Himalayan heights potentially perfect for India's 'Quantum Leap' to space: Study

In a pioneering study for the Indian subcontinent, scientists have mapped out optimal locations for beaming quantum signals into space.

Satellite-based quantum communications including quantum key distribution (QKD) represent one of the most promising approaches toward global-scale quantum communications. To determine the viability of transmitting quantum signals through the atmosphere, it is essential to conduct atmospheric simulations for both uplink and downlink quantum communications and practicality of potential locations for the same need to be determined.

In meticulous research, Raman Research Institute (RRI) scientists analysed existing open-source data available on three of India's most sophisticated observatory sites, and found that the Indian Astronomical Observatory (IAO) in Hanle, nestled in the pristine heights of Ladakh, as the prime candidate for this revolutionary technology.

While similar studies have been conducted in regions like Canada, Europe, and China, India's remarkable geographical diversity – from the Himalayas to coastal plains, from deserts to tropical regions – could make this analysis particularly valuable. The analysis takes into account the deeply interdisciplinary nature of satellite-based quantum communications, where success depends on understanding everything from high-precision telescope operations to complex atmospheric turbulence patterns that can distort quantum signals.

This site in Hanle is a dry and a cold desert, with temperatures in winter plummeting to minus 25 to 30 degrees Celsius; suffers from low atmospheric water vapour levels and oxygen concentrations.

“Hanle offers all required natural settings suitable for setting up a ground-station and undertaking quantum communication over long distances,” said Professor Urbasi Sinha, head, Quantum Information and Computing (QuIC) lab at the RRI, an autonomous institute funded by the Department of Science and Technology, Government of India.

Other than the quantum nature of the signal, what sets quantum communication apart from the well-established satellite-based communication is the signal band that each of them use. While satellite-communication works in frequencies ranging in Mega Hertz (MHz) or Giga Hertz (GHz), quantum communication operates in Tera Hertz (THz), with 100 THz being the most commonly represented in wavelength, often represented in nanometre.

In the paper titled 'Estimating the link budget of satellite-based Quantum Key Distribution (QKD) for uplink transmission through the atmosphere', published in *EPJ Quantum Technology, Springer Nature*, the researchers have mentioned working in the signal band of 370 *THz* (810 *nm*). Authors Urbasi Sinha and Satya Ranjan Behera at QuIC lab, have used existing open-source data on temperature, humidity, atmospheric pressure and other vital meteorological parameters from three sites namely -- IAO Hanle, Mt Abu in Rajasthan and Aryabhatta Institute of Observational Sciences (ARIES), Nainital in Uttarakhand.

"India offers such vast and a variety of geographical terrains and this diversity could potentially make this work as a universal template that could be applied anywhere in India or across the globe. This versatility could make the research invaluable for future quantum satellite projects worldwide," said Sinha.

Proposed satellites for establishing secure satellite-based quantum communications orbiting in the Low Earth Orbit(LEO), where the maximum altitude from earth is 500 kms, are considered in this work. For establishing quantum communication, one has to initially send a beacon signal from the ground station of a particular site every time the designated satellite hovers close to the location. Once the beacon signal is detected by the satellite, another beacon signal is sent by the satellite to the ground station to lock it. It is then ready to facilitate quantum signal transmission.

"Beacon signals are used to track the moving satellite and point it towards the corresponding telescope. Our main signal would be at 810 nm while the uplink and downlink would use 532 nm and 1550 nm of wavelength, respectively," said Satya Ranjan Behera, the paper's lead author.

The main challenge is to identify a site that will allow them to send quantum signals through the multi-layered and complex Earth's atmosphere and, yet, continue to travel to the receiver satellite.

"In order to transmit the beam to a distance across 500 km, the beam width has to be magnified and its divergence has to be minimal. Hence, a telescope is used for this purpose and ideally, small telescopes are best suitable. In the same manner, the receiver side of the telescope is used to collect and de-magnify the beam for detection purposes," explained Behera.

Based on their analysis, the RRI researchers concluded that IAO Hanle (signal loss - 44dB) was ideal among the sites in India considered in this study for establishing a potential-ground station. The two next best sites were Mt Abu (signal loss - 47dB) and Nainital (signal loss - 48dB), where some unavoidable signal losses were likely, they said. This study can form the basis of estimating link-budgets ahead of finalizing the Indian ground-stations for quantum communication purposes.

Paper link – Behera, S.R., Sinha, U., *EPJ Quantum Technology.* **11**, 66 (2024)

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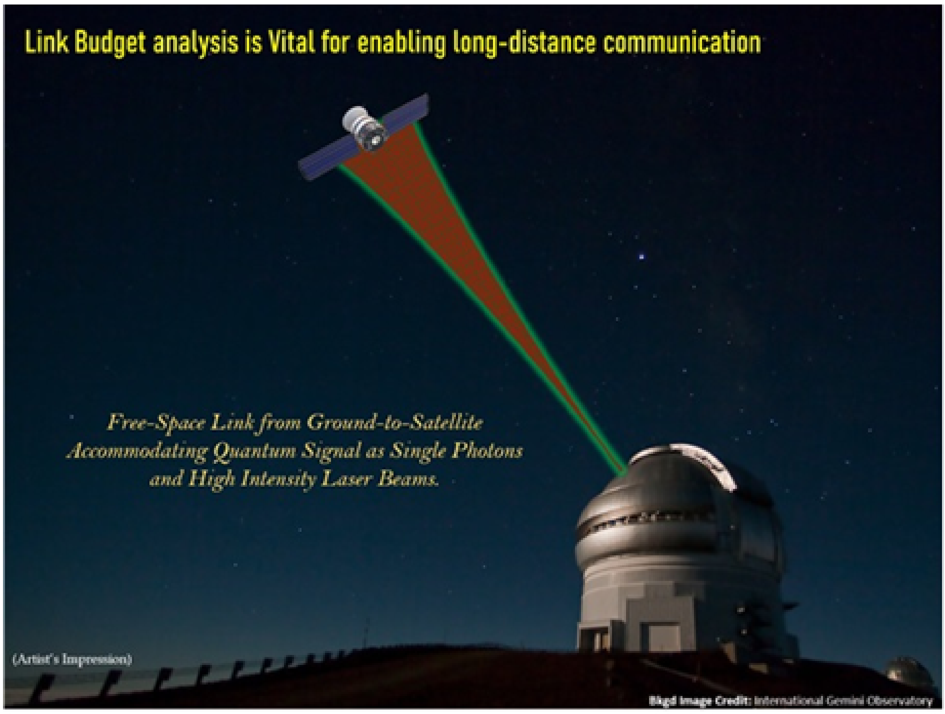

Image : An artist impression of the working of the quantum communication's signal transmission.