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Quantum Optical Communication

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Special Assignment : Optical Devices and Network

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1 Introduction

The last decade has observed the major shoot up in data traffic. The 5G is already in deployment phase and the research for 6G and more innovative future networks have already commenced. The Quantum computation and information are predicted to be a game changer in computing and telecommunication industry. Just exploiting the special quantum features of materials we can achieve new innovative ways of computation, information and communications.

The radio spectrum is broadened to millimeter wave and Terahertz band communication in order to provide terabit-per-second on communication link. Factors like high propagation loss, low power of millimeter wave curb the distance communication.

The current electronics technology is facing a fundamental limitations where the transistors are shrinking less than the size of the atom. Due to this reduced size of transistor to the level comparable to the size of charge carrier hence arising new quantum paradoxes and dilemma, such as Quantum tunnelling etc. Hence it is believed that the electronic technologies will be complemented by Quantum Optics.

The Fibre optic or Telecommunication optics have been employed mainly for wavelength transmission, however the Quantum optic is a proficient technique to transmit and control the optical signal with with a greater number of degrees of freedom.

2 Qubit

The Quantum bit (Qubit) just like a classical bit is used to represent the information in classical computer is used to represent information in Quantum computer. Unlike classical bit which only stores the ’0’ or ’1’, Qubit can store information as ’0’, ’1’ or a superposition of ’1’ and ’0’.

$$q = |0\rangle \tag{1}$$

$$q = |1\rangle \tag{2}$$

$$q = a\,|0\rangle + b\,|0\rangle \tag{3}$$

The eq-3 shows the superposition state of the Qubit, the 'a' and 'b' are complex numbers and are as shown;

$$|a|^2 + |b|^2 = 1 \tag{4}$$

This superposition state is what makes the Qubit special, due to superposition the Qubit can store more data. A N-Qubit system is equivalent to 2^N classical bits. (30 qubit is 10 teraflops of computing power).

2.1 Photon as Qubits

The Quantum optics addresses quantum state with multiple quantum degree of freedom. For example each mode of electromagnetic field can be considered as an distinct quantum degree of freedom. This distinct set of modes open possibility of considering the same quantum state from different perspectives: a given state can be entangled to one basis and factorised to another. Hence Qubits can be encoded into a photons degree of freedom, for example polarisation and orbital angular momentum.

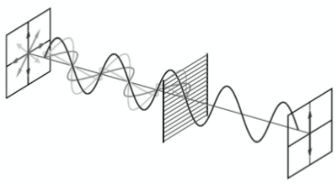

Figure 1: Example of Polarization of light

The Advantages of using photon for qubits are;

- Weak interaction with the environment thus reducing risk of decoherence.
- Can be controlled with standard optical instruments.
- High speed Low loss transmission through long optical and radio channels.

3 Entanglement

Quantum Entanglement is the essential resource building the backbone of Quantum technologies, quantum communication, quantum networks and quantum computation. It is a quantum phenomenon in which the quantum states of two or more objects have to be described with reference to each other, even through the individual objects my be spatially separated.

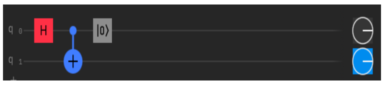

Figure 2: Entanglement using CNOT gate

Simulation of Quantum Entanglement on IBM open Quantum cloud computer. Figure 2 shows a two qubit system. The Hadamard gate on the qubit 'q0' help achieve the 'q0' to superposition state. the CNOT gate is used to entangle the qubit 'q1' to 'q0'. As result we can observe that after entanglement setting the 'q0' to '0' sets 'q1' to '1'. Hence suggesting that this qubits have successfully entangled.

Quantum entanglement allows qubits separated by incredible distances to interact with one another instantaneously. The mechanism of this "spooky action at a distance" is yet not explained by any theory, however this and superposition create an enormously enhanced computing power.

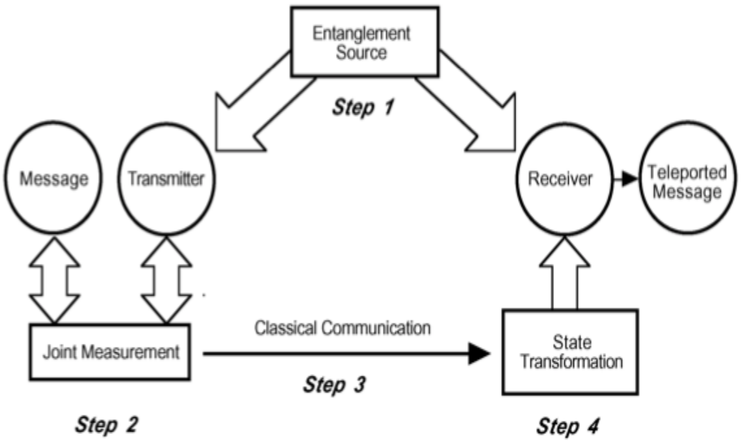

Figure 3: Teleportation of photon state

The Fig.3 shows a block diagram for a basic quantum communication link incorporating a classical communication link. For Teleportation of the photons state the quantum entanglement is an essential feature. Hence feature of Quantum entanglement can be exploited in communication faster than speed of light.

4 Quantum Key Distribution (QKD)

It is the simplest application of quantum information in the field of secure communication. This protocol enables two parties to share a randomly produced secret key only known to them which can be applied for encryption or decryption of the information.

The most common example of QKD is suppose there are 2 parties A and B. Both the parties employs a single photon which is randomly polarised to states encoded as ones and zeros to transmit a series of random number sequences which will be used as cryptographic keys.

The link between 'A' and 'B' can be Quantum and Classical channels. If 'A' generates a random stream of qubits which will be delivered to 'B'. The presence of eavesdropper is detected by an imperfect correlation between the two lists of bits obtained after the transmission of the keys between the emitter and the receiver.

Hence it can it can be seen that the fundamental principle behind QKD is that a quantum state cannot be replicated exactly and the states get altered in process of replicating them. The QKD can be implemented with both Quantum and classical communication links. The QKD is already in testing phase and is applied in following classical links;

- Long Distance Fibre Optic
- Satellite communication
- Free Space Fibre Optic
- Wireless links

5 Optical Access Network

Access network is a type of network which connects their subscriber to their immediate service provider. Optical Access network are typically called Fibre-to-the-x (FTTx). The 'x' can be home, building, curb and node. The most common topology used in optical access network in ring or tree or combination of both. The link can be Point to Point(PTP), Point to Multi-Point(PTMP) to analyze the efficiency of integrating QKD.

The architecture of QKD network is similar to a classical link. The only difference is the signal power and the method of encoding information. The Quantum Information is encoded on the quantum signal with only one photon per bit corresponding to a pulse energy of $1.28x10^{-19}$J at 1550 nm. Using quantum dots single photons can be generated without any partner photon. Photon statistic of such heavily attenuated have Poisson distribution. However the quantum dots technology is still in its premature phase and hence strongly attenuated pulses are employed. The rate of nowadays QKD systems is 10MHz. In recent experiment it was observed that using better detection scheme rate of GHz level was achieved.

Considering all the research and the study underway a new innovative system is necessary to implement QKD in access network. Standard passive optical networks(PON) are the nearest eligible model for QKD transmission as no optical amplification is needed for distance of 20km. The link can operate at one of the telecommunication wavelength in range on 1550 nm which provides minimum loss of 0.2db/km.

The figure 4 represents a schematic of a simplified phase-encoding QKD system. The synchronisation is provided by the 10MHz rubidium clock. After passing through transmitter(alice's) encoder the optical signals are attenuated to single-photon level and is coupled into the spool of 202km single mode optical fibre. Transmitter(Alice) and receiver(Bob) encode information and choose measurement basis by applying phases to the photon appropriate to the BB84 protocol using their respective fast electro-optic phase modulators. Alice only modulates the phase of the part of the wavepackect that travels through her phase encoder, while bob modulates the phase of the part that look the short part.

Typically in such phase encoded system the half of the transmitted signals yield no information, which might be due to photons are either delayed or advanced by few ns. This creates a problem for detectors, such as TES, the lack sufficient timing resolution to discriminate the different time of arrivals. Hence using novel switching timing resolution at input of bob's interferometer to eliminate these amplitudes. This allows the TES to be used in the system and doubles the implementation efficiency of a phase encoded system.

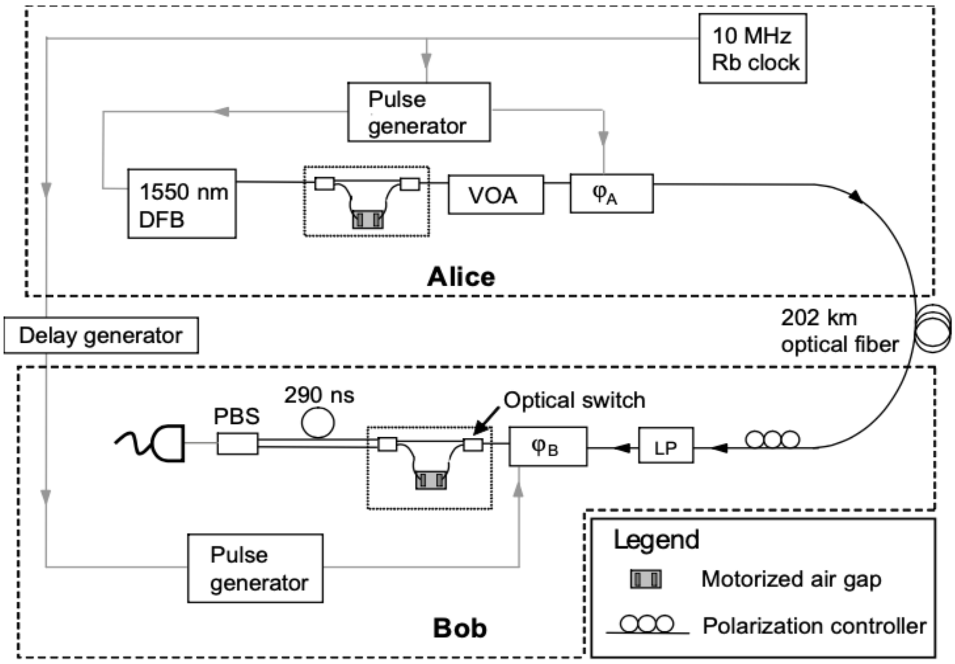

Figure 4: Simplified schematic of phase-coding QKD system. LP = linear polarizer; VOA = variable optical attenuator; PBS = polarizing beam splitter; DFB = distributed feedback laser.

6 Conclusion

This report discusses the fundamentals of Quantum mechanics applied in computing and information and discusses recent implementation of QKD, a first step toward exploiting quantum properties for computation. currently this task are carried out on classical communication system, however creating a quantum communication model and using the quantum computing the model would work at its true and finest potential.

Quantum realm is yet under study and there are many concepts and phenomenon which are mysterious however with time and experiments this phenomenon will be studied and successfully implemented and will be applied in day-to-day life.

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