A New Assessment of Quantum Key Distribution, Attenuation and Data Loss over Foggy, Misty and Humid Environment

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***Abstract* - Quantum encryption is a method of key transfer in cryptography by using quantum entanglement of photons. The real power of quantum entanglement is instantaneous communication that is non intercept able. The advantage of quantum encryption method is, it can be incorporated with conventional encryption methods safely. The quantum cryptography can replace conventional key exchange mechanism with the polarized photons using channels like optic fiber cables. Quantum cryptographic can also provide far and secure data communication. The present day experiments clearly proved that the quantum cryptography can be implemented through medium like optic fiber cable or air. But the distance of transmission through the air is limited by rule of line of sight propagation. The quantum key distribution will have uses in different types of communication between distant parts of earth. So this paper discussing various aspects of Quantum key distribution and successfully calculated polarized photon loss during transmission of Quantum cryptography link, while using in various type of atmospheric conditions like Mist Fog Haze. Also successfully calculated probability of single polarized photon missing by successfully utilizing the Light transmission characteristics and power measurements in various Atmospheric conditions**

Keywords - Quantum cryptography, Communication network, Free-space optical communication

I. INTRODUCTION

The research on quantum cryptography is very important for future fully secured communication requirement. The quantum encryption can create codes that are unbreakable and not intercept able Quantum key distribution codes. Because of these feature quantum encryption systems is considered as far secure and safer. The computing power of quantum computers increasing day by day as compared with conventional computing systems and so it can be used for breaking currently existing key distribution scenarios [1]. The different malicious activities and cybercrimes are increasing over the communication networks .The attacks over the critical computer networks can causes huge losses with challenging the security of nations. The developments in quantum key encryption can significantly improve the security of communication networks. So this work can help to improve the security in communication systems. But the limitation of quantum cryptography mainly because of polarized photons that is limited to the line of sight and hence here we discuss the various aspect of this propagation over the surface of earth. So this paper discussing various aspects of Quantum key distribution and successfully calculated polarized photon loss during transmission of Quantum cryptography link, while using in various type of atmospheric conditions like Mist Fog Haze. Also successfully calculated probability of single polarized photon missing by successfully utilizing the Light transmission characteristics and power measurements in various Atmospheric conditions.

II. QUANTUM CRYPTOGRAPHY AND EVOLUTION

In early 1980s, C. Bennet, P. Benioff, Richard Feynman proposed that a new powerful way for information processing with the possible quantum states. Richard Feynman was proposed an idea in 1981 that Quantum systems could be performed more powerful than the existing classical computing systems [3], and so the concept of Quantum computing was originated. David Deutsch was studied more passionately about it and eventually published a paper in 1985 [4]. However the origin of quantum cryptography was considering was started since 1983 from the work of Weisner[5], when he proposed single quantum states could be used for information transmission.

In 1989, Deutch published another paper "Quantum computational networks"[6] and proposed a new idea that quantum gates could be combined for quantum computation so that boolean gates, fundamentals of computing, could be achieved computation and so similarly quantum circuits also. The critical advancement in theoretical quantum cryptography was considered to be happened in 1991 when Ekert was suggested that Einstein- Podolsky- Rosen [7], two particle states of entanglement could be used to establish a quantum information system.

III. QUANTUM KEY DISTRIBUTION BASED COMMUNICATION LINK

The quantum key distribution based communication link establish between Alice and Bob can be represented as the figure-1 below. The quantum channel is using for establishing secure quantum cryptography based secure key transfer.

While the classical channel is used for conventional data transfer between the devices by medium like optic fiber cables or air or free space. The quantum channel is used for secured key transfer between the source and destination [8] using the polarized photons and corresponding bit values as given in the figure. The photons can either Rectilinear or Diagonal polarization mode that can hold the value of zero or one. Detector can receive and identify this bit values by checking the polarization state of the received photons

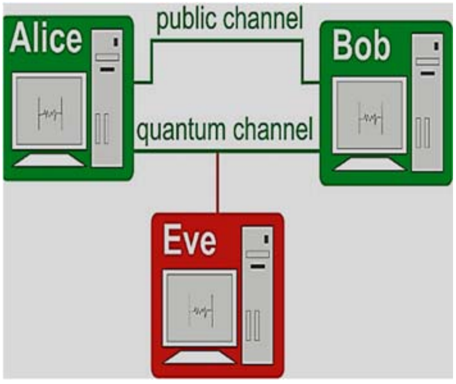

Fig 1. Simplified Quantum key distribution

A. Quantum Key Distribution Based Data Transfer

The quantum channel is used for secured key transfer between the source and destination using the polarized photons and corresponding bit values

Alice and bob performs the quantum key transfer and conventional data transfer as per the procedures given below [8].

- Alice starts communicates with Bob through the quantum channel by sending data carrying polarized photons.
- Then Alice and Bob discuss the results using n available public channel
- Soon after that receiving encryption key, Bob can encrypt any messages and communicate through public channel. If any attempt for eavesdropping not only unsuccessful but also gives a wrong reading that would be destroyed information content.

Eventually, Alice and Bob both have no longer same key because of information already loss and so eavesdropper's presence would be known to both sender and receiver so attempt would not succeed further.

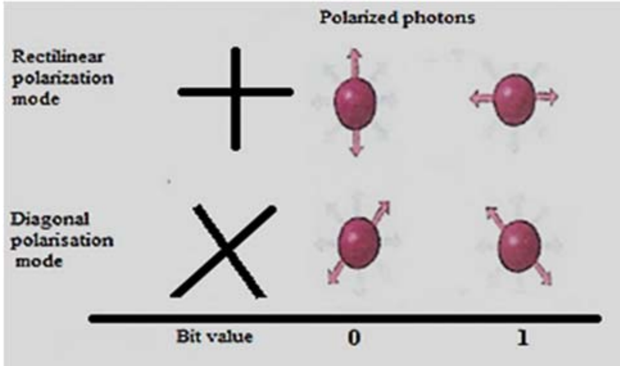

Fig 2.Polarized photons and corresponding bit values.

IV. QUANTUM CRYPTOGRAPHY POSSIBILITIES OF COMMUNICATION OVER THE EARTH SURFACE

- The QKD(Quantum Key Distribution) can be used for secure communication between ships to command center via satellite
- The QKD can be used for communication between the command centers to the aircraft from a remote location
- The QKD between the ship to ship or aircraft is limited within the visible horizon due to QKD uses polarized photons for communication.

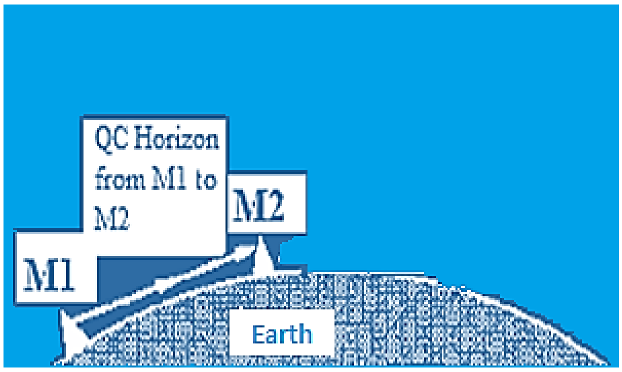

Fig 3. The Quantum Cryptography (QC) and Line of Sight propagation with horizon from two points over earth surface.

V. QUANTUM CRYPTOGRAPHY LINK AND HORIZON CALCULATION

The term horizon is a virtual apparent line that separates earth from sky it divides all visible directions into two separate categories, those which intersect the earth's surface and another that does not. At many surface point of Earth, the true horizon is being hided by tall trees, tall buildings, mountains, etc. but it is clearly visible in ocean or flat desert or large lakes and the resulting point of intersection on earth and sky is termed as the visible horizon. Historically, the distance to the visible horizon has long been very important

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for the successful sea navigation , because it is using for determining an observer's maximum range of visibility[9] and the same applicable for Line of sight propagation(LOS) of the Quantum Key Distribution(QKD).This became less significant due to the significant research and development of the area radio communication systems, however the horizon calculation can become again significant now a days due to emerging area Quantum Cryptography communication systems.

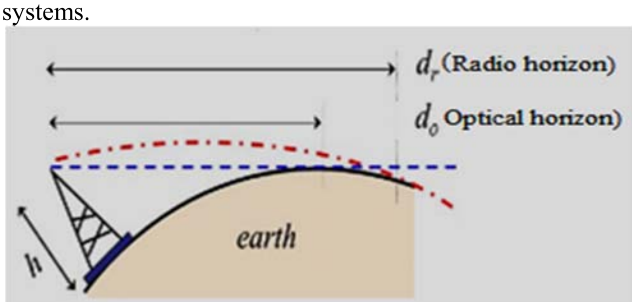

Fig 4. Optical and Radio Horizon

The radio horizon is can be termed as a locus of points which deviates rays from the antenna tangential to surface of Earth surface. Consider if the Earth surface was a spherical perfectly and with there was no atmosphere, the radio horizon shaped as a circle. The effective communication is the result of radio horizon of the transmitting and receiving antennas would be combined together with both heights and eventually increase the effective communication range. In astronomy the horizon described as the horizontal plane of the observing platform. It is the fundamental plane of the horizontal coordinate system, which the locus of points that have an altitude of zero degrees. While similar ways of the geometrical horizon, for this context a horizon may be termed as a plane in space. This importance of Light spectrum using for communication purpose was reduced s due to the development of the radio communication systems, but now a days and future, the horizon calculation can become again significant due to Quantum Cryptography based communication system, that could provide high security in data transfer using polarized photons.. The refractive error on Earth's curved surface causes an error in geometric calculation. When any ground, water or surface is cooler than the air above which creates a dense layer of air forms close to the surface and so light bends downward direction while traveling through air. The reverse phenomenon happens when the ground is hotter than air above it, usually happening at desert environment.

The height for finding Line of Sight propagation and Horizon of a Quantum Key Distribution devices in a platform can be calculated as below equations:

h = The height of the platform holding QKD device (X) + Height of the platform person or holding platform standing from sea level (H).

The equation derived earlier studies [10] can be transformed for this scenario as below:

$3.570\sqrt{h}$, Where h is the height from sea level

Horizon OG $=3.570\sqrt{h}$, Where h = H + X. So that the horizon of a person or any holding platform of Quantum key distribution device is:

$$3.570\sqrt{\mathrm{H} + \mathrm{X}} \tag{1}$$

Theoretically calculated Line of Sight (LOS) of a vertically Polarized Laser Light source in a hundred Feet Height, equal to 30.48 Meter, Platform can be calculated as:

$3.570\sqrt{30.48}$ = 20 Kilometer

VI. THE QUANTUM CRYPTOGRAPHIC SYSTEM

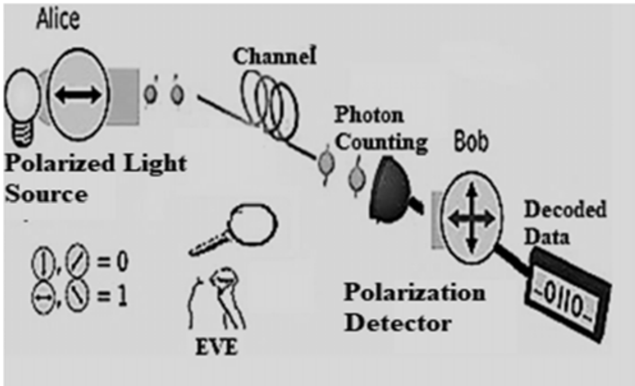

Fig 5. Quantum Key Distribution System

A. *LASER beam as a Polarized Light Source*

The transmission of polarized photons using LASER beam are the main source for long distance Quantum Key Distribution system. Generally there are three classes of high energy LASERs currently under developed an d widely using is Chemical lasers, Solid-state lasers, and Free electron lasers [11] . Work on other types of High energy LASERs like the Gas dynamic laser and Pulsed electric gas discharge laser, was abandoned a few years ago due to the lasers produced beams were at unfavorable wave lengths for propagation in real world applications.

A1. Chemical LASER

Chemical lasers are producing beams by excited atoms or molecules from different chemical reactions. High quality chemical laser's example are hydrogen and deuterium fluoride or chemical oxygen or iodine lasers. These devices capable of producing high energy beams with megawatt power levels with high quality. The MIRACL was an example of Deuterium fluoride laser operated around at a wavelengths of 3.8 microns that had been in continuous operation at

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megawatt power level since the mid of 1980's .The hydrogen fluoride (HF) LASERs similar to the Deuterium fluoride laser is operating in a shorter wavelength of 2.7 Microns, that cannot propagate properly in atmospheric conditions over Earth surface but can work well in free space applications . The United states and other Navies discontinued the development program and applications of chemical lasers due to the propagation losses in the operational wavelengths.

A2. Solid State Lasers

Solid-state lasers (SSLs) are most widely using type of LASER now a days. It produce laser beams from an excited atoms or ionic state of a solid-state material. This atomic excitation is achieving by the supply of a power source to the solid-state material. This type of LASERs have huge potential for a compact weapons but current devices are yet large and complex. The advantage of this type of laser is does not need flowing gases or relativistic electron beams. The system has comparatively smaller size and complexity than other type of lasers and can operate around 1.06 Microns. However, this type of LASERS have the disadvantage is wastage of energy by heat production. Waste heat from a laser could be passed over to the flowing gas medium or using through a huge heat sink. Also other ways are short pulses followed by cooling down each time of operation. But this will also reduce the efficiency of LASERs. Other possibility to tackle this situation is combining the power output of many small power lasers into a single beam of high power coherent has been also investigating for further development. But using this concept, will eradicate system simplicity .But same time there is a huge industrial market for various range of Laser diodes for commercial applications.

A3. Free Electron Lasers

Free electron laser (FEL) is another type of Laser that producing beam of radiation by allowing passage of the electron beam through the magnetic field known as wiggler. The spatial variations of the wiggler and electromagnetic radiation combines and eventually would generate a beat wave that causes the electron beam to create coherent bunches and would give rise to stimulated emission in forward direction of the electron beam flow. Electrons from an injector are feeding into an accelerator to electric field so accelerated to approximately the speed of light. One type of common accelerator for producing high-power free-electron lasers is the radio frequency linear accelerator. The producing Laser beams would be based upon micro pulses with typically of micro seconds with continues train of Pico second pulses. Free Electron LASER can design to operate with any desired frequency spectrum up to Visible range .There are researches going on to extend the range to the ultraviolet as well. .In Free electron Lasers, the laser beam is producing inside a vacuum cavity, so the beam quality is excellent. However technical challenges are existing both to scale existing kilowatt class type laser beam to megawatt powers and eventually build a laboratory device into a weapon grade Laser .This type of LASERS is the most complex than other type of Lasers likely suitable only for ground or ship board applications.

Fig 6 .LASER beams

VII. FREE SPACE OPTICAL (FSO) COMMUNICATION MODEL

Free space optical communications (FSO) networks involves with turbulent, scattering atmosphere as a communication medium for establishing optical wireless communication between sender and receiver. The Line of sight propagation (LOS) path has a variable from hundreds of meters up to tens of Kilometers. Consider the case of a visible and Infrared wavelengths, light propagation through the atmosphere affects by two phenomena, Absorption and Scattering of the air molecules, solid or liquid smaller particles that naturally exist in atmosphere. These are termed as aerosols such as dust, haze, mist, and fog. The power of signals could loss during trans mission and could be explained according to Beer's law [14],

$$P(z) = P_0 e^{-\epsilon z} \tag{2}$$

where P is the total power delivered for a surface located at distance 'z' from source and P_0 is the initial power generated by the beam director. The variable 'ε' represents the total extinction coefficient of light due to the different atmospheric phenomena absorption and scattering of the signals

$$\epsilon = \alpha_m + \alpha_a + \beta_m + \beta_a \tag{3}$$

where α represents to the absorption coefficient and β refers as scattering coefficient, while subscripts *a* and *m* denote the aerosol and molecular terms respectively. An increase in ε causes higher attenuation of laser light by the atmosphere. In order to calculate attenuations effectively due to the fog, smoke, dust, snow effects, mostly calculating by empirical approaches as they are convenient when approximation for

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complex and time attrition theoretical calculations based on micro models. Visibility range estimations is the most commonly using empirical model based on the establishment of visibility range estimate with the five percentage transmission threshold over the atmospheric path. Attenuation resulting from scattering phenomenon could be estimated by [13]:

$$\gamma(\lambda) \approx Ba \approx (17.35/V)(\lambda/550)^{-q} \quad (4)$$

where λ is transmission wavelength in Nanometer, V is visibility in Kilometers. Where q is the size distribution coefficient, and γ(λ) is the total extinction coefficient of fog and scattering related to size distribution of fog particles. The parameter q in (4) above depends on the distance visibility range and could be expressed by the following equation [11]:

$$q = \begin{cases} 1.6 \text{ if } V > 50 \text{ km} \\ 1.3 \text{ if } 6\text{km} < V < 50 \text{ km} \\ 0.16V+0.34 \text{ if } 1\text{km} < V < 6 \text{ km} \\ V- 0.5 \text{ if } 0.5\text{km} < V < 1\text{km} \\ 0 \text{ if } V < 0.5 \text{ km} \end{cases}$$

VIII. TRANSMISSION OF QUANTUM BIT ENCODED POLARISED PHOTON THROUGH MIST

A Attenuation of Polarized Photon through Mist

Communication transceivers are typically situated in terrestrial Free space optical communication scenario is in the troposphere. Troposphere is origin to all different kinds of weather phenomena and a very crucial role for communications in lower visibility range due to rain, snow, fog and clouds mainly. We could simulate rain fog, and snow attenuation effects using empirical models as mentioned in Equation below. Established over the visibility range estimate with a two percentage transmission threshold on the atmospheric path, attenuation resulting from scattering phenomenon could be estimated as below [13].

$$\gamma(\lambda) \approx Ba \approx (3.912/V)(\lambda/550)^{-q} \quad (5)$$

If we consider a five percentage transmittance threshold, then the fog attenuation coefficient is

$$\gamma(\lambda) \approx Ba \approx (17.35/V)(\lambda/550)^{-q} \quad (6)$$

$$q = \begin{cases} 1.6 \text{ if } V > 50 \text{ km} \\ 1.3 \text{ if } 6\text{km} < V < 50 \text{ km} \\ 0.16V+0.34 \text{ if } 1\text{km} < V < 6 \text{ km} \\ V- 0.5 \text{ if } 0.5\text{km} < V < 1\text{km} \\ 0 \text{ if } V < 0.5 \text{ km} \end{cases}$$

Fig 7. Different humid environments

Kim, Kruse and Al Naboulsi, radiation fog and advection models [10] are the most common empirical models available for the prediction of the fog attenuations from visibility range estimation empirically. Similarly, possible to interpret the snow attenuations of the optical communication signal by the visibility range with approximated well by the following empirical model Some typical values of terrestrial short range path attenuations for 650nm, 785nm, 1550 nm laser waves with corresponding visibilities are represented in following figures below [12], which was obtained from conventional Laser based propagation studies for conventional data transfer. These results are effectively converted for Quantum cryptography scenario in this paper. The intention of this section is for developing the various parameters like signal Attenuation, Data rate that is necessary for calculating the performance of the polarized photon based Quantum cryptographic link. We can consider situation of optical link between points in free-space over Earth surface. Consider a laser device of Quantum cryptography link sending a polarized light with total power PT at the wavelength 650nm, 785nm, 1550 nm. The signal power received (P_R) at the communications detector can be expressed as equation [12].

$$P_R = P_T \frac{D^2}{\theta^2 L^2} 10^{-\gamma L/10} \tau_T \tau_R \quad (7)$$

where D is the diameter of receiver, θ is the divergence angle, γ is the atmospheric attenuation factor in Decibel per Kilometer(dB/km), τT, τR are the transmitter and receiver optical efficiency respectively.

Table I shows the Attenuation of Polarized Photon through Mist and Atmospheric attenuation in Decibel per Kilometers (dB/km) as a function of visibilities for 650nm, 785nm and 1550nm.

TABLE I .SYSTEM PARAMETERS USED

parameter	Value		
	650 nm	785 nm	1550 nm
Transmitter optical power (mw)	5	20	70
Transmitter divergence angle (mrad)	1	1.5	3
Transmitter efficiency	0.5	0.5	0.5
Receiver sensitivity (dBm)	–20	–20	–20
Receiver diameter (cm)	10	10	10
Receiver efficiency	0.5	0.5	0.5

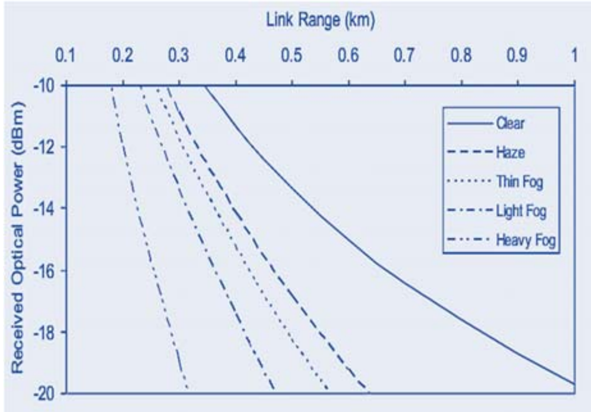

Fig 9. Link range versus Received optical power for 785 nm transmission

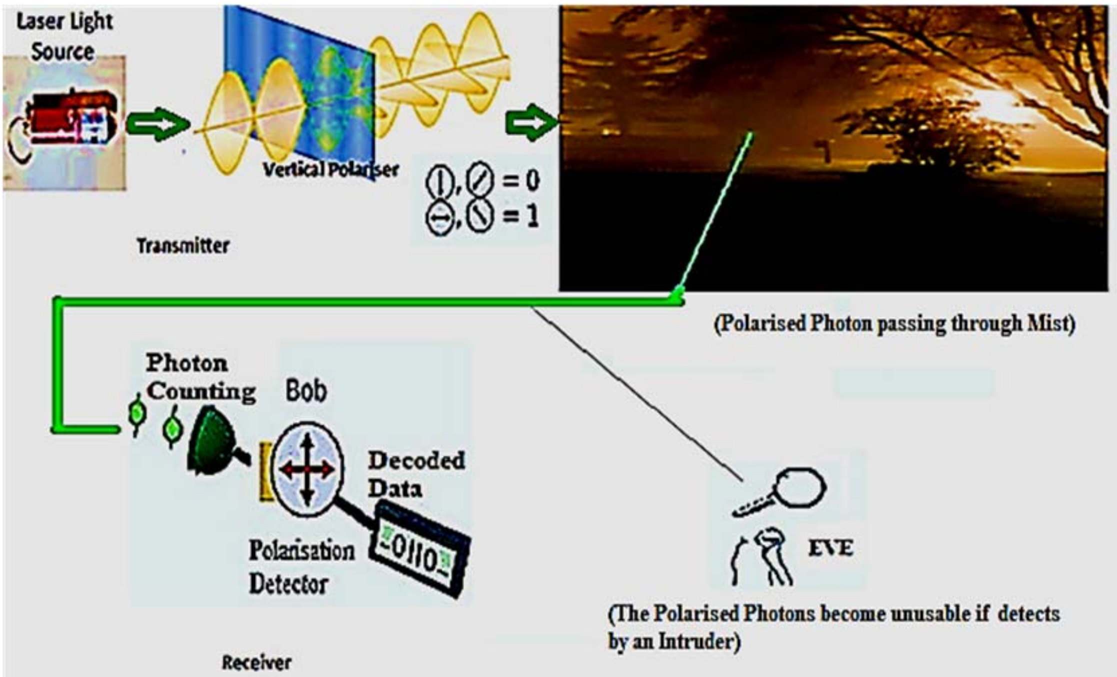

Fig 8 .Quantum key distributions through Misty and Fog environment.

The parameters using for sending of polarized photon in different atmospheric are represented here in table for 650nm, 785nm and 1550nm . Attenuation of polarized photon in different atmospheric conditions and received power as a function of visibilities for 650nm, 785nm and 1550nm can be represented as a graphical figures from previous conventional studies as following[13,14]

The attenuation coefficient alpha during snow is:

$$\alpha_{Snow} = \frac{58}{V} \qquad (8)$$

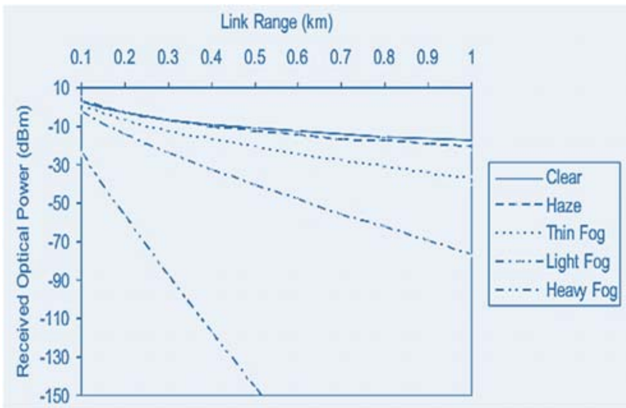

Fig 10. Link range versus Received optical power for 1550 nm transmission

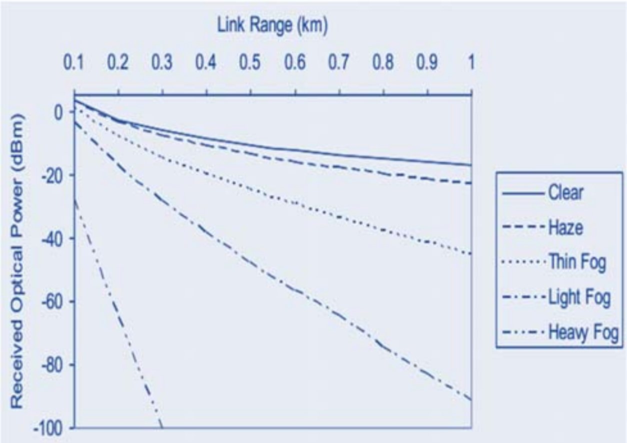

Fig 11. Link range versus Received optical power for 650 nm transmission

The above results are previously obtained from the conventional LASER propagation studies for conventional Data transfer. These results can now effectively could be converted for Quantum cryptography scenario. The intention of this paper is for developing the Photon count that loss during transmission and so can find out Data rate as well as probability of single polarized photon loss during Quantum key distribution. It is necessary for calculating the performance of the polarized photon based on its count in Quantum cryptographic link for efficient and secured data transfer

IX. CALCULATION OF POLARISED PHOTON TRANSMISSION COUNT OF 650NM,785NM, 1550 NM BEAM FOR QUANTUM KEY DISTRIBUTION FROM THE RECEIVED OPTICAL POWER

In Quantum cryptography we are using polarized photons to transport Data bits from one location to another. So loss of polarized photons during transmission can cause Data loss. Which can be explained as below, consider a beam of light with power of 5MW and wavelength of 620nm, we can calculate the energy of the photons in the beam, the frequency of the light wave and number of photons in the beam in one second for a 620nm light beam. This would be a high quality laser pointer at λ= 620nm wavelength. 5mW is 5 mJ per second, and each photon has an energy of:

$$E = hc/\lambda \tag{9}$$

$$E = ((6.62\times10^{-34}) \times (3\times10^{8})/620\times10^{-9})$$

where h is Plank's Constant, C is the speed of light.

Then we get:

$E=3.06\times10^{-19}$

The number of transmitted photons per second 'N' is:

N= Total Energy 'E' /given 'E'
$N= 0.005/3.06\times10^{-19}$
Number photons per second is $=1.63\times10^{16}$

We can calculate number of polarized photons that holds bit value loss during transmission based on power received as given in previous diagrams

Power(dBm)	Power(Watts)
-30 dBm	0.000001 W
-20 dBm	0.00001 W
-10 dBm	0.0001 W
0 dBm	0.001 W
1 dBm	0.0012589 W
2 dBm	0.0015849 W
3 dBm	0.0019953 W
4 dBm	0.0025119 W
5 dBm	0.0031628 W
6 dBm	0.0039811 W
7 dBm	0.0050119 W
8 dBm	0.0063096 W
9 dBm	0.0079433 W
10 dBm	0.01 W
20 dBm	0.1 W
30 dBm	1 W
40 dBm	10 W
50 dBm	100 W

Fig 12. dBm to Watts Conversion table.

A. Receiving polarized photons in different link range for 650 nm, when using in Quantum Cryptography

Polarized Photon loss or Data loss = Received Polarized Photon Count/Transmitted Polarized Photon Count, where Transmitted Polarized Photon Count is 1.63×10^{16}, so Data loss and Probability of single photon missing during transmission of beam 650nm as following table.

TABLE II. PHOTON COUNT IN 650 NM LINK IN DIFFERENT CLIMATE

Climate (Fog)	Link Range (Km)	Received Power (dBm)	Receiving Polarized Photon Count	Probability of a single polarized photon Arriving Receiver	Photon or Data Loss
Clear	0.5	-10	3.27×10^{14}	1/2	50%
Haze	0.4	-10	3.27×10^{14}	1/2	50%
Thin Fog	0.25	-10	3.27×10^{14}	1/2	50%
Light Fog	0.20	-10	3.27×10^{14}	1/2	50%
Heavy Fog	0.10	-30	3.27×10^{12}	1/100	99.9%

Polarized Photon loss or Data loss = Received Polarized Photon Count/Transmitted Polarized Photon Count
Where Transmitted Polarized Photon Count calculating from Fig.9 for 785nm

$E = hc/\lambda,$

$E = ((6.62\times10^{-34}) \times (3\times10^{8})/785\times10^{-9})$, Where h is Plank's Constant, C is the speed of light, then
$E = 2.53\times10^{-19}$
Number of transmitted photons per second 'N'

N= Total Energy 'E' /given 'E'
$N= 0.005/2.53\times10^{-19} = 1.98\times10^{16}$

Data loss and Probability of single photon missing during transmission of beam 785nm can be calculated as the following data given

TABLE III. PHOTON COUNT IN 785NM LINK OF DIFFERENT CLIMATE

Climate (Fog)	Link Range (Km)	Received Power (dBm)	Receiving Polarized Photon Count	Probability of a single polarized photon Arriving Receiver	Photon or Data Loss
Clear	0.35	-10	3.95×10^{14}	1/50	98.0%
Haze	0.28	-10	3.95×10^{14}	1/50	98.0%
Thin Fog	0.25	-10	3.95×10^{14}	1/50	98.0%
Light Fog	0.22	-10	3.95×10^{14}	1/50	98.0%
Heavy Fog	0.18	-10	3.95×10^{14}	1/50	98.0%

B. Received polarized photons versus link range for 1550 nm

Polarized Photon loss or Data loss = Received Polarized Photon Count / Transmitted Polarized Photon Count, Where Transmitted Polarized Photon Count calculated as below from(9)
$E = hc/\lambda$,

$E = ((6.62\times10^{-34}) \times (3\times10^{8})/(1550\times10^{-9}))$, Where h is Plank's Constant, C is the speed of light, then we gets $E = 2.53\times10^{-19}$

N= Total Energy 'E' /given 'E'
$N= 0.005/1.28\times10^{-19} = 3.90\times10^{16}$

Number of transmitted photons per second is = 3.90×10^{16}, so Data loss and Probability of single photon missing during transmission of beam 1550nm as following table

TABLE IV. PHOTON COUNT IN 1550NM LINK OF DIFFERENT CLIMATE

Climate (Fog)	Link Range (Km)	Received Power (dBm)	Receiving Polarized Photon Count	Probability of a single polarized photon Arriving Receiver	Photon or Data Loss
Clear	0.15	00	7.81×10^{15}	1/5	80%
Haze	0.15	00	7.81×10^{15}	1/5	80%
Thin Fog	0.10	00	7.81×10^{15}	1/5	80%
Light Fog	0.15	-10	7.81×10^{14}	1/50	98%
Heavy Fog	0.05	-10	7.81×10^{14}	1/50	98%

X. CONCLUSION AND FUTURE WORK

We have successfully calculated photon loss, which is significant in polarized photon transmission for Quantum cryptography link, when using in various type of atmospheric conditions like Mist Fog Haze. Also successfully calculated number of photons can loss during Quantum cryptography transmission with probability of single polarized photon loss. Also successfully utilized the Light transmission characteristics and power measurements through various Atmospheric conditions of previous work and converted to photon numbers. However this values have to be verified for Quantum cryptography link using polarized photons with suitable experimental setup.

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