzy sets and dynamic equilibrium—a roof of modern science. Thus, this work has opened some major challenges. Among them are the following floor-roof mysteries for future research:

(1) Is ICS an information theoretic extension to ITS?

(2) Is S-OTP just OTP plus data compression and there is nothing new?

(3) Could S-OTP become fully scalable with quantum digital machinery?

(4) Could modern science, such as modern physics and information theory [6], have been like a well-founded building with a floor of observable being and truth but with a missing roof for equilibrium and information conservation [9,10,16,17]?

Floor-roof assertions. While the above mysteries are left for future research, we have the following floor-roof assertions:

(1) Can the floor perform some functions not performed by the roof? The answer is definitely YES.

(2) Can the roof perform some functions not performed by the floor? The answer is definitely YES.

(3) Can information conservational security on the roof solve some unsolved problems by information theoretic security on the floor? The answer should be LOGICALY YES.

The significance of this work lies in the opening of a holistic ICC approach with the above mysteries and assertions. The findings prove that S-OTP can bypass the assumptions of Shannon's theorem on OTP key length [5] without falsifying it but only to find some very limited applications with partial minimumal informatin conservation. This approach, however, leads to the prediction that if the key length requirement of OTP for information

theoretic security remains an impasse without major a breakthrough, the only efficient solution for post-quantum cryptography could be quantum communication S-OTP$_Q$ (Fig. 7)

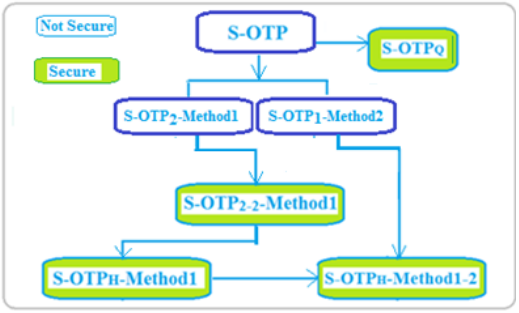


Figure 7. Road to information conservational security

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