Introduction to Satellite Quantum Transmission Networks and Handover Inter-Domain Systems for World Coverage Communications*

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Abstract

During the last decades, quantum cryptography has been a subject of information security and rapid communications progress. It is extending into devices industry and commercial products. Quantum satellite transmissions have a great potential to become the key technology for assuring the confidentiality and the privacy of the communications in the future commercial networks for a world-width coverage, and thus, to become the driver for the success of the military services, the field of banks, and many others domains. In cellular access networks, the user mobility is a serious problem. Generally, users may, during the same call, go through several different base stations, which generate the mechanisms of inter-cell handover or intra-cellular handover. In order to guarantee the higher reliability in quantum information, it is necessary to use the satellite technology in long distance transmission systems.

In the present research, free space quantum satellite theory is proved and the scheme of quantum constellation based on handover inter-satellite domain is presented. Based on the several schemes of quantum repeating, a novel idea and new quantum satellite communication system is presented and discussed. The main goal of the present research is to present different scenarios and requires the necessary material in the satellite and base station for securing the information or the transmitted signal between the users.

Keywords

Quantum communications, Quantum Satellite transmission, Hand-over Inter-satellite Domain

1. Introduction

Quantum communications [1] as a broad technological field, are gaining an increasing interest. They have come out from a purely fundamental quantum physics research area to an applied science with huge potential economic impact. The most promising application, quantum cryptography, has been demonstrated in various scenarios, and initial systems are already commercially available.

A fascinating technological challenge is the establishment of a quantum communication network, which eventually allows quantum communication on a global scale. Most existing implementations of quantum communication schemes are based on the transmission and detection of single photon or entangled photons pairs. With the present technology, the distance that can be bridged is limited, basically by atmospheric attenuation and detected background noise, to some hundred kilometers for both fiber systems and free-space transmission through the atmosphere near the Earth's surface.

These limitations could be overcome by the use of space and satellite technology [2]. Namely, inter-satellite link technology [3] Polarization-encoding is currently one of the most widespread realizations of photonic qubits [4], which utilizes two orthogonal states of polarization to encode information onto the optical mode of a single photon. Since the atmosphere does not affect the polarization of photons, then, it is the suitable system for free-space quantum communication schemes. In order to establish a

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quantum communication protocol between two sections, a system is needed to send the single photon emitted by the source onboard the satellite to the ground station, where the receiver is located [5].

This is achieved thanks to the satellite and cryptography team in the LSIACIO laboratory in University of Constantine 1, and thanks to the sets of work of my end-of-cycle Master students. In this article, a simplified pattern with two planes is considered: the first one, on the satellite side. The satellite sends the photons to the ground station whatever its position in the sky. While the second one, on the ground station. It receives the photons and, wherever they come from, sends them to the polarization analysis device [6].

2. Quantum Satellite transmission statement

The use of satellites for the quantum distribution is our objective (see figure 1). The transmission of photons using satellites can be considered as a solution for long distance transmissions [7]. This principle has overcome the limitations of Earth-related technology, namely, the range of about 100 km provided by optical fibers [8].

Quantum scenarios involving some problems based on Earth allows sharing quantum transmission between the ground station and the satellite, between two ground stations, or even between two satellites, and thus communicates with terminals using such quantum communication protocols. In the simplest case, a direct uplink to a satellite receiver can be used to perform quantum key distribution (QKD) between the transmitter and the receiver station.

Figure 1: The Satellite constellation networks.

We will start by presenting the frequently used methods for quantum cryptography, including the advantages and disadvantages of each in practical applications based on BB84 protocol [4]. The maximum scale of current quantum communications systems is limited by the fact that optical fibers amplifiers would destroy the quantum key coherence of a single photon and cannot be used in large free space kinds of systems [8].

One potential solution to this problem is the transmission of the single photon in free space, which would allow a global coverage system for quantum transmissions based on a network of satellites and ground stations. Free-space with applied quantum systems of that kind of photonics transmission has now been demonstrated over relatively short distances [9].

The idea of quantum satellite systems can also be extended using handover quantum repeaters that make use of entanglement swapping, and quantum teleportation [10]. These same techniques could also be used to implement a secret key for the transmission of qubits from base stations to satellite, or from satellite to another. The practical challenges that will have to be met in order to implement quantum satellite repeaters and quantum teleportation over large distances will be discussed.

3. Principal Operation for Quantum Satellite Communications

The establishment of quantum communications in space and, subsequently, its use for fundamental quantum physics experiments and quantum communication applications requires three experimental operations [11]:

- `Operation I` : Creation and detection of qubits (single photon) via an optical space link (see figure2). From an application point of view this achievement method would already allow to perform Quantum Key Distribution based on single photon algorithm transmission.

Figure 2: The Optical space link in the satellite.

- `Operation II` : Establishment of entanglement (classical correlations via shared entangled particles) between the communicating sections. This includes the ability to detect single qubits synchronously at the spatially separated locations of the communicating sections. At this stage already the most fundamental experiment in quantum physics (QKD based on entangled qubits).

- `Operation III`:Analysis of independent qubits. For the case of photons, the most efficient scheme relies on two-photons interferometer at a beam splitter. Technically, the arrival time of the photonic qubits at the receiver module has to be synchronized such that photons wave packets overlap at the beam splitter within their coherence length. If this problem is solved, all advanced quantum communications and computation protocols such as quantum-state teleportation or quantum dense coding could be implemented. .

4. Quantum Objective in Satellite Transmission

In today's quantum communications systems, there are two major issues under consideration, that are the need to extend transmission and control distance, and even more to increase throughput which is key in secure communication [12]. As it was suggested above, the desire to extend the transmission distance is to focus efforts on satellite-based free space communications systems. Thus, the purpose of this work is to obtain long-distance satellite-based free space quantum communication with better secure communication bit rate by pursuing the following specific objectives [11, 13]:

- Create a mathematical model to control the performance of the BB84 and/or BB92 protocol in quantum satellite communication links between a ground station and a satellite in low Earth orbit (LEO), taking into account the different atmospheric attenuation parameters.

- To develop a suitable theoretical model in order to investigate the physical layer limitation of the satellite vibration in satellite-based quantum optical communication systems.

- To compare the performance of a single photon pulsed polarization based BB84 signal for the satellite-based free space quantum optical communication links between a ground station and a satellite in a LEO, against individual eavesdropping attacks.

- The use of handover inter-domain satellites using quantum photonic transmission (single photon transmission) offers a typical solution for long-range quantum communications networks. This overcomes the main limitations of the terrestrial technology, i.e. the range of the order of 100 km offered by both optical fiber and free space terrestrial links.|

5. Scheme of quantum constellation based on handover inter-satellite domain

The use of LEO satellite constellations, as global communication networks [3], has known a large diffusion, not only in the services but in large scale communication networks as it is possible to communicate wirelessly at any point in the globe [14]. In recent years, cellular satellite communications have achieved great importance through Low Earth Orbit (LEO) satellites and GEO satellite orbit [15]. The general system components are shown in a figure 3.

The communication system allows the optical link between two terminals mounted respectively on a LEO satellite which is in a low earth orbit (LEO) and a dedicate other satellite which is in a geostationary one (GEO), the distance between the two terminals is about 45,000 km (in the worst case). The mission scenario foresees an optical link from LEO to GEO /or LEO to LEO and an optical link and/or from GEO to ground station. Our objectives with this scheme are coupled quantum cryptography transmission or BB84 protocol with the main survey of networks by a demonstration of satellite constellations constitutions and the different interfering factors: the satellites number in each orbit, modeling the handover problems or different handovers satellite probability (blocking) In order not to lose the information, to make sure to maintain the communication uninterrupted between two satellite zones, the handover inter-domain should be continuously present in satellite networks [16].

While, the realization of such schemes is a routine work in our laboratory, non-trivial problems emerge in long-distance applications. At present, the only suitable system for long-distance quantum communication is photons. The essential work carried out in our research laboratory propose approaches in the software development of implement Quantum Key Distribution (QKD) Networks with LEO satellites and reduce the telecommunication interruption risks and this will provide, indeed, a better communication quality and to make sure of data information security with quantum cryptography [17].

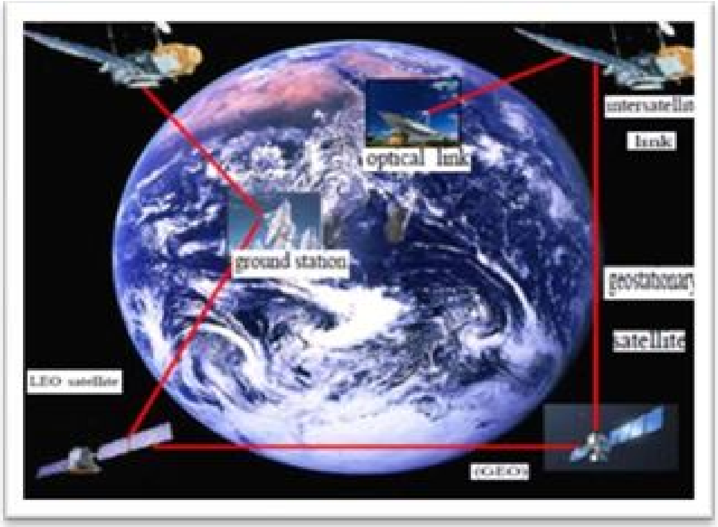

Figure 3: Mission Scenario of LEO satellite constellation

We consider various scenarios for entanglement quantum communication. While, it is already an interesting and outstanding experimental challenge, there are various specific novel opportunities which such a technology would offer. First and foremost, from a technological perspective, our study gives the possibilities to establish a secure and efficient communication using the methods of entanglement based quantum cryptography. As we explained above, one of them could not only establish a secure communication link between two arbitrary locations on Earth. It would also be possible to establish a secure communication from Earth to satellites, or between satellites. This would certainly increase the security and control of the range of the signal that propagates depending on the distance from the satellite, which currently constitutes a very sensitive area and a technical problem so far unresolved.

Using different scenarios of secure key exchange in the free space, it is not difficult to exchange the key between two points. The problem suggested here is the coverage of a huge space. Therefore, we need networks of satellite constellations since the satellite constellations guarantee a global communication routing [18].

6. Practical Considerations and Problematic Statement

The Quantum distribution of the key information in the satellite constellation coverage may require that exchange cellular domain into shorter segments [19]. The problem with this concept is that the required quantum transmitters are still beyond the scope of present day technology. Thus, the technique of transferring cells to cover large distances consists of using optical satellite constellations in free space [20].

By exploiting this technique, free space optical communication systems could enable the realization of secure key exchange between two widely separated locations on the globe [16] via inter-satellite links [3]. Most of satellite communication systems are viewed as an alternative solution to the realization of relatively long-distance secure key exchange, obtainment of large scale key exchange is still challenging. This is due to the fact that the long-distance propagation of the optical beam is affected by several parameters, namely, atmospheric turbulence and geographical structures and infra-structures [18].

In this regard, some of the most outstanding problems include [13]:

a : descrAtmospheric turbulence which leads to wave front distortion.
b :Environmental vibration effects which lead to pointing errors.
c :The absorption, scattering and reflection of radiation in the lower layers of the atmosphere

7. Handover Inter-satellite Domain Solution

In the present study, the main problem consists of the fact that when a user changes its positions, the communication link switches from a satellite to another. This occurs when the first satellite cannot cover the user as he enters in the next satellite zone [16]. This technical operation consisting in a communication exchange from a satellite to another is called the handover. Up to now, many surveys talk about Inter-cellular domain have been carried out to improve this technical operation [11]. The main purpose is to improve the technology in order to better manage the communications by eliminating the interruption risks while crossing from a satellite zone to another or Inter-cellular zone, see figure 4.

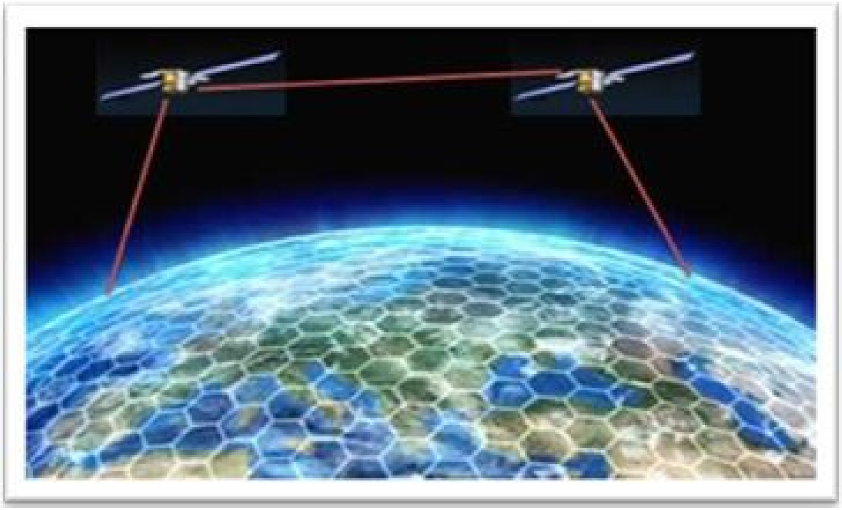

Figure 4: handover inter-satellite domain coverage.

A handover management strategy is proposed to efficiently manage the channel resource of a cell in a multi-beam mobile satellite system (MSS) and improves its quality of service by reducing the inter-beam handover failure rate (Ph1) caused by limited number of communication channels. The handover triggering probability in a source cell for any communication is given by:

$$P_{h1} = \frac{1 - \exp^{-\lambda}}{\lambda} \tag{1}$$

The handover blocking triggering probability of transit cell for any communication is given by:

$$P_{h2} = \exp^{-\lambda} \tag{2}$$

λ is the movement factor:

$$\lambda = \frac{2R_{\text{cell}}}{V_{\text{orb}} \cdot T_m} \tag{3}$$

where R_{cell} :hexagon half circle,T_m: call duration,V_{orb}: the satellite speed in an orbit.

$$V_{\text{orb}} = \left(\frac{\mu}{H + R_{\text{cell}}}\right)^{\frac{1}{2}} \tag{4}$$

where $\mu = 3{,}9861014\ \mathrm{m}^3 \cdot \mathrm{s}^{-2}$, where μ is the gravitation factor.

The average number of over triggering is:

$$K = \frac{P_{h1}}{1 - P_{h1}} \tag{5}$$

8. Simulation Section and discussion

Figure 5 shows the handover triggering probability (HTP) depending on the altitude h (km) of satellite, with, $\mu = 3.9861014\ \mathrm{m}^3 \cdot \mathrm{s}^{-2}$, $R_{\text{cell}} = 100$ km, and $T_m = 5$ minutes (300 s).

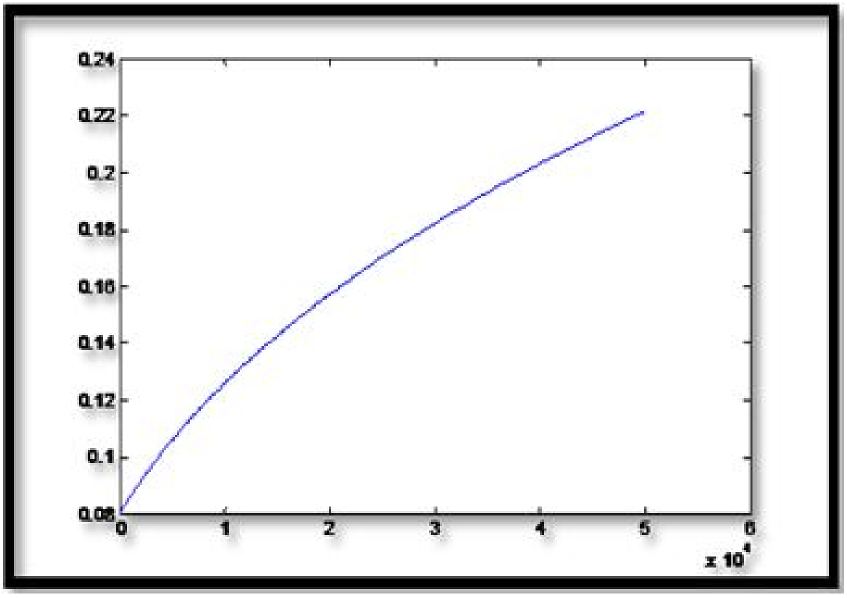

Figure 5: The handover triggering probability.

Figure 6 shows the handover triggering probability (HTP) in a transit cell depending on the altitude h (km) of the satellite.

Figure 7 shows the average number of handover triggering (NHT) necessary depending on the handover triggering probability.

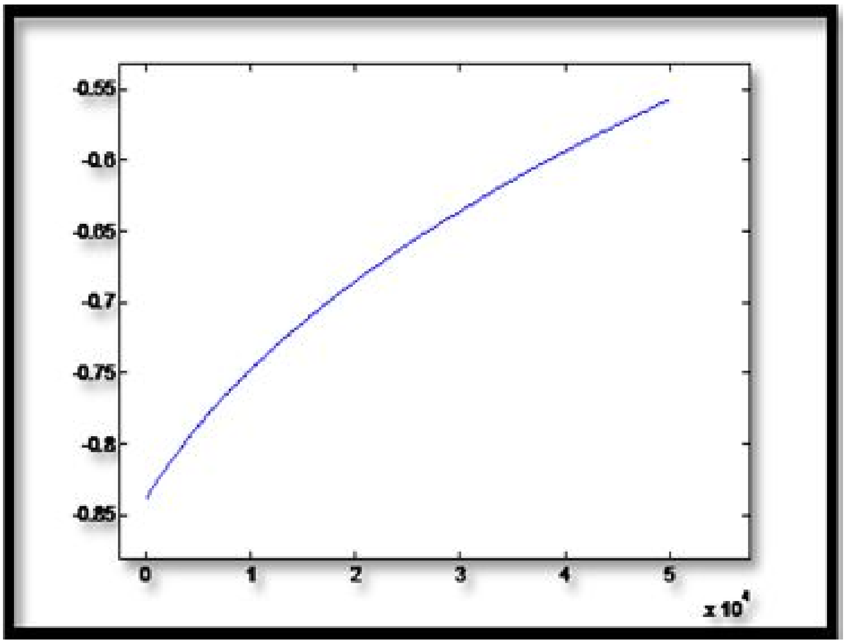

Figure 6: The handover blocking triggering probability of transit cell.

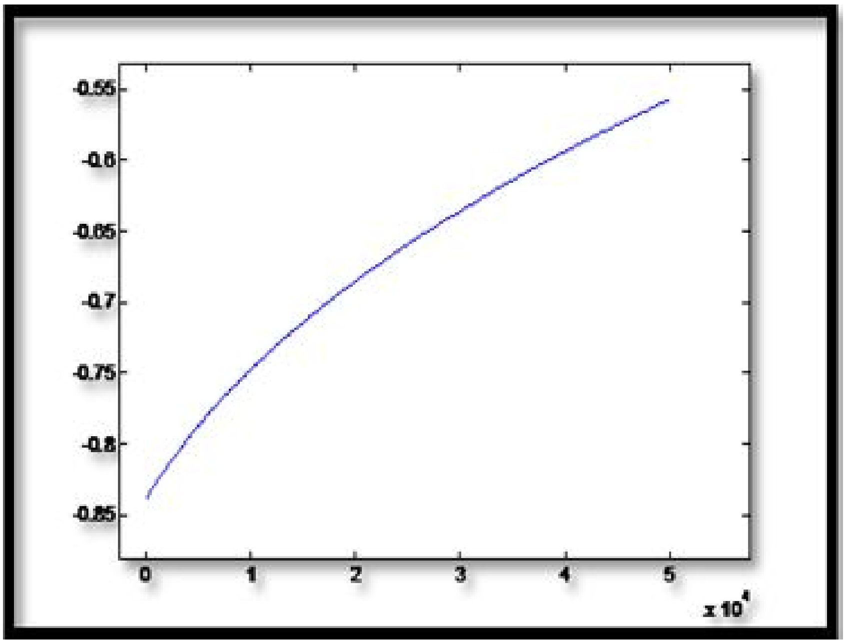

Figure 7: The average number of over triggering handover.

The handover effective value uses the various probabilities as upper and lower values, so that the information reaching the user. Communication earth station followed by transfer to the comparison between the two values, when the level of a user binds to a station that is less than the actual value, there is an outbreak or more out of the box was covering the satellite and tries another nearby area, which gives the two stations of the communication exchange. There are many researches for better regulations have an effective approach for decreasing this operation, to avoid the risk of breaking down links and enhance the quality factor services.

9. Conclusion

In Quantum Communication access networks, the problem of user security is crucial. Generally, they may, during the same call, go through several different base stations, thus generating procedures of the mechanism are inter-cell handover or intra-cellular handover. We used them to size the better network and ensure a good Quality of Service given to users. We studied and simulated an evolution approximate the probability of failure and trigger handover to a change of satellite to base station, or satellite to another one, and describe the probability of the handover by planning an approach under some last research conditions. We classify the different parameters affecting the stability of our system, with a demonstration of a model which manages quantum cellular operator, as examples of explanations. To see a simulation by different probabilities, this is a description and analysis of the team of our laboratory. We are interested in the influential parameters in the mechanism of handover in inter-satellite domain to achieve a well detailed report on the Quality of Services (QoS) of Quantum Key Distribution (QKD). These points are the primary aim of our study. We will try to highlight our next research papers to calculate some different probabilities. There are a lot of researches to arrive at an effective one way to reduce this, and partly to avoid the risk of outages links between BTS - User and to improve the quality factor of services.

10. Declaration on Generative AI

The authors have not employed any Generative AI tools.

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