Physics

VIEWPOINT

Sending Quantum Messages Through Space

Fragile photon states useful for quantum communication can be faithfully transmitted and distinguished over a link between an orbiting satellite and a telescope on Earth.

by Eleni Diamanti*

Besides providing a fertile ground for visions of human life in space and spy movie scenarios, the 2000 man-made satellites currently orbiting our planet play a central role in global telecommunication: they relay analog and digital signals carrying voice, video, and other forms of data to and from various locations worldwide. The potential use of this vast infrastructure for performing communication tasks with absolute security, guaranteed by the laws of quantum physics, is exciting, but it has remained largely elusive. Now, Paolo Villoresi and colleagues at the University of Padova in Italy report [1] a major step in this direction. They show that photons—acting as carriers of quantum information—preserve their state, on which such information is encoded, even after having been reflected by satellites located more than a thousand kilometers away from Earth. Crucially, the researchers demonstrate that, back on Earth, different encoded states can be faithfully told apart; this is indispensable for the secure transmission of messages. The results suggest that global quantum communication may be within reach in the foreseeable future.

A founding milestone for the field of quantum information science was the realization, a bit more than 30 years ago, that encoding information on photon properties, such as their polarization, could be used to distribute encryption keys between two communicating parties (a transmitter and a receiver) with absolute security [2]. In such polarization-based quantum key distribution (QKD), the transmitter sends a series of single photons, each prepared in one of four possible polarization states: horizontal, vertical, left-circular or right-circular. The receiver then performs a measurement that differentiates between these states. Researchers around the world have made great strides to implement QKD protocols that are able to distribute keys at high speed and over long distances. These studies have opened the way to applications such as a one-time pad, a type of encryption method that cannot be cracked. They have also led to QKD schemes that rely on more readily accessible states generated by lasers rather than by single-photon sources [3]. As a result, it is now possible to perform QKD over more than 300 kilometers (km) of optical fiber [4], and fiber networks have been deployed as a means to expand the communication range of individual QKD systems [5].

These advances notwithstanding, the attenuation of light, which is intrinsic to its propagation through fibers, sets a limit on the distances over which it is possible to perform quantum communication. Propagation through free space also has limitations, owing to various noise sources, but it is an appealing alternative to fiber propagation, especially because it can provide a test bed for investigating global quantum communication via links between satellites and the ground. Core quantum communication protocols such as the distribution of entangled photons—photons whose states are intertwined even at a distance—have been implemented over free-space links on Earth that reach almost 150 km [6, 7]. Such experiments are required for both fundamental tests of quantum mechanics and entanglement-based QKD. However, transposing them into a real satellite-to-ground communication scenario is a daunting task. This would require the development of devices for the generation and detection of quantum states that are tailored to constraints, such as the payload, of the equipment allowed on communication satellites [8].

Enter Villoresi and colleagues. The authors have managed to transpose a basic quantum communication function into the realm of satellite-to-ground communication. This function is the essential element of the polarization-based QKD protocol mentioned earlier, which does not require entanglement. The authors sent a series of laser-generated photon pulses, each carrying one of the four polarization states required for QKD, from a ground-based telescope at the Matera observatory in Italy to a satellite equipped with light-reflecting devices (Fig. 1). They performed this experiment with five different satellites; in four of them, these reflecting devices preserve the polarization states, but they do not in the fifth. The researchers ensured that the pulses sent from the ground were sufficiently strong that upon reflection from the devices, the average number of photons per pulse was of the order of 1, a value similar to that of typical

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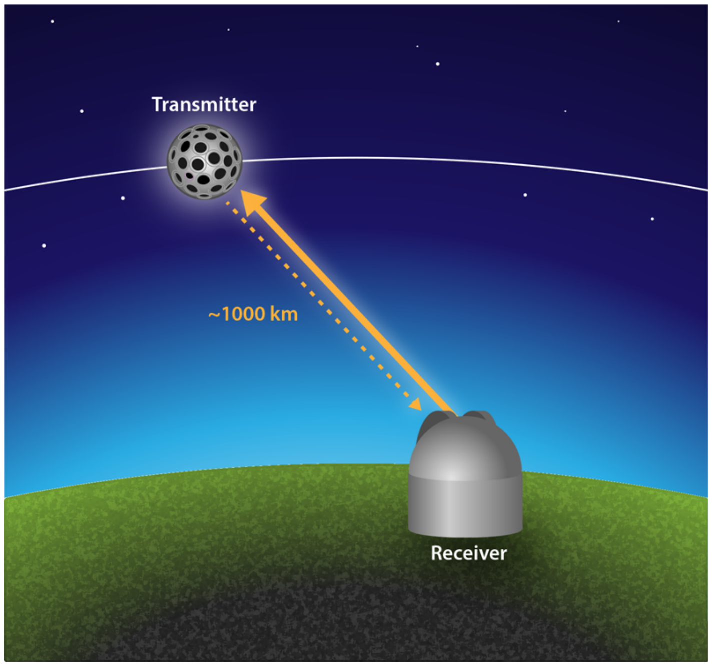

Figure 1: Villoresi and co-workers have shown that the delicate polarization states of photons, which are needed for quantum-encrypted communication, can be transmitted via a laser beam (yellow arrows) from a distant satellite (transmitter) down to a telescope on Earth (receiver), where they are faithfully detected. (APS/Alan Stonebraker)

QKD transmitters. The photons then followed the same path back to Earth, to be suitably detected by a receiver at the telescope. For the four satellites with polarization-preserving reflecting devices, the different polarization states were distinguished with an error that was compatible with that of standard QKD systems. However, for the fifth satellite the error was, as expected, too big to enable QKD to be performed.

Satellites equipped with reflecting devices have been previously used for manipulating quantum states [9]. However, the authors' work represents the first time that they were employed in experiments that analyze and differentiate polarization states. Remarkably, the results were obtained using existing satellites and with only small modifications to equipment in the ground station. In fact, the researchers applied current techniques for standard satellite communication, in particular for satellite laser ranging, to synchronize the transmitted and received signals. Such synchronization is particularly challenging, because of variations in the photons' travelling time caused by satellite motion.

So what are the next steps on the path to reaching global quantum communication? In the near short term, Villoresi and co-workers' approach may open up a possibility for the distribution of secret quantum keys on a satellite-to-ground link spanning more than a thousand kilometers. However, several challenges will need to be met for that to happen, including the installation of a few simple optical components on the satellites and a rigorous analysis of the security of the QKD experiments. The proposed scheme may also be adapted to perform QKD protocols based on electromagnetic-field properties of laser-generated states [10], which can provide a viable alternative to the use of single-photon properties for practical QKD implementations. Once satellite-to-ground QKD links are available, it will also be possible to distribute secret quantum keys between distant locations on Earth via a trusted node installed on an orbiting satellite [5].

Such demonstrations would place quantum physics on the map of space communication and would fuel investment and technological developments in this area. The ultimate goal is to perform satellite-to-ground quantum communication experiments based on entanglement and on the underlying quantum effect of nonlocality. These experiments would ideally link communicating parties spatially separated on Earth using satellites that contain entangled-photon sources. They would allow researchers to fully explore the vast possibilities offered by quantum resources for communication and to build truly global quantum-communication networks. These networks may sound like science fiction now, but as Villoresi and colleagues have shown with single particles of light bouncing off distant satellites and being detected faithfully on Earth, what seems like science fantasy today, may become reality tomorrow.

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REFERENCES

[1] G. Vallone *et al.*, "Experimental Satellite Quantum Communications," Phys. Rev. Lett. **115**, 040502 (2015).

[2] C. H. Bennett and G. Brassard, "Quantum Cryptography: Public Key Distribution and Coin Tossing," in Proceedings of IEEE International Conference on Computers, Systems, and Signal Processing, Bangalore, India, 1984, p. 175–179.

[3] H.-K. Lo, X. Ma, and K. Chen, "Decoy State Quantum Key Distribution," Phys. Rev. Lett. **94**, 230504 (2005).

[4] B. Korzh, C. C. W. Lim, Houlmann, N. Gisin, M.-J. Li, D. Nolan, B. Sanguinetti, R. Thew, and H. Zbinden, "Provably Secure and Practical Quantum Key Distribution over 307 km of Optical Fibre," Nature Photon. **9**, 163 (2015).

[5] M. Peev *et al.*, "The SECOQC Quantum Key Distribution Network in Vienna," New J. Phys. **11**, 075001 (2009).

[6] A. Fedrizzi, R. Ursin, T. Herbst, M. Nespoli, R. Prevedel, T. Scheidl, F. Tiefenbacher, T. Jennewein, and A. Zeilinger, "High-Fidelity Transmission of Entanglement over a High-Loss Freespace Channel," Nature Phys. **5**, 389 (2009).

[7] J. Yin *et al.*, "Quantum Teleportation and Entanglement Distribution over 100-Kilometer Free-Space Channels," Nature **488**, 185 (2012).

[8] R. Ursin *et al.*, "Space-QUEST: Experiments with Quantum Entanglement in Space," in Proceedings of the 59th International

Astronautical Congress (IAC-08) (International Astronautical Federation, Paris, 2008), p. A2.1.3.

[9] J. Yin, Y. Cao, S.-B. Liu, G.-S. Pan, J.-H. Wang, T. Yang, Z.-P. Zhang, F.-M. Yang, Y.-A. Chen, C.-Z. Peng, and J.-W. Pan, ‘‘Experimental Quasi-Single-Photon Transmission from Satellite to Earth,’’ Opt. Express **21**, 20032 (2013).

[10] P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, and E. Diamanti, ‘‘Experimental Demonstration of Long-Distance Continuous-Variable Quantum Key Distribution,’’ Nature Photon. **7**, 378 (2013).

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