ISSN: 2456–7698

RNI: UPBIL 04909

SRI JNPG COLLEGE

REVELATION

A JOURNAL OF POPULAR SCIENCE

Year 2023

Volume 8 Issue 1

A Peer reviewed and
Refereed Journal

VIGYAN PARISHAD

FACULTY OF SCIENCE

SRI JAI NARAIN MISHRA PG COLLEGE, LUCKNOW

About the Cover page:

The picture shows Vikram lander and Pragyan rover being transported inside ISRO for final launch.

(Source: ISRO www.isro.gov.in)

The Chandrayaan also known as the Indian Lunar Exploration Programme is an ongoing series of outer space missions by the Indian Space Research Organization (ISRO) for the exploration of the Moon. The program incorporates a lunar orbiter, an impactor, a soft lander Vikram and a rover spacecraft Pragyan.

There have been three missions so far with a total of two orbiters, landers and rovers each. While the two orbiters were successful, the first lander and rover which were part of the Chandrayaan-2 mission, crashed on the surface. The second lander and rover mission Chandrayaan-3 successfully landed on the Moon on 23 August 2023, making India the first nation to successfully land a spacecraft in the lunar south pole region, and the fourth country to soft land on the Moon after the Soviet Union, the United States and China.

The First Volume of the Journal was published in 2017. All issues thereafter have been digitally archived. For purchase: Contact Managing Editor.

The Journal is duly registered as an ISSN Journal No. 2456-7698 since 2017.

The Journal is duly registered as an RNI Journal No. UPBIL 04909 since 2017.

ISSN: 2456–7698 RNI: UPBIL 04909

SRI JNPG COLLEGE

REVELATION

A Peer Reviewed Refereed Annual Journal of Popular Science

Sri JNPG College, REVELATION
A Peer Reviewed & Refereed Annual Journal of Popular Science
Vol. 8, No. 1 (2023), ISSN : 2456-7698 RNI: UPBIL 04909

Contents

Sri JNPG College, REVELATION
A Peer Reviewed & Refereed Annual Journal of Popular Science
Vol. 8, No. 1 (2023), ISSN : 2456-7698 RNI: UPBIL 04909

Satellite Signal Range Dependence study of Functionalities and Technologies of a Quantum Internet in a communication system

M. K. Maurya[1*], Harsh Verma[2] S. K. Dewangan[3]

[1]Department of Physics, Rajeev Gandhi Government P.G. College, Ambikapur-497001, Chhattisgarh
[2]Department of Physics, Swami Atamanand English Medium Model College, Ambikapur-497001, Chhattisgarh
[3]Department of Physics, Shri, Sai Baba Aadarsh Mahavidyalay, Ambikapur-497001, Chhattisgarh

*Email: mahendrabhu@gmail.com

Abstract

In the communication system, the satellite signal range dependence of functionalities and quantum Internet technologies has been investigated. These technologies are depending on qubits, which are the future technology in the creation of considerably faster, more secure, and remarkable network technologies. Quantum networks have an advantage over regular networks in many ways because of the exceptional qualities of qubits which are superposition of qubits, entanglement of qubits, and teleportation of qubits. The effects of PSK modelling for quantum Internet technology, probability to quantum cryptography, interference probability with photon density, Signal to noise ratio and Noise to Loss in different quantum internet channel and repeater have been investigated. It is found the classical multiplexing techniques can be efficiently used to multiplex quantum signals without any deterioration in Secure Key Rates. It has also been observed that the quantum cryptography offers definitive security and the immense detection properties for secure communication. These properties can guarantee security for cyberspace in the future Internet and network technologies.

Keywords: *Quantum Internet, qubits, Quantum key distribution and entanglement*

Introduction

Quantum internet (QI) is a popular internet technology that allows quantum communication between faraway quantum devices or nodes using quantum bits (qubits). To overcome the restrictions caused by traditional interconnect technologies, such a system will work with the regular internet [1-2]. The internet has had a transformative effect on our society. The objective quantum internet is to initiate quantum communication between any two points or nodes, resulting in a new network technology [1]. This quantum internet will join the processors of quantum information in order to accomplish unmatched potentiality that is probably impossible to obtain with only the classical data. It will work in tandem along the "classical" internet that we are having and using today [3]. It's difficult to forecast all applications of the upcoming quantum internet, as it is with any completely new technology. Ultra secure communication, clock synchronisation, expanding the technologies of telescopes, secure identification, attaining effective agreement on remote data, and augmented computing are only a few of the key uses that have already been identified.[1, 3, 5].

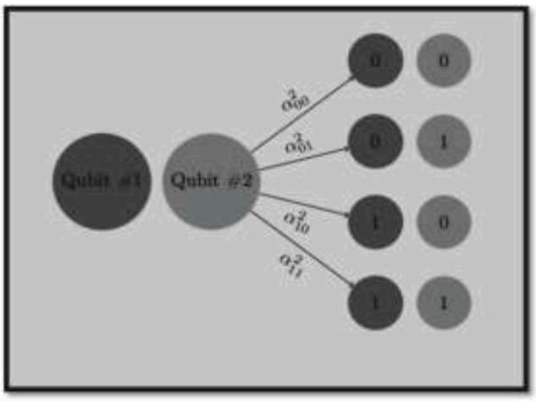

Fig 1:- Representation of Qubits

This novel erais runvia way of means of the legal guidelines of quantum mechanics, where in one of the legal guidelines states that it's miles not possible to degree assets of a machine without converting its state [5, 6-9]. Consequently, qubits can't be copied and any try toachieve thismight be detected, therefore making the conversationgreaterstable and private. Due to the remarkable residences of qubits, it offersanfacet to QI over conventionalin lots of ways [7, 8].Qubits additionally display bizarre phenomena of quantum entanglement, wherein qubits at far off nodes are connected with each other. This connection is more potent than it is ever feasiblewithinside the classical domain of network [2, 9]. Entanglement is intrinsically private, because itisn'tfeasible, due tothe property of no-cloning, for a 3rdqubitis entangled with both of the 2 entangled quantum bits [12-14]. And so, with this bizarre quantum property, quantum internetmay want to form a special galaxy having programs with world-transforming potential [2-5, 8, 15-20].

Theoretical Description

The destiny quantum Internet (QI) is predicted to interconnect quantum computers (QCs) a good way to gain unparalleled abilities which are not possible to gain via way of means ofthe usage ofbest classical facts. In a quantum community (QN), a quantum kingdommay be teleported over an arbitrarily lengthy distance, furnished that an entangled pair of debris is exchanged via a quantum channel, and a classical conversation channel is hooked up over the identical link. Through the QI, far off quantum gadgets can speak and cooperate to remedy computational responsibilitiesvia way of means of adopting a dispensed computing approach. In fact, as defined in, via the interconnection of more than one QCs, it's miles feasible to achieve a unmarried quantum tool with some of qubits that scales linearly with the quantity of far off QCs. Moreover, the QI ought toofferdifferent benefits, along with a close to ultimate community security [6-9]. The constructing block of each Quantum Signal Processing and Quantum Internet is the quantum bit, or qubit, describing a discrete -degree quantum kingdom. As extensively known, a classical bit encodes certainly considered one amongtogetherone-of-a-kind states – zero or 1 –being in best one kingdom at any time. Conversely, a qubit may be in a superposition of the 2 states, being so concurrentlyzero and 1 at a sure time. Hence, a qubit provide richer, greatercomplicatedpossibilities for factssporting and facts processing. And this quantum benefit over classical facts grows exponentially with the quantity of qubits. In fact, way to the superposition principle, n qubits can concurrently encode 2n quantum states at once. Differently, n classical bits can encode bestcertainly considered one among 2n feasible states at any time. In this article, we gift the preliminary results, primarily based totally on numerical analysis, to signify and compare the distribution of stablefacts to the subscribers via way of means ofenforcing the Quantum-to-the-Home (QTTH) idea. We have systematically evaluated the overall performance of the usage of (a) section encoded facts, that is, -PSK (in which = 2, 4, 8, 16, . . .), to generate quantum keys and (b) limits of the usage of a high-pace BHD, in phrases of digital and shot noise for commercially to be had coherent receiver to hit upon the CV-QKD signals.

Furthermore, the transceivers, noise equal power (NEP) contributions from analogue-to-virtual converter (ADC), and transimpedance amplifier (TIA) are modelled in line with the economic off-the-shelf (COTS) equipment. Both unmarried-channel and specifically wavelength department multiplexed (WDM) transmissions are investigated. We have additionally implemented (a) nearby oscillator (LLO) idea to keep away fromfeasible eavesdropping at the reference sign and (b) a section noise cancellation (PNC) module for offline virtual sign processing of the acquired signals. Moreover, we've got depicted the trade-of among the steady key quotescompleted and the cut up ratio of the get right of entry tocommunitythinking about the hybrid classical-quantum traffic. These preciseeffects will assist the human beings from teachers and enterprise to put into effect the QTTH idea in real-time networks. Furthermore, the designed gadget is power green and value effective. The schematic of the proposed simplified QTTH community with -PSK primarily based totally quantum transmitter (Transmitter) and LLO primarily based totally coherent receiver (Bob) is depicted in Figure 1. At Transmitter, a slender line-width laser is used on the wavelength of 1550nm having a line width of ≤five kHz permitting it to preserve low section noise characteristics [15-20].

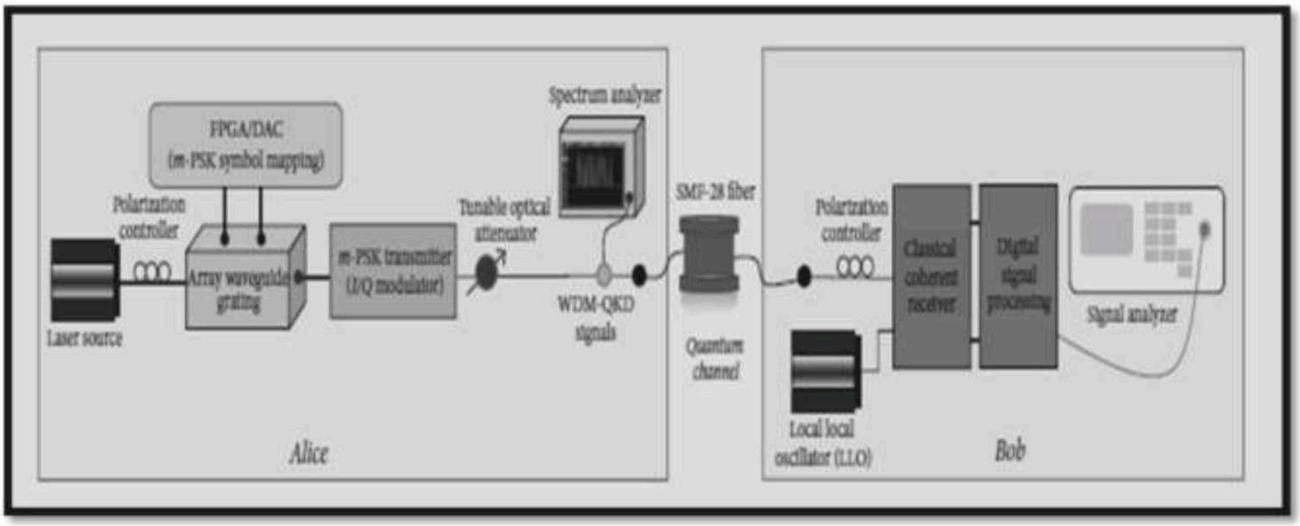

Fig2 :- Pictorial View of the *m*-PSK based quantum transmitter (abbreviated as Alice) and quantum receiver (abbreviated as Bob) for Quantum Internet applications

A. Mathematical model for above QTTH application is demonstrated below:-

Transmitter generates an arbitrary *m*-PSK symbols that can be enhanced from **pseudo-random binary sequence** (PRBS) at the transmitter section; that is, (ti), $(ti) \in \{-1, +1\}$. These arbitrary symbols are up converted through up converter to radio-frequency (RF) domain with analogous in-phase and quadrature signals that are denoted by $_E(ti)$ and $_Q(ti)$. Mathematically these components can be expressed as in[15-19]:-

$$S_E(ti) = E(ti)\cos(\upsilon_1 t) - Q(ti)\sin(\upsilon_1 t), \ldots\ldots\ldots(1)$$

$$S_Q(ti) = E(ti)\cos(\upsilon_1 t) + Q(ti)\sin(\upsilon_1 t), \ldots\ldots\ldots(2)$$

Here,

υ_1 is the Radio Frequency angular frequency. The output is then used as the input for next stage.

The obtained optical field can be expressed as:-

$$E(ti) = \{\cos[VS_E(ti) + \pi/2] + j\cos[A S_Q(ti) + \pi/2]\} \,.\, \sqrt{P_s}\exp.j\,[\upsilon t + \varphi_1(ti)] \ldots\ldots\ldots(3)$$

Where, V denotes the modulation index and P_s, υ & $\varphi_1(ti)$ denotes the power, angular frequency of the carrier, and phase noise.For calculating the modulation variance V_A of the optical signal, represented as shot-noise units (SNU), the parameter V and variable optical attenuator (VOA) are modeled. To simply the mathematical model further, the quantum channel loss is known as the attenuation of the optical fiber. More over, noise variance in channel is expressed as in:-

$$\chi_{line} = 1/G + \eta - 1, \ldots\ldots\ldots(4)$$

Where, G denotes the transmittance and η is the excessive noise. Practically, the noise contributions which aredescribed as SNUs, may originate from the imperfectmodulation, laser phase noise, laser line width, local oscillator fluctuations, and coherent detector imbalance .In this paper, the concept of a local local oscillator (LLOSC) has been used. It is a very intrinsicconfiguration to keep the Laser at the receiver, that is, in the receiver's side, to prevent any attempt of eavesdropping on the quantum channel to get the reference information of the incoming signal. The electric field of the LLOSC can be expressed as in :-

$$E_{LLOSC}(ti) = \sqrt{P_{LLO}}\,.\ \exp.j\,[\upsilon_{LLOSC}(ti) + \varphi_2(ti)], \ldots\ldots\ldots(5)$$

Where, P_{LLOSC}, $\upsilon_{LLOSC,}$ and $\varphi_2(ti)$ denotes the power, angular frequency, and phase noise of the LLOSC, respectively. The structure of the Bob comprises a 90^o optical hybrid and two balanced photodetectors. The coherent receiver has an overall efficiency of η and electrical noise of V_e. Practically, V_e comprises electrical noise from transimpedance amplifiers (TIAMP) as well as contribution from the analog-to-digital converters (ADCs). The receiver added noise deviation can be expressed as in :-

$$\chi_{de} = (2 + 2V_e - \eta)/\eta, \ldots\ldots\ldots(6)$$

where, η is efficiency and V_e is electrical noise.

Furthermore, the total noise variance of the system, including Transmitter and Bob, can be expressed as in :-

$$\chi_{system} = (\chi_{line} + \chi_{de})/T \ldots\ldots\ldots(7)$$

Entangled Qubit Signal Processing :-

Traditionally, a very high-powered local oscillator is necessary to detect delicately powered incoming quantum signals. It's critical to use a oscillator locally with a short line width so that laser variations don't contribute to excessive noise in the system. Moreover, having a little-complexity digital signal processing (DSPR) module, such as the phase noise cancellation (PNCN) method, will aid the coherent receiver. After the balanced photodetectors, the photocurrents of the in-phase and quadrature signals must be correctly monitored as a precondition for the PNC module. They can be stated mathematically as in:-

- $$i_I(ti)\ \alpha\ \sqrt{2}\cos[\{(\upsilon - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti) + \pi/4\} - VI(ti)\cos\{(\upsilon + \upsilon_1 - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti)\} + VI(Q)\cos\{(\upsilon + \upsilon_1 - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti)\}] + n_i, \ldots\ldots\ldots(8)$$

- $$i_Q(ti)\ \alpha\ \sqrt{2}\sin[\{(\upsilon - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti) + \pi/4\} - VI(ti)\cos\{(\upsilon + \upsilon_1 - \upsilon_{LO})ti + \varphi_1(ti) - \varphi_2(ti)\} + VI(Q)\cos\{(\upsilon + \upsilon_1 - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti)\}] + n_q, \ldots\ldots\ldots(9)$$

Where ,n_i and n_q define the in-phase and quadrature units of the additive phase noise that needs to be indemnified. We have rigged the phase noise cancellation(PNC) algorithm . By joining the squares of the inphase and quadrature units of photocurrents and cancelling the DC unit, the final result can be described as :-

- $i_S(ti)\ \alpha\ 2\sqrt{2}\,AI\,(ti)\cos(\upsilon_1 t - \pi/4) + 2\sqrt{2}\,AQ\,(ti)$

$$.\cos(\upsilon_1 t - \pi/4) + 2\sqrt{2}\,[\,ni\,.$$
$$.\cos\{(\upsilon - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti) + \pi/4\}\,nq$$
$$\sin\{(\upsilon - \upsilon_{LO})t + \varphi_1(ti) - \varphi_2(ti) + \pi/4\}\,]. \quad \ldots\ldots\ldots\ldots(10)$$

The final step in the Digital signal processing module is to downconvert the RF signal. The conclusive in-phase and quadrature components can be expressed as in :-

$$R_i = LPFT[\,i_S(ti)\cos(\upsilon_1 t - \pi/4)\,] = -\sqrt{2}\,AI + n'_i, \ldots\ldots\ldots(11)$$
$$R_q = LPFT[\,i_S(ti)\ \sin(\upsilon_1 t - \pi/4)\,] = -\sqrt{2}\,AQ + n'_q, \ldots\ldots\ldots(12)$$

Where n'_i and n'_q are the correspondent additive noise that is added during the transmission and detection processes prior to Digital signal processing module. By mentioning it is concluded that the original *m*-PSK signals can be identified without any phase andfrequency distortions.

Results and Discussion

Qubit Entanglement

The entangled network dynamics architectures and entanglement flux in the quantum Internet technology are quantified using an analytical model developed here. The interpetive solutions of the model characterise the stability and fluctuation properties of entangled quantum networks, as well as the flux of entangled dynamics within the entangled network architectures. Because the suggested conclusions are unaffected by existing physical implementations, they can be used in the composite architecture of a universal-scale quantum Internet.

Fig 3 shows the relation between entanglement rate to the distance. Computed Quantum Key Distribution secure key rates as a function of transmitting distance for 4-PSK and 8-PSK modulation. The results conclude that the classical multiplexing techniques can be efficiently used to multiplex quantum signals without any deterioration in the SKR (Secure Key Rates). The peak of 100Mbits/s SKR can be achieved with this structure by employing transmittance modules for transmittance (T) = 1 for 4-PSK modulation method, while SKR are ≈25Mbits/s & 1Mbit/s at T= 0.8 and 0.6, respectively.

From the graph it can also be resulted that the maximum transmitting range for QKD (Quantum Key Distribution) based on network is 60 km. Hence it is suggested that this QKD protocol can be used for access network, that is, QTTH technology. Based on the above-defined values, we further studied to calculate the secure key rates (SKR) at different transmission that to achieve successful transmission of Qubits, the distance must be kept as low as possible and repeater must be used at each node where qubit reception at full potential takes place.

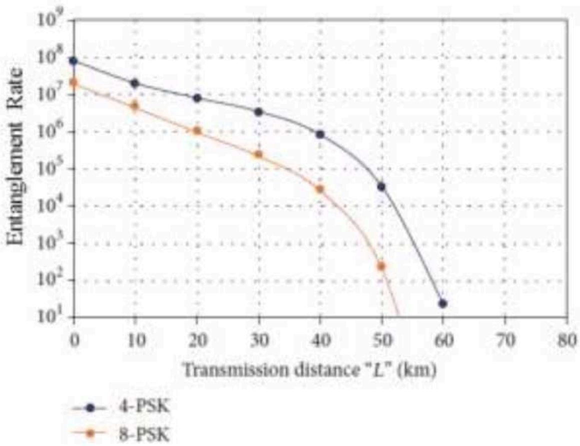

Fig 3:- Entanglement rate of Qubit to distance in Km

Probability of Quantum Cryptography

Sender and Receiver alternate records in public channel. In order to make sure confidentiality, their recordsis encrypted, however they can'tsave you an attacker from eavesdropping at the channel. Moreover, due to the traits of the tool itself, the eavesdropper cannot be detected whether or notit's miles in cable communications or in optical fiber communications. In cable type communications, the listener can use a multimeter or an oscilloscope to monitor the signal. In optical fiber communications, the eavesdropper or hearer can get records from part of the mild signal. It is to be noted that the fiber loss is prompted with the aid of using environmental factors, which includes thetemperature and pressure, which causes the loss due to eavesdropping which is no longer be anticipated. In quantum networking, the eavesdropping is positive to be identified, attributable tothe quantum no-cloning theory. To evaluationsafety of QKD signals, we are listing the encoder values of quantum records and the sizeconsequencesbelowspecificsize bases in Table. The events agree earlier that theindirect downwards polarization and the horizontal polarization represents "1" at the same time as the vertical and indirectupper polarization represents "0."

Fig. 4 represents the eavesdropper being detected when it eavesdrops on the channel in different probability. In this picture, the blue line shows that the raider monitors the channel in the probability of 100% whereas the red line and the yellow line shows that the raider monitors the channel in the probability of 50% and 20%, respectively. From these three curves, we can see that in spite of probability of the eavesdrop monitoring the channel, the probability of it getting detected is nearly 100% as the number of transmitted bits is increasing. From the above consideration, we can conclude that the quantum cryptography offers definitive security and the immense detection properties for secure communication. These properties can guarantee security for cyberspace in the future Internet and network technologies.

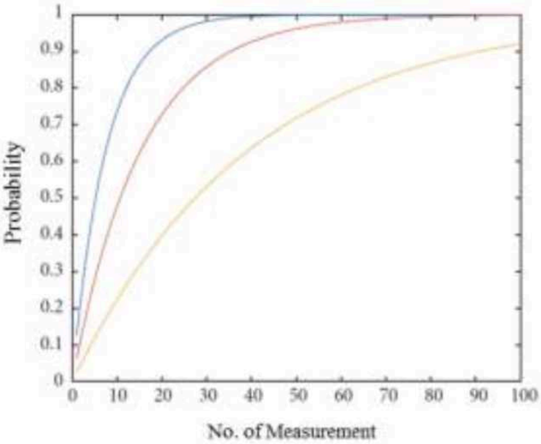

Fig 4:-Probability graph

Signal to Noise Ratio

Technologies for space-primarily based totally optical hyperlinkswereevolved over numerousa long time and are gettingtailored thatoffer laser communications structures regarding small spacecraft primarily based totally on Quantum Internet. In many cases, the statistics sign isn't always vibrant sufficient to additionally offer a supply for detecting and monitoring; hence, commonly a distinct "beacon" collaborated with the statisticssign is applied. In this case, the receiver can setup its vector to the incoming "beacon" and holdmonitoringamong the nodes. A very high electricity laser type diodes are commonly used as "beacons". Typical laser communications structures shows rough and best pointing functionality and, relyingat the applications, a factorin advance structureto persuading optical beam among the terminals. The function of receiver (slave) is thought with an uncertainty constrainedwith the aid of using the uncertainty withinside the GPS statisticspresenting its function information.

Fig.5 represents a plot of the signal as a function of range between the two spacecrafts, where the beacon laser is emitting radiation at a maximum Power output of 0.25 W and the frame rate is set to 25 fps with an integration time of 100 μs. The Signal to Noise ratio of the beacon channel remains above 10 for separation distances approaching 100 km.. A lower power setting can be selected at these distances.An estimate equal to 1 × 10−4 is produced due to RMS pointing error ratio between the loss in beacon signal and the probability of burst errors(PBE) as a function of beam width. To raise the operational range for the system and lower the PBE even further, a higher power beacon laser can be considered or longer integration times. The initial concept of operations foresees QKD only being performed while the spacecraft is in eclipse to avoid noise from stray light.

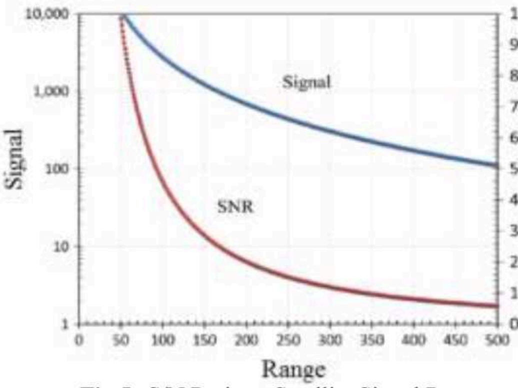

Fig 5:-S/N Ratio to Satellite Signal Range

Noise and Loss Relationship

A specific number of elemental links in a connected quantum repeater chain that creates a 4-qubit 4-photon elemental link state using frequency-division multiplexing and a linearity at one given frequency over 2 qubits. After connecting the optical , we solved the qubit accurately. The memory of the repeater node announced that the deformation of the logistic map can be accurately solved from the chaos theory. By expressing the quantum state, we determined the quantity such as the success probability of entanglement exchange. The central problem of the quantum internet is the theory of deriving the stability of quantum repeaters and maximizing the entanglement rate in entangled network structures.

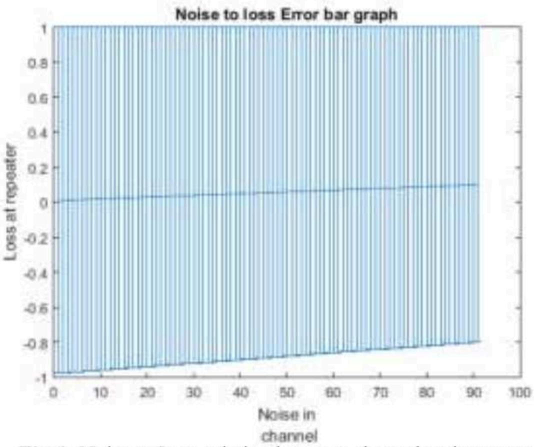

Fig 6:-Noise to Loss relation between channel and repeater

Fig.6 shows an error bar graph plotted between the loss of photons at the repeater nodes v/s noise present in the classical channel made for secure transmission of quantum signals with respect to the Quantum Key Distribution (QKD). As it can be seen from the above graph that as the noise present in the channel increases, the loss at the repeater nodes also gradually increases. The classical link between the nodes is the real cause of noise and this noise produces loss at the end nodes.

At present it is a bit tough to transmit Quantum signal from one point to other and hence a classical link is made to make proper exchange of signals between the end nodes. Noise can be considered the natural enemy of quantum information. Until now, it has always stood in the way of quantum communication outside of research laboratories. This is because one of the most important quantum phenomena, entanglement, which is characterized by strong correlations between particles over arbitrary distances and forms the basis for the advantages of quantum communication over conventional methods, is considered to be particularly susceptible to any disturbances from the environment. Even a minor interaction with the environment can lead to the destruction of entanglement.

Interference Probability

The probability of loss of qubits between sender and receiver also depends upon the interference (mainly due to eavesdropper) at the repeaters, where qubit entanglement is achieved. The graph shown below represents the probability of detection v/s the number of Photons measured.

Fig.7 represents the probability of the eavesdropper being detected in noise-free channel. From the graph it is clear that when the number of transmissions exceeds the value 40, the probabilities of the eavesdropper is near to 100%.I n quantum communication, the eavesdropper is definitely detected.

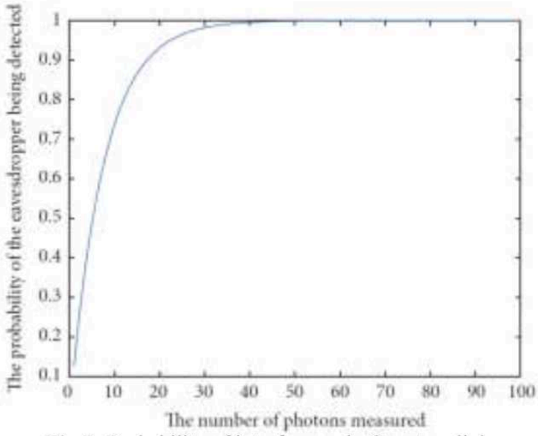

Fig 7:-Probability of interference in Quantum link v/sNumber of Photons Measured

Conclusions

PSK modelling dependence quantum Internet technology, probability to quantum cryptography and with photon density and Noise to Loss in different quantum internet channel and repeater in a optical communication system has been investigated. The quantum Internet provides a sufficient response to the processing power made available by quantum computers. The dynamics of the quantum Internet's entangled network architectures were examined and quantified in this paper. To enable robust quantum communications, we demonstrated the stable states of entangled network designs which determined the impact of noise on the stable states of the entangled quantum network. We recognized the characteristics of weak and strong type entangled quantum Internet structures and thereby calculated the effective consequences of local network entanglement justification in the quantum Internet's global quantum network structure. The model can be used in a global-scale quantum Internet's heterogeneous experimental architecture as it is independent of actual physical implementations. Although progress has been made in the construction of quantum networks, the current state of the art pales in comparison to what is needed to implement advanced network protocols in a reliable and scalable manner,whether it's for a short or long distance Quantum memory, local quantum computation, quantum repeaters, and error-corrected teleportation are all lofty ambitions. Nonetheless, there is a lot of work being done to achieve these goals all around the world.

References

1. S. Wehner, D. Elkouss, and R. Hanson, *Science,* **362:** 6412 (2018).
2. R. Van Meter, *IEEE Network*, **26:** 59 (2012).
A. K. Ekert, *Physical review letters*, **67:** 661 (1991).
3. H. E. Brandt, *Progress in Quantum Electronics*, **22:** 257 (1999).
4. L. Gyongyosi and S. Imre, *Computer Science Review* **31:** 51 (2019).
5. M. A. Nielsen, I. Chuang, and L. K. Grover, *American Journal of Physics*, **70:** 558 (2002)
6. J. F. Fitzsimons and E. Kashefi, *Physical Review A:* **96**: 012303 (2017)
7. J. Shen, J. Shen, X. Chen, X. Huang, and W. Susilo *IEEE Transactions on Information Forensics and Security,* **12:** 2402 (2017)
8. L. Gyongyosi, S. Imre, and H. V. Nguyen, *IEEE Communications Surveys & Tutorials*, **20:**1149 (2018).
B. Monroe, M. G. Raymer, and J. Taylor, *Science*, **364:** 440 (2019)
9. L. Gyongyosi and S. Imre, *Computer Science Review*, **31:** 51 (2019)

10. A. K. Ekert, *Phys. Rev. Lett*. **67**: 661 (1991).
11. N. Promwongsa, A. Ebrahimzadeh, D. Naboulsi, S. Kianpisheh, F. Belqasmi, R. Glitho, N. Crespi, and O. Alfandi, *IEEE Communications Surveys & Tutorials*, (2020).
12. V. Scarani. *Rev. Mod. Phys*. **81**: 1301 (2009).
13. E. Biham, B. Huttner, T. Mor, *Phys. Rev. A* **54**: 2651 (1996).
14. S. L. Braunstein, S. Pirandola, *Phys. Rev. Lett.* **108**: 130502 (2012)
15. H.-K. Lo, M. Curty, B. Qi, *Phys. Rev. Lett*. **108:** 130503 (2012).
16. M. M. Wilde, Quantum Information Theory, *Cambridge Univ. Press*, (2013).
17. C. Branciard, E. G. Cavalcanti, S. P. Walborn, V. Scarani, H. M. Wiseman, *Phys. Rev. A* **85:** 010301 (2012)
18. A. Gilchrist, N. K. Langford, M. A. Nielsen, *Phys. Rev. A* **71:** 062310 (2005).