Quantum-limited Measurements of Signals from a Satellite in Geostationary Earth Orbit

Dominique Elser[1,2,*], Kevin Günthner[1,2], Imran Khan[1,2], Birgit Stiller[1,2,], Ömer Bayraktar[1,2], Christian R. Müller[1,2], Karen Saucke[3], Daniel Tröndle[3], Frank Heine[3], Stefan Seel[3], Peter Greulich[3], Herwig Zech[3], Björn Gütlich[4], Ines Richter[4], Rolf Meyer[4], Christoph Marquardt[1,2], and Gerd Leuchs[1,2]**

[1]Max Planck Institute for the Science of Light, Erlangen, Germany

[2]Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany

[3]Tesat-Spacecom GmbH & Co. KG, Backnang, Germany

[4]Space Administration, German Aerospace Center (DLR), Bonn, Germany

[*]Dominique.Elser@mpl.mpg.de

Abstract: Quantum communication has been implemented in metropolitan area networks around the world. Optical satellite communication lends itself to interconnect such metropolitan networks over global distances. For this purpose, existing Laser Communication Terminals (LCTs) can be upgraded to quantum key distribution (QKD) application. We have performed first satellite measurement campaigns to validate this approach.

Introduction

For several years now, there has been growing interest in satellite-based quantum communication [1-9], since it promises to bridge inter-continental distances. Quantum key distribution (QKD) [10,11], for example, currently suffers from distance limitations on the order of a few hundred kilometers [12]. Although losses in glass fibers have reached ultra-low values [13], the loss still scales exponentially with distance. Consequently, numerous repeaters, in form of trusted nodes [14] or quantum repeaters [15], would be required to bridge inter-continental distances. A single satellite relay, by contrast, is capable of connecting large parts of the Earth without quantum repeaters that are not yet available.

Experimental setup

Our sender is a Laser Communication Terminal (LCT) [16-17] located on the satellite Alphasat (Inmarsat-4A F4) in geostationary Earth orbit at 25° east. The LCT generates a binary phase-modulation of coherent states [18] at a rate of 2.8125 GHz. The main purpose of this mission is to demonstrate data communication between spacecraft in geostationary Earth orbit (GEO) and low Earth orbit (LEO), as well as between GEO and ground. For current GEO-to-ground links, the phase-modulated signal laser beam is pointed towards the Teide observatory on Tenerife, where a Transportable Adaptive Optical Ground Station (T-AOGS) [19-20] is located. The T-AOGS is capable of spatially acquiring the signal beam, to correct for atmospheric phase front distortions and to phase-lock a local oscillator to the signal. This allows for homodyne detection of the signals from Alphasat.

Binary phase-shift keying (BPSK) of coherent states with quantum-limited homodyne detection has been employed over terrestrial free space quantum links before [21-22]. Their main difference with respect to the Alphasat system is the non-orthogonality of the two coherent states $|\pm\alpha\rangle$. While the Alphasat-LCT nominally produces nearly orthogonal coherent states, QKD requires sufficient non-orthogonality making the states nearly undistinguishable. Therefore, amplitude adaptation is an important step when upgrading LCTs for QKD application.

Furthermore, in contrast to other quantum communication systems [23], the local oscillator at the T-AOGS is generated at the receiver, not at the sender. Due to substantial link losses, a local oscillator from the sender would require enormous laser power in space. As an ancillary effect, attacks on the local

[**] *Now at the University of Sydney, School of Physics, NSW 2006, Australia*

oscillator [24] are impeded since it does not travel through the eavesdroppers' domain.

Measurement results

Our detector operates in the quantum-noise limited regime, where the contribution of inherent detector noise is small compared to the observed quantum noise. This allows us resolving the quantum properties of the signals from Alphasat. We determine the homodyne measurement distribution of two binary phase-shift keyed coherent states $|\pm\alpha\rangle$ (see Fig. 1). The expected measurement distribution has the shape of two overlapping Gaussians whose individual variances are primarily given by quantum uncertainty. Our measurement results are in excellent agreement with the theoretical prediction and show that our system is capable of resolving quantum features of the signal states from Alphasat.

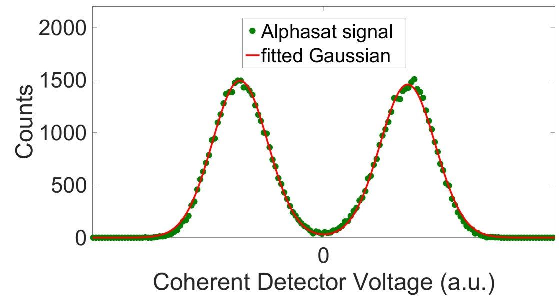

Fig. 1: Measured homodyne distributions of optical signals from Alphasat. As predicted by theory, the measured histogram of the binary phase-shift keyed signals (green dots) yields Gaussian shaped measurement distributions (red lines). The homodyne detector operates in the quantum-noise limited regime [25], such that we can resolve the quantum features of our signal states.

Summary and Outlook

We are able to perform quantum-limited measurements of coherent signals from geostationary Earth orbit (GEO). This result underpins the feasibility of satellite quantum communication using an existing data communication system. In order to optimize the system for quantum communication, our next step is the adaptation of the sender alphabet. A satellite in GEO could then interconnect numerous metropolitan area quantum networks (see Fig. 2).

On the more fundamental side, it is theoretically predicted that quantum communication can be affected by gravity under certain circumstances [26-28]. In our case, the large gravitational potential difference between sender and receiver might facilitate measurements of such effects.

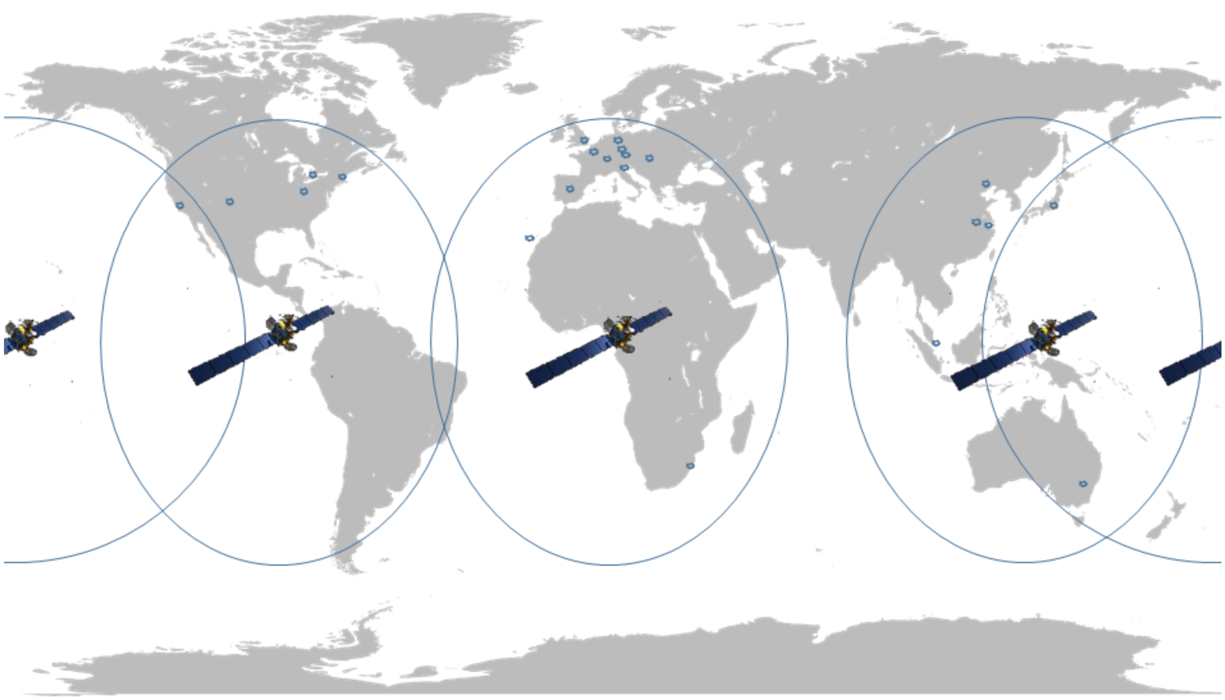

Fig. 2: Satellites in geostationary Earth orbit (GEO) can provide a wide area network (WAN) to interconnect existing quantum metropolitan area networks (MANs). Blue dots: real-world implementations of quantum communication networks and links, blue circles: coverage from GEO. Picture from [25].

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