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Transcendental Pythagorean Cryptography: Symmetric Key Generation via Diophantine Triples and Algebraic Structures

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ABSTRACT: Key generation and Secure is critical to the security of a Cryptosystem. In fact, key generation and key exchange is the most challenging part of cryptography. In this paper, a scheme for symmetric key generation based on Pythagorean Triple has been presented. This paper focused the innovative blend of Diophantine equations, transcendental forms, Pythagorean triples (primitive and reciprocal), monoids/semigroups, and their application to secure symmetric key generation through a KDC-based scheme.

$$A = \left\{(x,y,z): \frac{z}{y} = 1 + \frac{2}{x^2-1} \text{ if } x \text{ is an odd prime number or its power}\right\}$$

$$B = \left\{(x,y,z): \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{(2p-1)^2}\right)^2 - 1} \text{ if } x \text{ is an odd composite or its Power, for some } p = 1,2,3\ldots\right\}$$

$$C = \left\{(x,y,z): \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2}\right)^2 - 1} \quad if\ x\ is \text{ geometric power of 2}\right\}$$

$$D = \left\{(x,y,z): \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2p^2}\right)^2 - 1}, \text{otherwise (even composite or its power)}\right\}$$

It positions the work as a novel cryptosystem while nodding to the algebraic extensions (e.g., triangular numbers) and future scopes like ring/field theory.

Also, P $= \{(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) \in \boldsymbol{Z}^3 : \boldsymbol{x}^2 + \boldsymbol{y}^2 = \boldsymbol{z}^2\}$,can becoming a commutative cyclic Monoid, under the following binary operations

$P_1.P_2 = (|y_1y_2 - x_1x_2|,\ x_1y_2 + x_2y_1,\ z_1z_2)$ and

$P_1.P_2 = (x_1x_2,\ y_1z_2 + y_2z_1,\ y_1y_2 + z_1z_2)$.

KEYWORDS: Cryptosystem, Diophantine equation, Pythagorean triples, Triangular numbers.

I.INTRODUCTION

Consider the Diophantine Equation $x^n + y^n = z^n$, which is reducible as

$$\left(x^{\frac{n}{2}}\right)^2 + \left(y^{\frac{n}{2}}\right)^2 = \left(z^{\frac{n}{2}}\right)^2 \text{ implies } \left(\frac{z^{\frac{n}{2}}+y^{\frac{n}{2}}}{x^{\frac{n}{2}}}\right)\left(\frac{z^{\frac{n}{2}}-y^{\frac{n}{2}}}{x^{\frac{n}{2}}}\right) = 1 .$$

It follows that the above two factors are reciprocals to each other.

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Now assume that $\frac{z^{\frac{n}{2}}+y^{\frac{n}{2}}}{x^{\frac{n}{2}}} = \frac{a}{b}$, $\frac{z^{\frac{n}{2}}-y^{\frac{n}{2}}}{x^{\frac{n}{2}}} = \frac{b}{a}$.

Now chooses $\frac{a}{b} = x$, where a and b are the integers with a is a multiple of b, which is necessarily x is an integer. Hence above two equations are reducible into the Transcendental representation of the above Diophantine Equation $x^n + y^n = z^n$ is

$$\left(\frac{z}{y}\right)^{\frac{n}{2}} = \frac{a^2+b^2}{a^2-b^2} = 1 + \frac{2}{x^2-1}.$$

The solutions of above quadratic Diophantine Equation are satisfying Pythagorean Theorem. Hence $\boldsymbol{n} = \mathbf{2}$, to obtain the Transcendental Representation of the Pythagorean theorem $x^2 + y^2 = z^2$ is $\frac{z}{y} = 1 + \frac{2}{x^2-1}$, where $x = \frac{a}{b}$

Hence Generate Pythagorean Triples depending on Prime factors of x.

Suppose, if x is an odd integer, $x = p_1^{a_1}p_2^{a_2}p_3^{a_3} \ldots\ldots p_n^{a_n}$ here $p_1, p_2, \ldots p_n$ are odd primes.

then obtain different combinations of Pythagorean primitive Triples (x, y, z), depending on odd prime factors with $x > (2p-1)^2$ for $p = 1,2, 3,\ldots$etc. and $a_1 = a_2 = a_3 = \cdots = a_n = 1$.

If any $a_i \neq 1$ then ($\frac{x}{p_i^{a_i}}$, y, z) becomes a Pythagorean primitive Triple.

It follows that $\frac{x}{(2p-1)^2} > 1$, which implies the Transcendental representation of the above Pythagorean theorem is $\frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{(2p-1)^2}\right)^2-1}$ for each odd integer x.

Similarly, $\frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2p^2}\right)^2-1}$ for each Even integer with $x > 2p^2$, where

$$x = 2^p\, p_1^{a_1}p_2^{a_2}p_3^{a_3} \ldots\ldots p_n^{a_n}$$

Now we can go to Generate Pythagorean Triples by choosing $\frac{a}{b} = x$ is

- i. an odd prime or its power
- ii. an odd composite or its power
- iii. a Geometric power of 2
- iv. an even composite or its power.

proposed non-empty subsets of the Set of Pythagorean are

$$A = \left\{(x, y, z) : \frac{z}{y} = 1 + \frac{2}{x^2-1} \text{ if } x \text{ is an odd prime number or its powers}\right\}$$

$$B = \left\{(x, y, z) : \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{(2p-1)^2}\right)^2-1} \text{ } if \text{ } x \text{ is an odd composite or its powers, for some } p = 1,2,3\ldots\right\}$$

$$C = \left\{(x, y, z) : \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2}\right)^2-1} \text{ if } x \text{ is geometric power of 2}\right\}$$

$$D = \left\{(x, y, z) : \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2p^2}\right)^2-1}, \text{ otherwise (even composite numbers or their power}\right\}$$

$$S_1 = \left\{\left(x, \left(\frac{x}{2}\right)^2 - 1, \left(\frac{x}{2}\right)^2 + 1\right) : x \text{ is even number}\right\}$$

$$S_2 = \left\{\left(x, \frac{x^2-1}{2}, \frac{x^2+1}{2}\right) : x \text{ is odd number}\right\}$$

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$P=\left\{x_1, ax_1^2-\frac{1}{4a}, ax_1^2+\frac{1}{4a}\right\}$ where $a=\left\{\begin{array}{c}\left\{\frac{1}{2p}, p \text{ is a factor of } x_1^2, if\ x_1 \text{ is odd}\right.\\ \left\{\frac{1}{4p}, p \text{ is a factor of } \left(\frac{x_1}{2}\right)^2, if\ x_1 \text{ is even}\right.\end{array}\right\}$

And Corresponding subsets of the Set of Reciprocal Pythagorean Triples are defined as follows.

$$A' = \left\{(xz, yz, xy): \frac{z}{y} = 1+\frac{2}{x^2-1}\ if\ x = x_1 + x_2 \text{ is odd prime number or its power}\right\}$$

$$B' = \left\{\begin{array}{c}(xz, yz, xy):\\ \frac{z}{y} = 1+\frac{2}{\left(\frac{x}{(2p-1)^2}\right)^2-1}\ if\ x = x_1 + x_2 \text{ is odd composite or its power and for some } p = 1,2,3\ldots\end{array}\right\}$$

$$C' = \left\{(xz, yz, xy): \frac{z}{y} = 1+\frac{2}{\left(\frac{x}{2}\right)^2-1}\ \ if\ x = x_1 + x_2 \text{ is geometric power of 2}\right\}$$

$$D' = \left\{\begin{array}{c}(xz, yz, xy):\\ \frac{z}{y} = 1+\frac{2}{\left(\frac{x}{2p^2}\right)^2-1}, \text{otherwise (Even composite numbers or its power)}\end{array}\right\}$$

$$Rpt_o(x) = \left\{\left(\frac{x(x^2+1)}{2}, \frac{(x^2-1)(x^2+1)}{4}, \frac{x(x^2-1)}{2}\right): x\ is\ an\ odd\ number\ greater\ than\ 1\right\}$$

$$Rpt_e(x) = \left\{\left(x\left(\left(\frac{x}{2}\right)^2+1\right)\right), \left(\left(\frac{x}{2}\right)^2-1\right)\left(\left(\frac{x}{2}\right)^2+1\right), x\left(\left(\frac{x}{2}\right)^2-1\right): x\ is\ an\ even\ number\ greater\ than\ 2\right\}$$

$$P' = \left\{x_1\ \left(ax_1^2+\frac{1}{4a}\right), \left(ax_1^2-\frac{1}{4a}\right)\left(ax_1^2+\frac{1}{4a}\right), x_1\left(ax_1^2-\frac{1}{4a}\right):\right\},$$

where $a=\left\{\begin{array}{c}\left\{\frac{1}{2p}, p \text{ is a factor of } x_1^2, if\ x_1 \text{ is odd}\right.\\ \left\{\frac{1}{4p}, p \text{ is a factor of } \left(\frac{x_1}{2}\right)^2, if\ x_1 \text{ is even}\right.\end{array}\right\}$

The proposed scheme incorporates a Key Distribution Center (KDC) for user authentication and the secure exchange of secret information to generate keys. KDC is the main server which is consulted before communication takes. Each time a connection is established between two computers in a network, they both request the KDC to generate a unique password that can be used by the end system users for verification. In this chapter, a scheme for symmetric key generation based on the Pythagorean Triple has been presented. The proposed system is based on a novel mechanism to determine Pythagorean Triples to generate keys. The formula uses factors of x to generate y and z such that x, y, z satisfies the Pythagorean theorem $\boldsymbol{x^2 + y^2 = z^2}$.

The following notation has been used for Pythagorean Triple calculation

x- input to calculate Pythagorean Triple

p_1 - First prime factor of x

p_2 - Second Prime factor of x

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y and z – Key Pair

the final key is computed by XORing y and z.

i.e. $p = y \oplus z$

Algebraic Structure on Set of Pythagorean Triplets:

P $= \{(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) \in \boldsymbol{Z}^3 : \boldsymbol{x}^2 + \boldsymbol{y}^2 = \boldsymbol{z}^2\}$,can becoming a commutative cyclic Monoid, under the following binary operations

$P_1.P_2 = (|y_1y_2 - x_1x_2|,\ x_1y_2 + x_2y_1,\ z_1z_2)$ and

$P_1.P_2 = (x_1x_2,\ y_1z_2 + y_2z_1,\ y_1y_2 + z_1z_2)$.

Also, extended above binary operations to a Set of Reciprocal Pythagorean Triple

RPT $= \left\{(x,y,h) \in z^3 : \frac{1}{x^2} + \frac{1}{y^2} = \frac{1}{h^2}\right\}$ as follows

$P_1'.P_2' = \left(|y_1y_2 - x_1x_2|z_1z_2,\ (x_1y_2 + x_2y_1)z_1z_2, |\ y_1y_2 - x_1x_2|(x_1y_2 + x_2y_1)\right)$ and

$P_1'.P_2' = \left(x_1x_2(y_1y_2 + z_1z_2),\ y_1z_2 + y_2z_1(y_1y_2 + z_1z_2),\ x_1x_2(y_1z_2 + y_2z_1)\right)$. Also verified, under this binary operations, Algebraic structure of RPT is a semi group.

In this chapter focused to discuss some inherent properties of Pythagorean Triples. Also, we can go to extend Trigonometric Relations and Properties of triangles are also applicable to Reciprocal Pythagorean Triples

Also, introduces Length of Pythagorean Primitive

$$A = \left\{(x,y,z) : \frac{z}{y} = 1 + \frac{2}{x^2 - 1} \text{ if } x \text{ is an odd prime number or its power}\right\}$$

$$B = \left\{(x,y,z) : \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{(2p-1)^2}\right)^2 - 1} \text{ if } x \text{ is an odd composite or its Power, for some } p = 1,2,3\ldots\right\}$$

$$C = \left\{(x,y,z) : \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2}\right)^2 - 1} \quad if\ x\ is \text{ geometric power of 2}\right\}$$

$$D = \left\{(x,y,z) : \frac{z}{y} = 1 + \frac{2}{\left(\frac{x}{2p^2}\right)^2 - 1}, \text{otherwise (even composite or its power)}\right\}$$

a sufficient condition for a given Triple is become to a Pythagorean Triple,

the Length of Pythagorean Primitive (L_p) and Non-Primitive Triples (L_{np})

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$$L_p(\mathrm{P}) = z - y = \begin{cases} 1 & \text{if } x \in A \\ (2p-1)^2 & \text{if } x \in B \\ 2 & \text{if } x \in C \\ 2p^2 & \text{if } x \in D \end{cases}$$ and

$$L_{np}(P) = z - y = \begin{cases} m(2p-1)^2 & \text{if } x \text{ is an odd} \\ 2mp^2 & \text{if } x \text{ is an even} \end{cases}$$

Evaluate the Length of the Pythagorean Triple for each integer x (key variable) and the relation between $\frac{z+y}{z-y}$ with the Key variable of x as follows.

$x^2 = \frac{z+y}{z-y}$ if $x \in A$, $\left(\frac{x}{(2p-1)^2}\right)^2 = \frac{z+y}{z-y}$ if $x \in B$,

$\left(\frac{x}{2}\right)^2 = \frac{z+y}{z-y}$ if $x \in$ C, $\left(\frac{x}{2p^2}\right)^2 = \frac{z+y}{z-y}$ if $x \in D$.

And **Geometric Series representation of Pythagorean Triples** and their relation with its Length. For primitives

$$\sum_{n=0}^{\infty}\left(\frac{y}{z}\right)^{n+1} = \frac{\left(\frac{x}{(2p-1)^2}\right)^2 - 1}{2} = \frac{y}{(2p-1)^2} \quad \text{if } x \text{ is odd },$$

$$\sum_{n=0}^{\infty}\left(\frac{y}{z}\right)^{n+1} = \frac{\left(\frac{x}{2p^2}\right)^2 - 1}{2} = \frac{y}{2p^2} \quad \text{if } x \text{ is even.}$$

For Non-primitives $\sum_{n=0}^{\infty}\left(\frac{y}{z}\right)^{n+1} = \frac{\left(\frac{x}{m(2p-1)^2}\right)^2 - 1}{2} = \frac{y}{m(2p-1)^2}$ if x is odd ,

$$\sum_{n=0}^{\infty}\left(\frac{y}{z}\right)^{n+1} = \frac{\left(\frac{x}{2mp^2}\right)^2 - 1}{2} = \frac{y}{2mp^2} \quad \text{if } x \text{ is even.}$$

Also , It satisfies some inherent properties of Reciprocal Pythagorean Triples.

The elements of RPT are satisfies following equivalent conditions.

i) $h = \frac{ab}{c}$ (Also, $c = \frac{ab}{h}$)

ii) $h = \sqrt{c_a c_b}$

iii) $a^2 = c_a . c$

iv) $b^2 = c_b . c$

v) $c = 2R$

vi) $r = \frac{a+b-c}{2}$

Also, verified the definition of **TRIANGULAR NUMBERS** for all integers. Also, defined binary operations of inner addition on the Set of triangular numbers as follows.

$$T_{n_1} \oplus T_{n_2} = T_{n_1+n_2} = \begin{cases} T_{n_1} + T_{n_2} + n_1 n_2 & \text{if } n_1, n_2 \text{ both are same sign} \\ T_{n_1} + T_{n_2} + (n_1+1)n_2 & if\ n_1 > 0, n_2 < 0 \text{ and } n_1+n_2 > 0 \\ T_{n_1} + T_{n_2} + n_1(n_2-1) & if\ n_1 > 0, n_2 < 0\ and\ n_1+n_2 < 0 \\ T_{n_1} + T_{n_2} + n_1(n_2+1) & if\ n_2 > 0, n_1 < 0\ and\ n_1+n_2 > 0 \\ T_{n_1} + T_{n_2} + (n_1-1)n_2 & if\ n_2 > 0, n_1\ is < 0\ and\ n_1+n_2 < 0 \end{cases}$$

And inner multiplication on the set of triangular numbers is as follows

$$T_{n_1} \odot T_{n_2} = T_{n_1 n_2} = \begin{cases} T_{n_1}T_{n_2} + T_{n_1-1}T_{n_2-1} & \text{if } n_1 \geq 0, n_2 \geq 0 \\ T_{n_1}T_{n_2} + T_{n_1+1}T_{n_2+1} & \text{if } n_1 < 0, n_2 < 0 \\ T_{n_1}T_{n_2} + T_{n_1-1}T_{n_2+1} & \text{if } n_1 \geq 0, n_2 < 0 \\ T_{n_1}T_{n_2} + T_{n_1+1}T_{n_2-1} & \text{if } n_2 \geq 0, n_1 < 0 \end{cases}$$

Hence the algebraic structure of triangular numbers $(T_n, \oplus, \odot)$ is almost Semi Ring. Also derived some standard results of Triangular numbers.

CONCLUSION &SCOPE OF FUTURE WORK

According to my side, the scope of future work is to implement the Algebraic structure of a set of Pythagorean and a set of reciprocal Pythagorean Triples to Ring theory, and Field theory. Also implement the applications of Pythagorean and Reciprocal Pythagorean Triples to convert given plain text to cipher text in Cryptography. Also implement the applications of triangular numbers to Cryptosystem. Also, to be focus to define Algebraic Structure of Square Numbers.

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