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ORIGINAL ARTICLE

Protocol Efficiency Using Multiple Level Encoding in Quantum Secure Direct Communication Protocol

Nur Syuhada Mohamad Rodzi1[1,2*], Nur Shahirah Azahari[1], Nur Ziadah Harun[1]

[1] Department of Information Security and Web Technology, Faculty of Computer Science and Information Technology, University Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[2] Department of Information Technology and Communication, Politeknik Balik Pulau, 11000 Penang, Malaysia.

ABSTRACT – One of the objectives of information security is to maintain the confidentiality and integrity of the information by ensuring that information is transferred in a way that is secure from any listener or attacker. There was no comparison experiment conducted in earlier studies regarding different level encoding performance towards multiphoton technique. In Quantum Secure Direct Communication (QSDC), when unpolarized light enters into the polarizer, the light value will be changed into a different value when it hit the Half Wave Plate (HWP) along the quantum communication channel. Multiphoton technique in the earlier study is particular to transmission time for data transfer encoding and extra time for polarizers to change polarization angles, both of which contribute to longer transmission times. With four different size of qubits, the three simulation experiments are carried out using Python coding with 2,4 and 8 levels of encoding. Experiment results demonstrate that the most efficient average photon transmission derived from 18 qubit size ranges from 98.71% to 98.73% depending on encoding level. With 18 qubit size, the four-level encoding result has the highest average efficiency, followed by the eight-level and two-level encodings, respectively. 4-level encoding exhibits the highest average photon efficiency between 2 and 8 level encoding.

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INTRODUCTION

The demand for information security with adequate risk control has increased [1]. Modern lifestyles allow society to perform multitasking tasks as long as they are connected to the internet. As an example, consider online e-commerce transactions like stock purchases and sales as well as money transfers and withdrawals. These actions must be secured in terms of confidentiality, integrity, and authenticity [2].

Integrity and confidentiality are crucial components of information security. During the authentication procedure, there is a chance that Eve could steal the secret message that transfer between the sender and the receiver. According to Quantum Physic Law, the security guarantee does not rely on computational power. The No-Cloning Theorem added that quantum states are unknown and impractical to recreate. According to the Heisenberg Theory of Uncertainty, an intrusive party is unable to distinguish the properties of multiple quantum states. All three theories' justifications contribute to Quantum Cryptography. Additionally, quantum cryptography has built-in mechanisms that can detect hacker interception, self-destruct the message, and prevent duplication. In accordance with [3], [4], Quantum Secure Direct Communication (QDSC) is one of the quantum cryptography protocols that may transmit secret messages without the need for a secret key via a quantum communication channel. This capacity can be used in quantum computing for a safe authentication procedure.

In QSDC, when unpolarised light enters into the polarizer, the light value will be changed into a different value when it hit the Half Wave Plate (HWP) along the quantum communication channel. Based on the previous study the two-levels encoding approach is represented as two states of polarization which each state represents as 1 or 0 bit of information [12]. To transfer the bit of information between the sender and receiver in QSDC channel requires HWP rotations. As for example, to send 80 bits of information in multiphoton quantum environment with two-level encoding, the process requires 80 times of HWP to rotate. This is because two-level encoding only transmits 1 bit of information at a time along with HWP rotation from sender to receiver. This scenario contributes to less efficiency in terms of information transmitted in multiphoton secure direct communication.

According to [8], the four-levels of encoding which are represented as states of polarization are capable to transmit 2 bits of information at a time. For eight-levels encoding, according to the formula it will has capacity to transmit 3 bits of information at a time while sixteen-level encoding will transmit 4 bits of information at a time. There are still lack of comparison through experiment for another level encoding beyond four-level.

The initial goal of this study is to examine how bit size input and level encoding methods relate to the quickest photon transmission time in polarized light. Secondly, to apply the 2,4 and 8 level encoding in the single stage for multiphoton

***CORRESPONDING AUTHOR** | N. S. M. Rodzi | ✉ syuhada.rodzi@gmail.com

techniques. Thirdly, to evaluate the performance of the single stage multiphoton in the QSDC protocol in terms of total photon transmission time, total HWP transmission time, and total HWP turning time.

This study offers three contributions. First, determine how the bit size input in polarized light and the various levels of encoding relate to the quickest photon transmission times. Second, using a comparison of the half wave plate, HWP turning time and different levels of encoding to determine the relationship between input bit size and polarized light. Thirdly, a decrease in the number of HWP turning times was found when the relationship between the various levels of encoding and bit size input in the polarized light was determined.

The rest of this paper are organized as follows: Section 2 describe the literature reviews of the related research study. Section 3 elaborates the research methodology. Section 4 discuss on the experiment result and discussion analysis. The conclusion of the research is discussed in Section 6.

LITERATURE REVIEW

This section describes the literature reviews conducted in the research study which focus on quantum cryptography, QSDC protocols, authentication communication, single photon and multiphoton technique.

Quantum Cryptography

The quantum cryptography is utilizing the physic laws to enable safe information transfer by combining information theory and quantum theory based on study conducted by [5]. According to [6], the safest and secure ways for data transfer is by using quantum cryptography protocol. This protocol is based on quantum physic principals whenever sender and receiver able to have a secure communication under the invincible condition of quantum mechanics which is the set of rules or mathematical framework for physical theories construction. Quantum Cryptography depends on two elements which are Heisenberg's Theory of Uncertainty and Principle of Photon Polarization. of rules or mathematical framework for physical theories construction.

The quantum bit which also known as qubits has the special properties to securely transfer bit of information in quantum cryptography. The bits of information are encoded using polarization of photon. Whenever an eavesdropper or attacker want to attack the information transfer process, they have to measure the qubit communication state. However, the bit of information will be automatically demolished whenever an eavesdropper or attacker are detected tapping on the quantum channel [7]. This detection is not applicable in classical cryptography.

In addition, the quantum cryptography is not able to be copied which supported by No-Cloning theorem discussed in [8] and [7]. Another quantum cryptography protocol which originated from the quantum cryptography branch which are Quantum Key Distribution (QKD), Quantum Secret Sharing (QSS) and Quantum Secure Direct Communication (QSDC).

Quantum Secure Direct Communication (QSDC)

The quantum secure direct communication (QSDC) which is derived under quantum communication channel has the capability to transfer secret messages without private key requirements [3]. These also supported by research performed by [4], [9] that no secret key is required to transfer secret message in QSDC.

The QSDC Protocol framework discussed in [10] that there are four main processes in QSDC protocols which are authentication, encoding, quantum properties transformation and decoding process respectively. Once Alice and Bob identity authentication are successfully verified as authorized sender and receiver, Alice as a sender insert confidential information by using QSDC encoding process then transfer the secret message along the quantum communication channel. Bob then received the confidential information by decoding process.

In contrary to classical computers which work with state 0 or 1 binary bits, the quantum computers work based on quantum bits which also known as qubits. The qubits can be simultaneously in state 0 and 1 with additional superposition and entanglement properties exhibited [11]. Qubit is the quantum state and the smallest particle unit in quantum information [12].

The QSDC protocol are permitting information transfer in the communication channel without the secret key [3] and has a detection channel to ensure the information data transfer [12]. While QSDC protocol requires the information transfer within the quantum environment, the QSDC protocol enables data transfer between sender and receiver whereby the sender is not in the quantum environment but the receiver is able to perform measurement and storage in quantum environment [13]. In summary, both two protocol comparisons are focusing on ensuring the security of information transfer within the communication channel.

In quantum cryptography, the authentication process is performing without depending on classical cryptography [12]. This approach able to avoid MITM attack. To address this weakness, the authentication process can be executed during quantum data communication process resulted no potential of Eve attacks in the quantum channel after the authentication process between Alice and Bob are authenticated [14].

Single Photon & Multi-Photon Approach

Multiphoton is derived from the upgraded version of a single photon with capability for long-distance travelling and wide transmission rates that neither entangled photon nor single photon is incapable [12]. Besides, the multiphoton has the capability for simultaneous transmission which refers to one information bit in order to increase the transmission success rate. For example, in a situation that one photon needs to be transferred, an assumption is made which is bit 0 is encoded as 0 degree while 1 is encoded as 90 degrees. The one-stage photon is high likely prone to be intercepted or edited by the intruder which is known as Eve in the Alice, Bob and Eve analogy compare to multiphoton in multi stage implementation. In this analogy example, Alice is defined as an information sender, Bob as information receiver and Eve is defined as an information intruder.

The comparison between single-photon and multiphoton characteristics is summarized based on Table 1. In summary, using multiphoton technique versus single photon in information transfer within quantum communication channel able to avoid eavesdropping and listener activity intervention such as MITM attack [8].

Table 1. Single Photon and Multiphoton Characteristic Comparison [8]

Characteristics	Single Photon	Multiphoton
Photon Per Pulse	One photon	More than one photon
Polarization	Limit to 4 angles 90°, 0°, 45°-45°	Any polarization angle
Theory	No cloning theorem. Copy of photon unable to be generated with accuracy	Heisenberg Uncertainty. Photon polarization state measurement with fewer number of photons than needed will contribute to noise generation.
Eavesdropping Capability	Easy for eavesdropping intervention capability as only have 4 probabilities based on four polarization angles.	Difficult for eavesdropping intervention capability because difficulty to identify multi-stage polarization angles.

The comparison of the single photon and multiphoton techniques is shown in Table 1. Multiphoton data transmission has been shown to perform significantly better than single photon data transmission in terms of key generation rate and communication range [15]. The multiphoton method is more advanced and offers advantages including faster transmission rates and greater photon travel distances [16]. The same quantum state can be sent several times using the multiphoton method of information sharing. Many photons could be emitted simultaneously to communicate one bit of information in order to increase the success rate of the transmission. In the event that one of the three photons makes a mistake, the original photon can be easily recovered. The rotation operator in the multiphoton tecchnique protects data against MITM attacks by utilising any state of polarisation.

There are four multiphoton protocols are studied to compare the advantages and disadvantages of each which are M-Ary Three-Stage Protocol, Four Level Three-Stage Using Initialization Vector Protocol, the Braided Single Stage and Hybrid M-Ary in Braided Single Stage (HMBSS). The summary of comparison as in Table 2 based on study conducted by [12] except stated otherwise.

Table 2. Multiphoton Advantage and Disadvantage Comparison among Protocol

Multiphoton Protocol	Advantage	Disadvantage
M-Ary Three-Stage [17]	• Increase channel efficiency and data throughput since a single pulse can carry many bits of information.	• Because the protocol permits more than one bit of information to be conveyed by a single pulse, the error rate is high in the case of an eavesdropper assault.
Multiphoton SS [18]	• Depend on secrecy at single stage.	• When Eve gets the keys, the protocol is not fully secured.
The Braided Single Stage [19]	• Increase time transmission based [10]. • Able to compress data without reducing the quality of data after compressed. • Achieved efficient resource and perseverant to security degree even the stage number is reduced.	• Increase in source redundancy. • Critical issue on encoded data transmission time due to additional time needed for optical device polarization angle.

Hybrid M-Ary in Braided Single Stage (HMBSS) [12]	• Use polarizer and HWP in the experiment. • The high occurrence of polarization change contributes to security level enhancement.	• Require longer time to transfer photon in quantum environment.

Based on these four QSDC protocols studied, the gap is found that only 2-level and 4-level encoding are compared in previous research work. Thus, there is a research opportunity to explore on another different level of encoding performance related to source redundancy improvement. The measurable value on specific source redundancy reduction performance comparison between different m-level of encoding are focusing into the transmission time based on total time taken to transmit photon, total time for HWP rotation time and total average efficiency.

RESEARCH FRAMEWORK

The framework of this research is based on Alice as the sender and Bob as the receiver able to encode multiple information bits into a single polarization state and successfully retrieve it back at the other end. Alice send photon to Bob using a polarizer. Whenever photon existent is detected by the polarizer, the photon will be polarized according to specific angle depends on level of encoding. Then the photon will go through a HWP and the angle rotation will change in every 8 bits of information to ensure the confidentiality of the message are secured and no attack by Eve happen. All the photon has it own intensity and prior to receive by Bob, two polarizers which play roles as detector will translate the photon light intensity into angle. Figure 1 shows research framework.

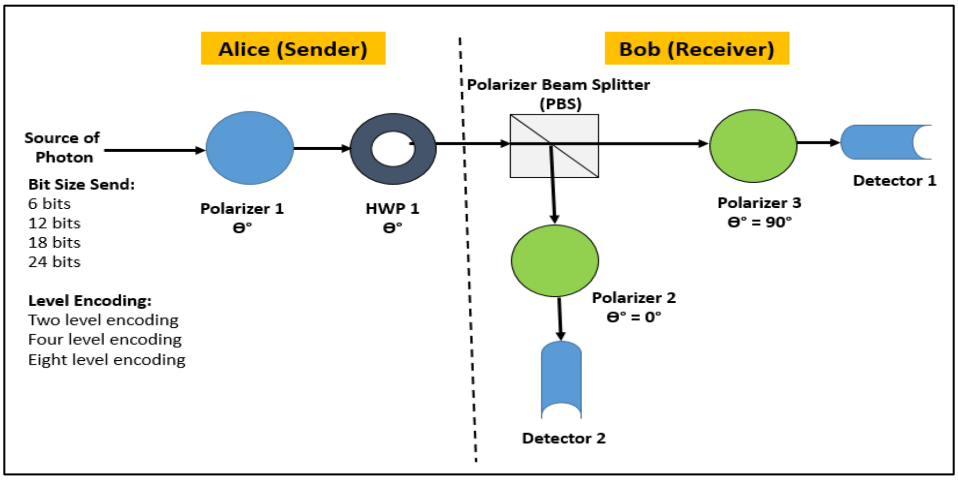

Figure 1. Research Framework

Next, the random message generated. Photon polarization is executed based on level of encoding. Photon then transmit to HWP and upon photon bit of information detected, the HWP rotation angle are changed range from 0° to 360° for every 8 bits of information transmitted through the HWP quantum environment. Then polarizer beam splitter (PBS) will split the photon into two polarizers which is polarizer 1 with 0° and polarizer 2 with 90°. Both polarizer 1 and 2 plays the role as detector will detect photon light intensity and translate the message into the original bit of information and decode the photon. Then Bob able to receive the original bit of information send by Alice. If there is any intruder by Eve such as eavesdropper or MITM attack, the bit of information will be automatically destroy based on Quantum Physic Law, No Cloning Theorem and Heisenberg's Theory of Uncertainty. The result of the experiment is measured for each level encoding for transmission time based on total time taken to transmit photon in quantum polarization environment, total time comparison for HWP turning time and total number of HWP. Comparison of collective result are analysed to highlight any significant improvements.

There are five equations are involve based on this research framework. Polarizer 1 is used Equation 1, HWP 1 used Equation 2, 3 and 4 and both Detector 1 and Detector 2 used Equation 5. The details of Equation 1 until Equation 5 are elaborated in Experiment Setup.

EXPERIMENT SETUP

The experiment implementations were tested using a Python-based simulation. Python was used because it can represent quantum states mathematically. The protocol was evaluated in comparison to m-level encoding. The comparable multi-level encoding was reimplemented to achieve objectivity. This procedure is carried out utilising the Python programming language in order for the protocols to function under a similar simulator. To demonstrate that the suggested approach is effective, the procedure was then tested and validated using the same setting of the equivalent level encoding. The time to transmit a small amount of information and the time it takes the HWP to rotate from its original position to its new position for each of the procedures under analysis are taken from earlier studies. For authentication, the update angle or rotation of the HWP is changed every eight bits [20]. Although it takes longer to transfer the information, the fast polarisation changes have increased the level of security.

Data Set: The experiment starts with initial 4 randomly generated datasets and each dataset tested on 3 different level encoding which result in 12 different dataset results. Each of the dataset result is run into 30 sample size. The input from randomly generated dataset is representing multiphoton random message generated by sender with 4 different bit size on every m-level of encoding. In the experiment, the m-level of encoding is referring to 2-level of encoding, 4-level of encoding and 8-level of encoding. In total, there are 12 different data set has been applied in this experiment.

Generation of Data Set: In general, the data set in this experiment are generated by running Python code with 3 different level of encoding. Each of encoding level are set with 4 different bit size. The data type is in random characters using Random Number Generator (RNG) which consist of number, lower case and upper-case characters. The number of characters generated is based on bit size set in the coding which are 6 bits, 12 bits, 18 bits and 24 bits.

The simulation parameters for this experiment setting are shown in Table 3.

Table 3. Simulation parameters [12]

Parameter	Values
Length of bit	6, 12, 18, 24
m-level encoding	2,4,8
Half wave plate rotation	20.7 sec
Time to send a bit of information	4.5 sec

During the encoding stage, Alice creates a state with a 0 linear polarisation using a 0º polarizer. By converting a bit into a quantum state known as a qubit, which is defined by a Mueller matrix, Alice and Bob are able to polarise light using two sets of polarizers [12].

$$M_{pol} = \frac{1}{2}\begin{bmatrix} 1 & \cos(2\theta) & \sin(2\theta) & 0 \\ \cos(2\theta) & \cos^2(2\theta) & \cos(2\theta)\sin(2\theta) & 0 \\ \sin(2\theta) & \cos(2\theta)\sin(2\theta) & \sin^2(2\theta) & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{1}$$

where M_{pol} is referring to the polarizer rotation θ is the degree of polarisation angle that is set from 0º to 180º. At this stage, the beam is directed towards the HWP in order to change its polarisation using a secret polarisation angle. The HWP is updated for each batch of bits and is oriented at a specific angle [20].

During rotation transformation stage, the configuration of the unitary transformations used with half wave plates, as well as the selection of the rotation angle (θ) of the half wave plates with respect to the horizontal axis is described. The decision ensures that the input and output polarisation angles of the half wave plate arrangement are equal by using the Mueller matrix formalism [20]. A half wave plate generates a 360° polarity change in the wave plate's fast and slow axes. Also included is a HWP that is mounted on a rotator and will rotate at a random angle chosen by Alice and Bob. This HWP device contain the optical components matrices are described by Mueller Matrices discussed in [12].

$$M_{HWP} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(4\theta) & \sin(4\theta) & 0 \\ 0 & \sin(4\theta) & -\cos(4\theta) & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} \tag{2}$$

where M_{HWP} is referring to the HWP rotation and θ is referring to the HWP angle degree between 0º to 360º.

During the decoding stage, the signals that exit the channel are combined using a beam combiner. The detector determines whether the bit is 0 or 1 when the beam passes through the 0° and 90° polarizers.

This experiment will be used for single stage multiphoton. The key requirement on the single stage photon transformation, the only set up are consider at the receiver side of HWP as explained in [12].

$$M_{HWP}(A\theta) \cdot M_{HWP}(A\theta) = I \tag{3}$$

Where by I is in the matrix form of:

$$I = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \tag{4}$$

The intensity of the output based on output light detected by the polarizer based on the polarization states. According to Malus Law, the intensity output can be calculated using Equation 5 in [12].

$$I_O = I_I \cos^2(\theta) \tag{5}$$

where θ is the secret polarization angle for the bits, I_O is the output intensity, I_I is the input intensity.

Based on the Equation 5, the intensity output and it polarization also known as bit representation for different m level encoding as listed based on the below table respectively.

Table 4. Output Intensity for 2-Level Encoding

Angle of Encoding, θ	Intensity, I	Bits Presentation
0	1	0
90	0	1

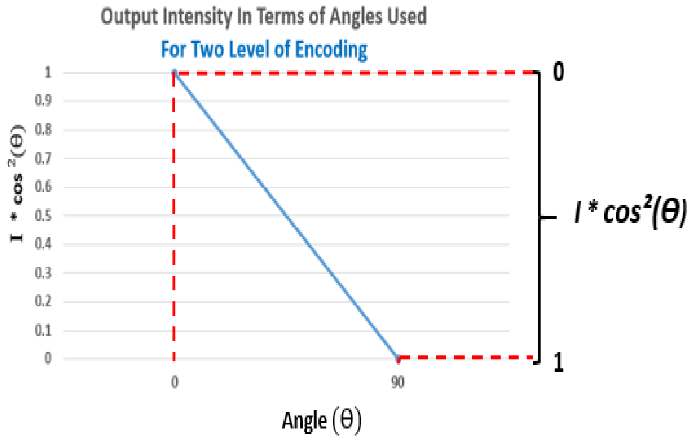

Figure 2. Output Intensity in Terms of Angles Used for 2-Level Encoding

Table 4 and Figure 2 shows that 2 polarizer state representations, denoted by the numbers 0 and 1, were produced via the 2-level encoding. Value 0 of the polarizer state representation corresponds to a 0° encoding angle and value 1 to a 90° encoding angle.

Table 5. Output Intensity for 4-Level Encoding

Angle of Encoding, θ	Intensity, I	Bits Presentation
20	0.88302	00
38	0.62096	01
52	0.37903	11
70	0.11697	10

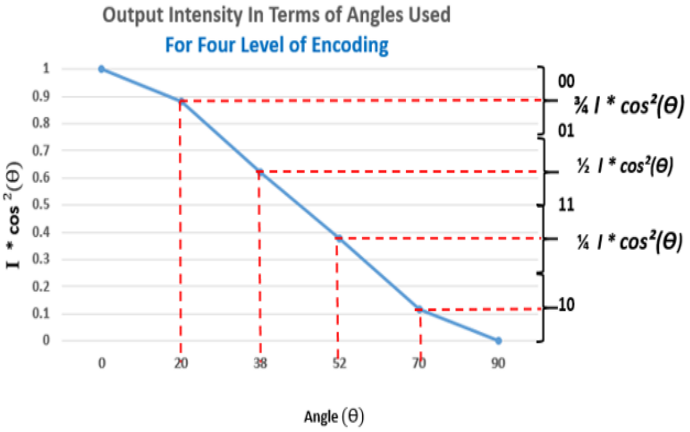

Figure 3. Output Intensity in Terms of Angles Used for 4-Level Encoding

Table 5 and Figure 3 shows that 4 polarizer state representations, denoted by the numbers 00, 01, 10 and 11, were produced via the 4-level encoding. Value 00 of the polarizer state representation corresponds to a 20° encoding angle, value 01 to a 38° encoding angle, value 10 to a 52° encoding angle and value 11 to a 70°.

Table 6. Output Intensity for 8-Level Encoding

Angle of Encoding, *θ*	Intensity, *I*	Bits Presentation
12	0.95677	000
23	0.84732	001
34	0.68730	010
45	0.50000	011
56	0.31269	100
67	0.15267	101
78	0.04322	110
89	0.00030	111

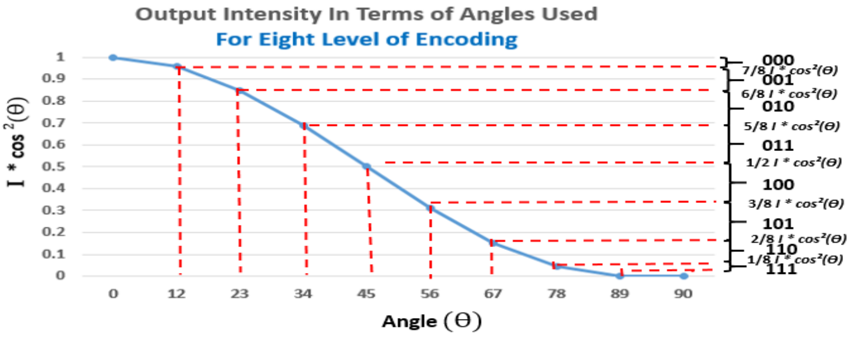

Figure 4. Output Intensity in Terms of Angles Used for 4-Level Encoding

Table 6 and Figure 4 shows that 8 polarizer state representations, denoted by the numbers 000, 001, 010, 011, 100, 101, 110, and 111, were produced via the 8-level encoding. Value 000 of the polarizer state representation corresponds to a 12° encoding angle, value 001 to a 23° encoding angle, value 010 to a 34° encoding angle, value 011 to a 45° encoding angle, and value 100 to a 56° encoding angle, value 101 to a 67° encoding angle, value 110 to a 78° encoding angle, and value 111 to an 89° encoding angle.

PERFORMANCE EVALUATION METRIC

The higher level of encoding will send more bits of information at a time. For example, in 2-level encoding, 1 bits are sent, 2 bits are sent at a time for 4-level encoding and 3 bits for 8-level encoding. The simulation experiment result will be measured based on performance of the followings evaluation metrics.

Total Time Taken to Transmit Photon

This protocol was carefully developed and put into use to analyse how long it took to encrypt the data. The number of bits capacity increase whenever encoding level is increased and contribute to faster transmission time. Thus, the overall transmission process is expected to show significant improvement. Total transmission time includes the time needed for multiphoton transmission across a quantum communication channel, T_{msg} , as well as the time needed for HWP to change angles for the transmission of 8 bits of information, which is represented by T_{HWP}. The amount of time is given in seconds. Equation 6 is used to calculate the result as shown by [12].

$$Transmission\ Time\ = T_{msg}\ + T_{HWP} \tag{6}$$

Total Time Taken for Half Wave Plate Turning Time

The overall HWP turning time needed to complete each information transmission procedure will reduce when encoding levels are increased. As a result, it is expected that the HWP turning time will decrease and thus make the overall process more efficient [12].

Average Efficiency

Average efficiency is measured based on H which is the optimal average number of bits per character over average length of characters which refer to:

$$Average\ Efficiency = \frac{H}{Average\ Length} \tag{7}$$

EXPERIMENT SIMULATION

Each of experiment is based on number of encoding levels. Random characters generated by Python coding are set to four different bit size which are 6 bits, 12 bits, 18 bits and 24 bits. The pseudo code of this experiment are based on three main part in sequence. Firstly, polarizer state representation and angle of encoding. Secondly, HWP angle of rotation. Thirdly, polarizer state representation and angle of decoding. The experiments are design based on three different level of encoding which involve multiphoton generated by Python simulation program. The information transfer in single stage multiphoton as of the following experiment 1, 2 and 3. When more than one photon is generated at a time, the terms of photons is known as multiphoton as well. The photons then go through the HWP. Upon photons detection at HWP, HWP rotation transform it rotation angles range from 0° to 360° for every 8 bits of information transmission. Whenever theta value exceeds 360°, the transmission process needs to stop for theta value reset back to 0°. The transmission time for overall process, number for HWP rotation and coding efficiency result will be collected while running the coding for each 30 set sample size. Next the same process is repeated from beginning to collect the transmission time and coding efficiency for another 3 different bit size which is 12 bits, 18 bits and 24 bits for two-level encoding.

Experiment 1

2-Level Encoding. The 2-level encoding has generated two polarizer state representation which is 0 and 1. The polarizer state representation value 0 is map to 0° angle of encoding and value 1 is map to 90° angle of encoding. When photons with value 0 while entering the polarizer, it will map to 0° of encoding as well as photon with value 1 will map to 90°.The photons then go through the HWP. Algorithm 1 details the pseudo-code of the Experiment 1.

Algorithm 1

```
Notation:
Transmission Time
CodingEfficiency
theta ← HWP's rotation angle
time_taken ← Period of the photon transfer
Initialization:
```

```
X = random string message with bits size = 6, 12,18 and 24
B ← A bit sequence B
Encoding stage: A photon generated represents a qubit after it is passed through a linear polarizer:
  pol()←is the polarization of linear polarizer using Equation 1
  For each bit from B do
    B ← pol()
    if B[i] == 0 then
      pol() = 0◦
    else B[i] == 1 then
      pol() = 90◦
    end if
  end for
Photon distribution:
  Len(B) ← is the length of bit sequence B
  f(B, theta, time_taken) ← is the function that returns the next theta values and photon's transmission time for every photon
  for I (theta, time) ← in numerate (f(B, theta, time)) do
    for j = 1 in range B do
      Transmission of photon
      if i *B + j >= len(B) then
        break transmission
      end if
    end for
Decoding Stage: the polarizer will then detect for polarization states according to the level of intensity using Equation 5:
  For each bit from B do
    B ← pol()
    if intensity == 1 then
      B[i] == 0
    else intensity == 0 then
      B[i] == 1
    end if
  end for
Calculate transmission time and coding efficiency using Equation 6 and 7
```

Next, the decoding process happen at the polarizer with play the role as detector to detect the present of photon light intensity then translate the intensity to the original bit of information and decode the photons. The photon with intensity value 1 will map to bit 0 while photon with intensity value 0 will map to bit 1.

Experiment 2

4-Level Encoding. The 4-level encoding has generated four polarizer state representation which is 00, 01, 11 and 10. The polarizer state representation value 00 is map to 20° angle of encoding, respectively until the fourth value 10 is map for 70° angle of encoding. When photons with value 00 while entering the polarizer, it will map to 20° of encoding, 01 photon value map with 38° of encoding, 11 photon value will be match with 52° of encoding as well as photon with value 10 will map to 70° as shown in table 5. Algorithm 2 parts of the pseudo-code of the experiment 2.

Algorithm 2

```
A photon generated represents a qubit after it is passed through a linear polarizer.
For each bit from B do
  B ← pol()
  if B[i] == 00 then
    pol() = 20◦
  else B[i] == 01 then
    pol() = 38◦
  else B[i] == 10 then
    pol() = 70◦
```

```
    else B[i] == 11 then
        pol() = 90◦
    end if
end for

Polarizer will then detect for polarization states according to the level of intensity.
For each bit from B do
    B ← pol()
    if intensity == 0.88302 then
        B[i] == 00
    else intensity == 0.62096 then
        B[i] == 01
    else intensity == 0.37903 then
        B[i] == 11
    else intensity == 0.11697 then
        B[i] == 10
    end if
end for
```

The decoding process happen at the polarizer with play the role as detector to detect the present of photon light intensity then translate the intensity to the original bit of information and decode the photons.

Based on algorithm 2, the photons with intensity value 0.88302 will map to bit 00, follow by photons with intensity 0.62096 will match with bit 01, while photons with intensity value 0.37903 will map to bit 11 and finally photons with intensity 0.11697 map to bit 10.

Experiment 3

8-Level Encoding. The 8-level encoding has generated eight polarizer state representation which is 000, 001, 010, 011, 100, 101, 110 and 111. The polarizer state representation value 000 is map to 12° angle of encoding, value 001 is map to 23° angle of encoding, value 010 is set for 34° angle of encoding, value 011 is map for 45° angle of encoding, followed by state representation with value 100 is map to 56° encoding angle, value 101 is dedicate to 67°, value 110 is dedicate to 78° and value 111 is dedicate to 89° as shown in Table 6.

Algorithm 3

```
A photon generated represents a qubit after it is passed through a linear polarizer.
For each bit from B do
    B ← pol()
    if B[i] == 000 then
        pol() = 12◦
    else B[i] == 001 then
        pol() = 23◦
    else B[i] == 010 then
        pol() = 34◦
    else B[i] == 011 then
        pol() = 45◦
    else B[i] == 100 then
        pol() = 56◦
    if B[i] == 101 then
        pol() = 67◦
    else B[i] == 110 then
        pol() = 78◦
    else B[i] == 111 then
        pol() = 89◦
    end if
end for

```

```
Polarizer will then detect polarization states according to the level of intensity.
For each bit from B do
    B ← pol()
    if intensity == 0.95677 then
        B[i] == 000
    else intensity == 0.84732 then
        B[i] == 001
    else intensity == 0.68730 then
        B[i] == 010
    else intensity == 0.50000 then
        B[i] == 011
    if intensity == 0.31269 then
        B[i] == 100
    else intensity == 0.15267 then
        B[i] == 101
    else intensity == 0.04322 then
        B[i] == 110
    else intensity == 0.00030 then
        B[i] == 111
    end if
end for
```

The decoding process happen at the polarizer which play the role as a detector to detect the present of photon light intensity then translate the intensity to the original bit of information and decode the photons. The photons with intensity value 0.95677 will map to bit 000, follow by photons with intensity 0.84732 will match with bit 001, while photons with intensity value 0.6873 will map to bit 010 and photons with intensity 0.5000 map to bit 011. The last four photons with intensity value which are 0.31269, 0.15267, 0.04322 and 0.0003 are match to bit 100, 101, 110 and 111 respectively.

RESULTS & FINDINGS

This section describes the findings of this research study.

The result generated during experiment sample size are further analysed based on below performance metric as discussed and output intensity in terms of angles used by the three different *m* encoding level.

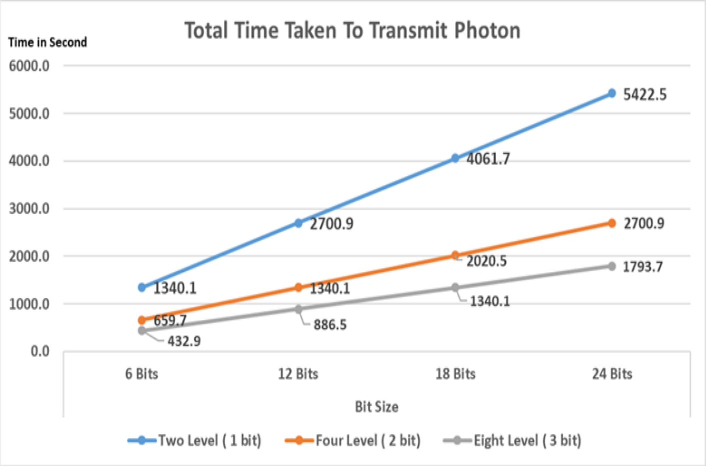

Figure 5. Total Time Taken to Transmit Photon

Figure 5 shows total time taken to transmit photons with different *m* level encoding and different length of bit. The line chart above shows a decrease of time taken to transmit photons when the level of encoding increases. The fastest time for photon transmission is 8-level encoding which is 3 qubits was transmit at a time then it followed by 4-level encoding with 2 qubits transfer at a time and the longest time is 2-level encoding which is only 1 qubit transfer at a time.

The line chart above also shows increase time taken to transmit photon when the length of bit increases. The length of bits also plays the important role in influencing the time taken to transmit photons in the quantum environment. The longer the bits, the longer time needed to complete the transmission process. As of the comparison based on Figure 2 as well, if referring to 8-level encoding, it takes 432.9 seconds to transfer 6 qubits of information versus 1793.7 seconds for 24 qubits of information to complete transmission which is 75.9% different.

It has been demonstrated that higher levels of encoding can carry more information during each transaction which can speed up the time taken to transmit photon, as stated in [21].

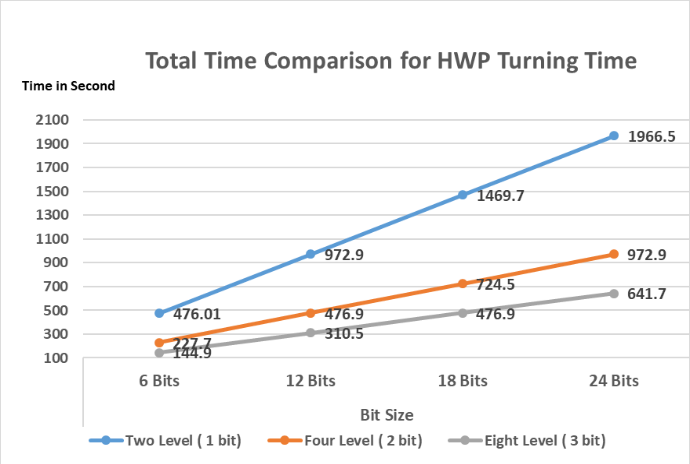

Figure 6. Total Time Taken for HWP Turning Time

Figure 6 shows total time taken for HWP turning time with different *m* level encoding and different length of bit. The line chart above shows a decrease of time taken for HWP turning time when the level of encoding increases. The longest time taken for HWP turning time is with 2-level encoding with 24 bits qubit lengths, 1966.5seconds versus the fastest time taken for HWP turning time is when transferring photons with 8-level encoding with 24 qubits length, 641.7 seconds as shows in Figure 6. From this experiment result, it shows that HWP turning time will be faster for 8-level encoding with the shortest qubit length.

It has been demonstrated that higher levels of encoding can carry more information during each transaction which can reduce time taken for HWP turning time, as stated in [21].

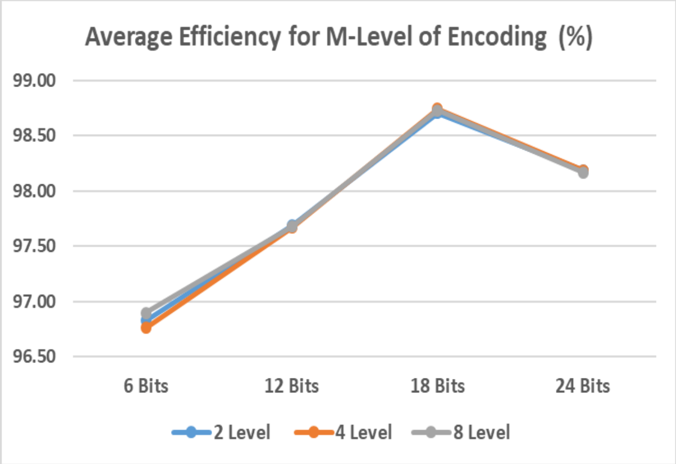

Figure 7. Average Efficiency for Photon Transmission in *m*-Level Encoding

Table 7. Average Efficiency for M-Level of Encoding

m-Level	6 bits	12 bits	18 bits	24 bits
2	96.82	97.68	98.71	98.19
4	96.76	97.67	98.74	98.19
8	96.90	97.68	98.73	98.17

Based on three different *m* encoding level compare with this experiment along with four different bit length as in Figure 7 and Table 5. The result shows that the most efficient photon transmission based on average efficiency is with 18 lengths of bits compare with 6, 12 and 24.

The average efficiency result run among 2, 4 and 8-level of encoding, the 18 bits size random characters input size scored the highest efficiency, followed by 24 bits, 12 bits and 6 bits respectively. In terms of level of encoding, the highest average efficiency shows by 4-level encoding which is the highest average efficiency recorded 98.74% with 2-level encoding followed by eight-level encoding with 98.73% average efficiency with delta only 0.01% and 2-level encoding recorded with 98.71% which delta only 0.02% compared to the 4-level encoding with 18 lengths of bits.

It has been demonstrated that higher levels of encoding can carry more information during each transaction which can increase the efficiency for photon transmission, as stated in [22]–[24]. Besides, the higher levels of encoding contribute to faster qubit can be transferred due to more information can be sent in one transmission. In real world quantum communication scenario, the 4-level encoding will save time and cost of source redundancy. The source redundancy is referring to reduction of total transmission time for HWP, total photon transmission time and half wave plate turning. In addition, the 4-level encoding can be used for information transfer due to its capability to send two photons at a time instead of one photon at a time. The higher encoding level, the information message transfer will be more efficient and faster because the transfer time will be reducing to send the bit of information. Among 2,4 and 8-level of encoding, the 8-level of encoding will contribute to the fastest bit of information transfer time.

CONCLUSION & FUTURE WORKS

In terms of overall outcome from this experimental simulation study, significant research contribution specific to multi-level encoding in single stage multiphoton using QSDC protocol are concluded with three summaries. Firstly, the higher encoding level and the lower bit size input in the polarization light resulted to the fastest time taken to transmit photon. Secondly, the higher the encoding level and the lower bit size input in the polarization light resulted to the less number of total time comparison of HWP turning time. Thirdly, the higher the encoding level and the lower bit size input in the polarization light contribute to the less number of HWP turning time. Thus, the higher level of encoding can help to increase the efficiency of protocol.

As for the contribution of the knowledge, based on the experiment conducted with two, four and eight-level of encoding, the most efficient average photon transmission resulted by 18 qubits bit size range from 98.71% to 98.73% based on different encoding level, follow by 24 qubits, 12 qubits and 6 qubits respectively. Among the 3 different level of encoding studied and experiment conducted, the four-level encoding result shows the highest average efficiency with 18 qubit bit size, follow by the eight-level encoding and two-level encoding respectively. The future recommendation to this study expansion in QSDC is exploration on different type of digital dataset such as image, voice, sound and video. In addition, the expand the research into another QSDC branch such as multi-stage multiphoton and quantum dialogue.

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