Global race for Unhackable Quantum Satellite based Communication networks among countries like China, Japan,United States, Canada, and EU

China’s quantum satellite has produced its first successful result. In a paper published in Science, researchers from the Chinese Academy of Sciences announced the satellite had successfully distributed entangled photons between three different terrestrial base stations, separated by as much as 1,200 kilometers on the ground. The result is the longest entanglement ever demonstrated, and the first that spanned between the Earth and space. Researchers say the system “opens up a new avenue to both practical quantum communications and fundamental quantum optics experiments at distances previously inaccessible on the ground.

China launched the world’s first quantum communications satellite officially known as Quantum Experiments at Space Scale, or QUESS, satellite. The launch took place at 17:40 UTC Monday (16th Aug 2016) from the Jiuquan Satellite Launch Centre in the Gobi Desert, with a Long March 2D rocket sending the 620 kilogram (1,367 pound) satellite to a 600 kilometer (373 mile) orbit at an inclination of 97.79 degrees. “In its two-year mission, QUESS is designed to establish ‘hack-proof’ quantum communications by transmitting uncrackable keys from space to the ground,” Xinhua news agency said. China then plans to put additional satellites into orbit China hopes to complete a QKD system linking Asia and Europe by 2020, and have a worldwide quantum Network.

“The newly-launched satellite marks a transition in China’s role – from a follower in classic information technology development to one of the leaders guiding future achievements,” Pan Jianwei, the project’s chief scientist, told the agency. Quantum communications holds “enormous prospects” in the field of defense, it added.

In November 2015, at the 18th Party 8 Congress’ 5th Plenum, Xi Jinping included quantum communications in his list of major science and technology projects that are prioritized for major breakthroughs by 2030, given their importance from the perspective of China’s long-term strategic requirement.

Many other countries like United States, Canada, Japan, and some EU countries are all racing to develop quantum communication networks as they are virtually un-hackable. Researchers from these countries are closely watching the China’s tests. Researchers at the National Institute of Information and Communications Technology (NICT) in Japan and recently published in the journal Nature Photonics, demonstrated Satellite based “unhackable” Quantum Key Distribution, or QKD.

The biggest challenge, Alexander Ling, principal investigator at the Centre for Quantum Technologies in Singapore said, is being able to orient the satellite with pinpoint accuracy to a location on Earth where it can send and receive data without being affected by any disturbances in Earth’s atmosphere. Ling said. “You’re trying to send a beam of light from a satellite that’s 500 kilometres (310 miles) above you.”

For more information on China’s quantum satellite: http://idstch.com/home5/international-defence-security-and-technology/technology/quantum/china-leading-the-global-race-of-satellite-based-quantum-communications-for-its-military/

Satellite based Quantum key cryptography

Quantum technology is considered to be unbreakable and impossible to hack. A unique aspect of quantum cryptography is that Heisenberg's uncertainty principle ensures that if Eve attempts to intercept and measure Alice's quantum transmissions to Bob, her activities must produce an irreversible change in the quantum states that are retransmitted to Bob. These changes will introduce an anomalously high error rate in the transmissions between Alice and Bob, allowing them to detect the attempted eavesdropping.

Quantum key distribution (QKD), establishes highly secure keys between distant parties by using single photons to transmit each bit of the key. Photons are ideal for propagating over long-distances in free-space and are thus best suited for quantum communication experiments between space and ground. The unit of quantum information is the "qubit" (a bit of information "stamped" in a quantum physical property, for instance the polarization of a photon).

QKD thus solves the long-standing problem of securely transporting cryptographic keys between distant locations. "Even if the keys were transmitted across hostile territory, their integrity could be unambiguously verified upon receipt," say Thomas Jennewein, Brendon Higgins and Eric Choi in SPIE.

Fiber optic based QKD systems are commercially available today, however are point to point links and limited to the order of few hundreds kms because of current optical fiber and photon detector technology. One way to overcome this limitation is by bringing quantum communication into space. An international team led by the Austrian physicist Anton Zeilinger has successfully transmitted quantum states between the two Canary Islands of La Palma and Tenerife, over a distance of 143 km. The previous record, set by researchers in China was 97 km. The process called quantum teleportation allows the state of one of the two entangled photons to be changed immediately without delay by changing the state of other photon even though they may be widely separated.

Japanese Researchers demonstrate Satellite based "unhackable" Quantum Key Distribution, or QKD

Researchers at the National Institute of Information and Communications Technology (NICT) in Japan and recently published in the journal Nature Photonics, demonstrated Satellite based "unhackable" Quantum Key Distribution, or QKD.

"The main advantage [of QKD] is the unconditional security," said team leader Alberto Carrasco-Casado. "When quantum computers are developed, the security of conventional communications will be compromised, since current cryptography is based only on computational complexity. "The development of practical quantum computers is only a matter of time, which has made quantum communication a hot topic in the last few years, and the tendency is foreseen to increase in the future," he added.

To demonstrate this secured, high-capacity transmission of data between an Earth-based station and a satellite in low-Earth orbit (LEO), Carrasco-Casado's team used the quantum-communication transmitter, called SOTA (Small Optical TrAnsponder), on board the microsatellite SOCRATES (Space Optical Communications Research Advanced Technology Satellite) that was launched by the Japan Aerospace Exploration Agency (JAXA) in 2014.

Weighing only 13 lbs. (6 kilograms), SOTA is the smallest quantum communications transmitter ever tested. Orbiting above Earth at 372 miles (600 kilometers), SOCRATES was traveling at over 15,000 mph (7 kilometers per second) when SOTA would establish contact with a 1-meter telescope located in Tokyo's

Koganei city. The received signal was then guided to a quantum receiver to decode the information using a QKD protocol, the researchers wrote in their study.

SOTA encoded the individual photons with 1 bit of data – either a “1” or a “0” – achieved by switching the photons between two polarized states – a method known as a “single-photon regime.” SOTA then beamed pulses of laser at a rate of 10 million bits per second. On reaching the ground station, the laser signal was extremely weak (the researchers say that, on average, only 0.1 laser photons were received per pulse), but the quantum receiver was still able to detect the signal and decode the information over a low level of noise.

In order to realize quantum communication and quantum cryptography with such a weak signal, a key step is to accurately time-stamp the signals, so that they are clearly recognized in the quantum receiver. Therefore, it is necessary to accurately synchronize the signals between SOCRATES and the OGS to detect the transmitted bits without errors. It is also necessary to carry out a polarization-axis matching, because the reference frames change,
due to the relative motion between the satellite and the ground station. Only Japan and China have been able to demonstrate these technologies in space, but China did it by using a 600-kg-class satellite, while Japan did it by using a 50-kg-class satellite.

Since the satellite moves at a fast speed relative to the OGS (about 7 km/s), the wavelength of the laser signal shifts due to the Doppler effect to a shorter wavelength when approaching the OGS, and to a longer wavelength when moving away from the OGS. Because of this Doppler effect, it is necessary to carry out an accurate time synchronization to be able to correctly detect the long sequences of bits without errors. In the China quantum-communication experiment, this synchronization was realized by using a dedicated laser transmitting a synchronization signal. By contrast, NICT was able to carry out this synchronization by using the quantum signal itself. A special synchronization sequence of about 32,000-bits was used in the quantum-communication signal for this purpose, and the quantum receiver was able to perform not only the quantum communication, but also the synchronization and the polarization-axis matching directly, by using only the weak quantum signal. In this experiment, NICT succeeded in demonstrating for the first time that quantum-communication technology can be implemented in small satellites.

The technology developed in this project demonstrated that satellite quantum communication can be implemented by using low-cost lightweight microsatellites. Therefore, it is expected that many research institutes and companies, which are interested in this technology, will accelerate the practical application of quantum communication from space. In addition, since it was proved that long-distance communication is possible with very-low electric power, this will open up a path to speed up deep-space optical communication with exploration spacecraft.

In the future, we plan to further increase the transmission speed and improve the precision of the tracking technology, to maximize the secure key delivery from space to ground by using quantum cryptography enabling a truly-secure global communication network, whose confidentiality is currently threatened by the upcoming development of quantum computers.

UK and Singapore's Quantum satellite device tests technology for global quantum network

Researchers from the National University of Singapore (NUS) and the University of Strathclyde, UK, have become the first to test in orbit technology for satellite-based quantum network nodes.

They have put a compact device carrying components used in quantum communication and computing into orbit. Their device, dubbed SPEQS, creates and measures pairs of light particles, called photons. Results from space show that SPEQS is making pairs of photons with correlated properties – an indicator of performance.

Team-leader Alexander Ling, an Assistant Professor at the Centre for Quantum Technologies (CQT) at NUS said, “This is the first time anyone has tested this kind of quantum technology in space.” The team had to be inventive to redesign a delicate, table-top quantum setup to be small and robust enough to fly inside a nanosatellite only the size of a shoebox. The whole satellite weighs just 1.65-kilogramm.

The group’s first device is a technology pathfinder. It takes photons from a BluRay laser and splits them into two, then measures the pair’s properties, all on board the satellite. To do this it contains a laser diode, crystals, mirrors and photon detectors carefully aligned inside an aluminum block. This sits on top of a 10 centimetres by 10 centimetres printed circuit board packed with control electronics.

Further testing and refinement may lead to a way to use entangled photons beamed from satellites to connect points on opposite sides of the planet. A fleet of nanosatellites carrying sources of entangled photons would be used to enable private encryption keys between any two points on Earth.

Even with the success of the more recent mission, a global network is still a few milestones away. The team’s roadmap calls for a series of launches, with the next space-bound SPEQS slated to produce entangled photons. SPEQS stands for Small Photon-Entangling Quantum System.

With later satellites, the researchers will try sending entangled photons to Earth and to other satellites. The team are working with standard “CubeSat” nanosatellites, which can get relatively cheap rides into space as rocket ballast. Ultimately, completing a global network would mean having a fleet of satellites in orbit and an array of ground stations.

In the meantime, quantum satellites could also carry out fundamental experiments – for example, testing entanglement over distances bigger than Earth-bound scientists can manage. “We are reaching the limits of how precisely we can test quantum theory on Earth,” said co-author Dr Daniel Oi at the University of Strathclyde.

Canada ‘s University of Waterloo Institute for Quantum Computing (IQC) carried out Airborne demonstration of a Satellite quantum key distribution

In a study published in Quantum Science and Technology, researchers from the University of Waterloo have shown that it’s possible to transmit quantum information from a ground station to a moving aircraft. “Here, we demonstrate QKD from a ground transmitter to a receiver prototype mounted on an airplane in flight. We have specifically designed our receiver prototype to consist of many components that are compatible with the environment and resource constraints of a satellite. Coupled with our relocatable ground station system, optical links with distances of 3–10 km were maintained and quantum signals transmitted while traversing angular rates similar to those observed of low-Earth-orbit satellites.”

The system was tested using an aircraft that mimicked how high or low a satellite might appear in the sky. The aircraft, with the name Twin Otter, carried out 14 passes over the facility at varying distances. Only half of the passes were successful in establishing a quantum link, and in six out of those seven passes, the team was successful in extracting the quantum key.

“This is an extremely important step that finally demonstrates our technology is viable,” team leader Professor Thomas Jennewein added. “We achieved optical links at similar angular rates to those of low-Earth-orbit satellites, and for some passes of the aircraft over the ground station, links were established within 10 seconds of position data transmission. We saw link times of a few minutes and received quantum bit error rates typically between three and five percent, generating secure keys up to 868 kb in length.”

Under similar conditions, the uplink configuration has a lower key generation rate than the downlink, owing to atmospheric turbulence affecting the beam path earlier in the propagation. Importantly, an uplink also possesses a number of advantages over a downlink, including relative simplicity of the satellite design, not requiring high-rate true random number generators, relaxed requirements on data processing and storage (only the photon reception events need be considered, which are many orders of magnitude fewer than the source events), and the flexibility of being able to incorporate and explore various different quantum source types with the same receiver apparatus (which would have major associated costs were the source located on the satellite, as for downlink).

Recently, China launched a quantum science satellite that aims to perform many quantum experiments with optical links between space and ground. However its exact capabilities are unverified as no details or results have been published at this time.

Earlier a team led by Professor Thomas Jennewein at the University of Waterloo’s Institute for Quantum Computing (IQC) completed a successful laboratory demonstration of a form, fit and function prototype of a Quantum Key Distribution Receiver (QKDR) suitable for airborne experiments and ultimately Earth orbiting satellite missions.

The team designed and built the QKDR under a $600,000 contract from the Canadian Space Agency (CSA). The prototype QKDR needed to accommodate the payload constraints of a microsatellite-class mission. That included using only 10 W of power and weighing less than 12 kg.

Through radiation testing at TRIUMF located at the University of British Columbia, it was shown that with adequate shielding and cooling the QKDR detector devices can survive and operate in the space radiation environment for at least one year and possibly up to 10 years. The team also defined a credible path-to-flight for all key technologies including the miniaturized integrated optics, detectors and data processing electronics for the satellite payload.

Utilising orbiting satellites, therefore, has potential to allow the establishment of global QKD networks, with 'quantum' satellites acting as intermediaries. Such satellites could operate as untrusted nodes linking two ground stations simultaneously, or trusted nodes connecting any two ground stations on Earth at different times

ISRO Collaborating With Research Institute to Develop Secure Quantum Communications in Space

Raman Research Institute (RRI) in Bengaluru has joined hands with the Indian Space Research Organisation (ISRO) to develop the quantum technologies that ISRO's satellites would need to establish such a network.

Under the memorandum of understanding signed recently between RRI and ISRO Space Applications Centre (ISAC) also in Bengaluru, the latter will fund the Quantum Information and Computing (QuiC) laboratory at RRI for developing the quantum technology tools.

“This is India’s first step towards quantum communications between ground and satellites,” said Urbasi Sinha, who heads the QuiC laboratory and has been pioneering fundamental quantum experiments “using single and entangled photons”.

QEYSSat (Quantum EncrYption and Science Satellite) microsatellite mission

Researchers from University of Waterloo have proposed microsatellite mission called QEYSSat (Quantum EncrYption and Science Satellite) through a series of conceptual and technical studies funded primarily by the Canadian Space Agency (CSA). QEYSSat’s mission objectives are to demonstrate the generation of encryption keys through the creation of quantum links between ground and space, and also to conduct fundamental science tests of long-distance quantum entanglement (the intriguing phenomenon in which the joint quantum state of, for example, two particles cannot be factored into a product of individual particle states).

“The quantum signals for QEYSSat will be generated in photon sources located on the ground. An optical transmitter on the ground will point the beam of photons toward the satellite. (QKD can be carried out via such quantum uplinks, along with ordinary classical communication with the satellite,” said the researchers. An important aspect of this mission concept is to keep the complex source technologies on the ground and ensure that the satellite is simple and cost-effective. This approach also allows the quantum link to be implemented using various different types of quantum sources, including entangled photons and weak coherent pulses.

“Placing the quantum receiver in space, however, poses some technical challenges of its own. In particular, the expected link losses will be higher for the uplink than they would be for a downlink because atmospheric turbulence perturbs the photons at the start of their journey up to the satellite. In addition, the dark counts of single-photon detectors will rise due to radiation exposure in orbit," write the researchers in SPIE.

The current platform for the QEYSSat mission proposal is based on a microsatellite, to be located in a low Earth orbit at an altitude of about 600km. The payload would have an optical receiver with 40cm aperture as the main optics.

"The QEYSSat payload will include the capability to analyze and detect single optical photons with high efficiency and accuracy. Each arriving photon will be analyzed in a polarization analyzer and detected in single-photon detectors. Onboard data acquisition will register all detection events and record their time-stamps to subnanosecond precision, for processing later on the ground."

To show the viability of this mission concept, Researchers have conducted several theoretical and experimental studies, including a comprehensive link performance analysis, as well as QKD experiments over high transmission losses and over a rapidly fluctuating channel.

Typical QKD experiments operate with 20–30dB of losses, but for a satellite link the losses are expected to be about 40dB or more. Researchers studied how to implement a QKD protocol in the case of such high transmission losses and operated a system successfully with losses up to nearly 60dB.

"Fluctuations caused by turbulence will be particularly important when sending quantum signals to a satellite. We showed that quantum communication using single photons is still possible even when the channel transmission is strongly fluctuating, down to complete drop outs of the signal. We also showed that in the extreme case of very high transmission losses, we can improve the signal-to-noise ratio and keep performing QKD by applying a threshold filter to the data in post-processing,” write the researchers in SPIE.

European scientists have proposed a quantum communications experiment that could be sent to the international space station.

References and Resources also include

http://idstch.com/home5/international-defence-security-and-technology/technology/quantum/china-leading-the-global-race-of-satellite-based-quantum-communications-for-its-military/

https://www.theverge.com/2017/6/15/15808436/china-satellite-quantum-network-encryption-entanglement-micius

https://thewire.in/191273/isro-space-secure-quantum-communications/