

Status of the DLR OGSOP and its Development towards QKD OGS and multi-mission operation

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ABSTRACT

The Institute of Communication and Navigation at the German Aerospace Center (DLR) hosts the Optical Ground Station Oberpfaffenhofen (OGSOP). The station is operating with an 80cm primary mirror telescope, including a Nasmyth configuration. These were guiding light to several different experimental ports at the Ground Station itself, as well as a free space optical Coudé-Path, leading onto an optical table inside the laboratory below the station. After the commissioning of the OGSOP (2021 – 2023) various projects and free space laser communication experiments have been conducted. OGSOP approved operations including data downlinks from the low orbit satellites Flying Laptop, CubeL and QUBE. Experiments with Alphasat (GEO stationary platform) were also carried out as well as an aircraft link campaign in the frame of QuNET project. The gained experiences and lessons learned of all these missions led to further development and upgrades of the OGSOP, especially from classical laser communication towards the direction of Quantum Key Distribution (QKD). The upgraded OGSOP and its peripheric systems are a designated test bed for QKD [1][2].

The QKD precursor Missions QUBE-I (launch August 2024) is already in the phase of an ongoing linking campaign at OGSOP. From first light to scientific experiments, the OGSOP could already proof its capability to support this type of optical free space satellite communication missions. The receiving Coudé-Path and system PUMUQL (Prototyping Unit for Modulated User-data and Quantum Links) was integrated for the quantum light, as well as an adaptive optics system in development. The follow up mission QUBE-II is also already launched (May 2026) and currently in its finally LEOP phase, it will go into first tests around autumn 2026 at OGSOP. The preparation for Eagle-1 is a main part of the work and development for the optical ground station. QKD up- and downlink path is redesigned, implemented and brought into operational service. The growth of the number of projects dropping into the OGSOP was one of the reasons to go from classical project-based time by time mission support to a matrix like solution for multi mission support and operations. An established configuration management, new commanding, booking and preparation processes are assisting the whole organization. Following an overview of the current status of the OGS, the ongoing projects (QUBE, Eagle-1, QuNET, and more) will be given. A description of the ground stations infrastructure and support facilities will be represented in relation to different project requirements and missions.

Keywords: Optical Ground Station, Quantum Key Distribution, Laser Communication,

1. INTRODUCTION

Laser communication technology, especially QKD (Quantum Key Distribution), is coming more and more into practical operations.[1] It is a state-of-the-art technology that enables the distribution of cryptographic keys between two entities. [1] The goal is to demonstrate secure communications even in times of quantum computers, artificial intelligence and computational processing power. DLRs Optical Ground Station has a high impact in this transformation of communication, systems and networks. To show this roadmap, OGSOP is part of many consecutively mentioned projects. To gain the high impact role it is necessary to spread the focus on several missions and support of different standards to enhance the development of worldwide comparable optical communication. Multi-mission support and flexibility of the experimental ground station OGSOP is a key assumption that needs to be fulfilled.

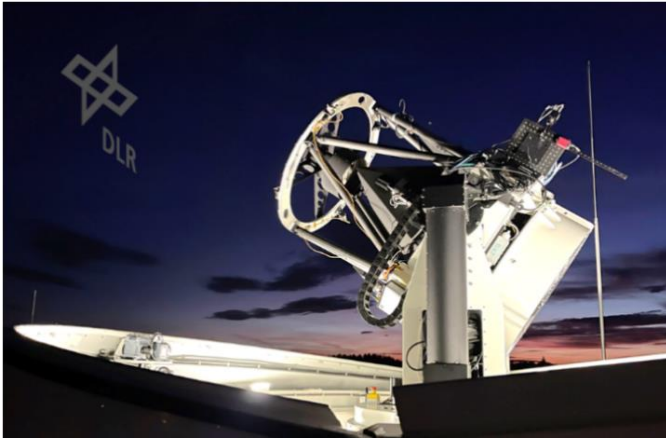


Figure 1 Optical Ground Station Oberpfaffenhofen (OGSOP)[2]

Table 1 Key parameters OGSOP [2]

Item	Value	Unit
Geographical latitude	48,0848° N	deg
Geographical longitude	11,2780° E	Deg
Altitude above sea level (nm)	650 (+/- 1,5)	m
Telescope aperture	800	mm
C shFocal length	5,59	m
Back-focal length	918,355	mm
Nasmyth Ports	4	--
Coudé path	1	--
Max. slewing speed	~20	°/s
Pointing possibility	-2° to 95°	deg

2. OPTICAL GROUND STATION OBERPFAFFENHOFEN

The optical ground station Oberpfaffenhofen was built up and commissioned from 2021 to 2023. The Station is an upgrade from the former station. Coming from a 40cm receiving telescope in Cassegrain Focus configuration to an 80cm three mirror Nasmyth Ritchey-Chrétien type with Coudé Path and Coudé Bench in the below laboratory (see Figure 6.). OGSOP was specially upgraded to improve the performance for QKD Missions. A second main reason for the new station was to enable multi-mission support. Through its Nasmyth configuration, several optical benches and attachment bases on the telescope the realization of the multi-mission support happened at OGSOP.

Telescope – Receiving Antenna

The key component of OGSOP is the receiving telescope. It is built in Ritchey-Chrétien type as a three mirror system in Nasmyth-configuration.[1] The telescope acts as the main receiver and transmitter. It is installed on an altitude-azimuth mount with two fork arms holding the mirror-cell. The main mirror (M1) has an aperture diameter of 80cm.[1] The collected light is directed to the second mirror (M2) with a diameter of 280mm.[1] From there the path goes to the 360° rotatable flat third mirror (M3) of an elliptical shape. This mirror is mounted at an angle of 45° to the optical axis sending the light into one of the four Nasmyth-Ports.[1]

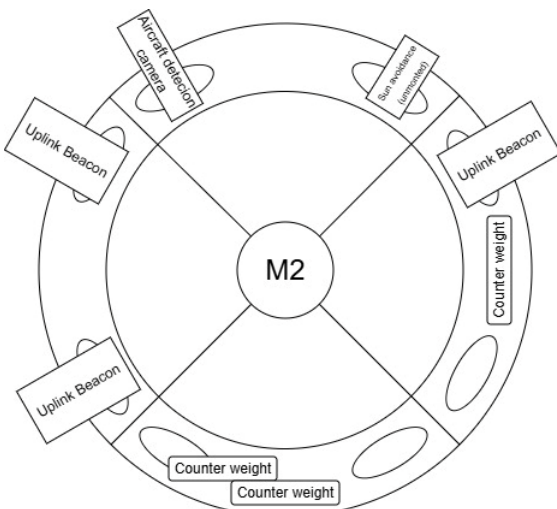


Figure 2 Schematic view "outer rim" OGSOP 2026

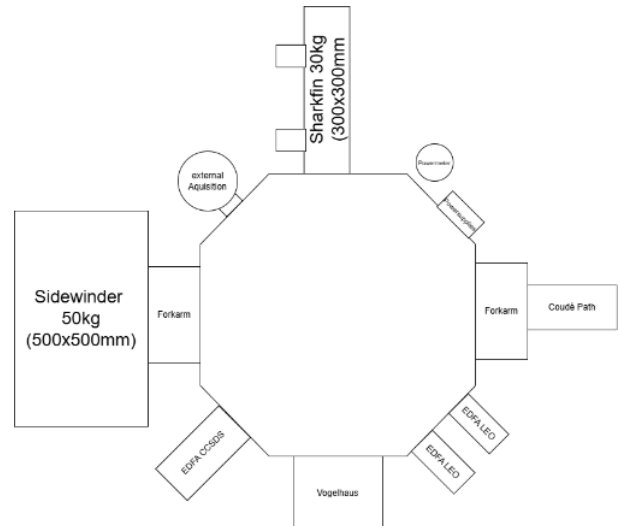


Figure 3 Schematic view of side-installations OGSOP 2026

Around the Mirror cell of M1 several Mounting options are realized to support side installations parallel to the telescope's optical axis, Figure 3 gives a schematic overview on the current setup in 2026, rearrangements are planned for incoming projects like Hydron and Eagle-1. The spider ring holding M2 called "outer rim" contains several additional mounting spaces for experimental and operational equipment, see Figure 2.

Nasmyth – System

OGSOP has currently 3 Nasmyth-Ports in permanent use. It is possible to switch fast between two ports – receiving parts, max. 30sec for a full cycle. OGSOP will perform open loop tracking continuously during a link if M3 and so the Nasmyth-Port is changed. This is required especially for link losses and need to research in the visible band, or during Aircraft campaigns if different setups are installed (e.g. QuNET Aircraft campaign SE3 flight tests around Oberpfaffenhofen).

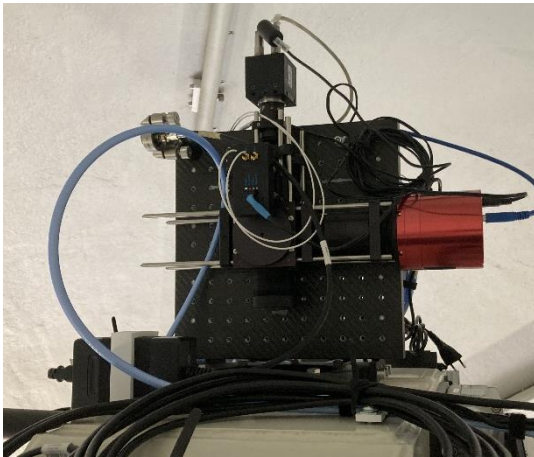


Figure 4 Sharkfin - Receiving setup and Uplink possibility 2026

Table 2 Nasmyth allocation[2]

Nasmyth-Port	Equipment	Wavelength (nm)
Nasmyth-Port 1 (Coudé path)	Optical table (M-RS2000) 1200x2400mm	589, 850, 950, 1064, 1550
Nasmyth-Port 2 (Sharkfin)	Optical bench 300x300mm	Uplink setup 1550nm
Nasmyth-Port 3 (Swing)	Optical bench 500x500mm	free
Nasmyth-Port 4 (Vogelhaus)	Thorlabs Cage and Constructions Rails	>950, 1550

Coudé Path

The OGSOP contains a Coudé Path for guiding the incoming received light from the telescope free space through an optical lens and mirror system into the laboratory below the station. The lens system contains 14 custom lenses designed and optimized for transmission of 1650nm, 1550nm, 1064nm, 950nm, 850nm, 589nm and 400nm, all central wavelength in narrow bands.

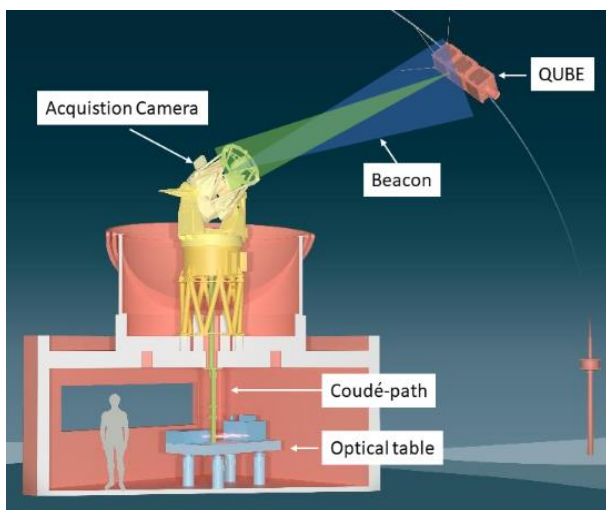


Figure 6 OGS Overview with QUBE and Test-Source-Tower[1][2][3]

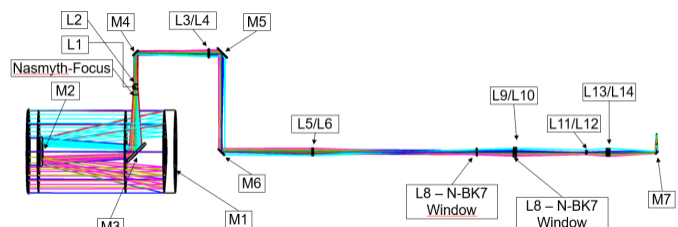


Figure 5 Optical Design Telescope and Coudé-Path[1]

Coudé Bench and Laboratory

Below the telescope the Coudé Laboratory with its optical bench, so called Coudé Bench is in operation. One part of the laboratory is the control center space, where three independent Operator Workspaces are available to support telescope and tracking control, Adaptive Optics Control and Experiment Control. Overhead Monitors show the weather and climate monitoring, as well as the aircraft detection and airspace control systems.

The Coudé Bench is an optical Table (M-RS2000) with an envelope of 1200x2400mm placement space for different optical systems and paths to guide the incoming light from the telescope to the measurement devices. Due to the size of the bench, it is possible to build up receiving and transmitting setups for different purposes and also different wavelength at the same time. [1]

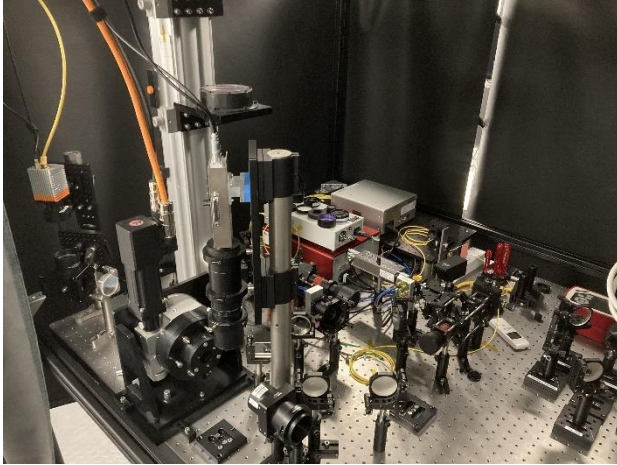


Figure 7 Coudé Bench - optical table



Figure 8 Coudé Laboratory - Control Center Workspace

The first third of the table space is used by the PAT (pointing acquisition and tracking) system, the tracking camera uses ~2% of the incoming light for the optical control loop. A telescope simulator is built besides the PAT system to simulate incoming light for alignment and configuration of the optical systems on the table. The PUMUQL (Prototyping Unit for Modulated User-data and Quantum Links) setup is also directly placed close to the incoming Coudé Path. The setup contains a power meter (FEMTO OE-200 in DLR configuration), a RFE (receiving front end) for data and clock signal reception, as well as currently two different QKD signal receivers, one for 850nm, free space based and the other for 1550nm which uses a fiber coupling solution. The fiber coupling is realized inside the PUMUQL setup, the signal is detected in a fiber connected SNSPD (Superconducting Nanowire Single-Photon Detector).

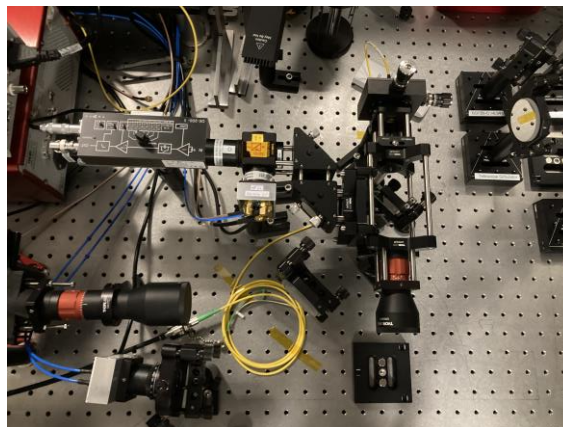


Figure 9 PUMUQL

3. PERIPHERIC SYSTEMS AT OGSOP

To implement save and high-quality operations, at OGSOP several peripheric systems are installed. A test source on a close by telecommunication tower, several weather stations and climate sensors are the main supplies to perform successful optical links.

Testlink - Tower

The static test source for experiments at OGSOP so called “Testlink Tower” features currently two permanent laser sources as well as place for changing systems on an additional optical bench. All sources are mounted on a hexapod for the simulation of movements, orbits and calibration. The fully from OGSOP remote controlled setup is at a distance of 6,6km in the northwest of the ground station. End-2-end tests with satellite terminals (e.g. with CubeISL has been conducted).



Figure 10 Testlink Tower

Table 3 Key parameters Testlink Tower [1]

Item	Value	Unit
Geographical latitude	48.132° N	deg
Geographical longitude	11.224° E	deg
Altitude above sea level	680m	m
Silicon Lightwave LB20 Collimator (divergence)	1	mrاد
Wavelength Infrared source (IR)	1545.32	nm
Laser source power (IR)	1.6	mW
EDFA, C-Band	250	mW
Wavelength red source	850	nm
Laser source power (red)	3.5	mW
Divergence	0.24 x 0.9	mrاد

Operational Support Equipment

The Laser safety system at OGSOP is upgraded according to German safety standards in dependency of several project requirements. The overall infrastructural update is supported by QuKomIn as a heritage of building the QKD infrastructure and network at the Institute of Communication and Navigation. For the multi mission support a flexible zone system is implemented at the OGS and connected laboratory spaces. Through that it is possible to have fast changes between different laser safety requirements according to the different project references.

Additionally, an ASS Aircraft detection system is installed besides the telescope facility in order to observe the airspace and do a passive aircraft detection through camera pictures and calculation if the detected systems will enter our laser safety zone.[14]

Because of experience due to OGS operations in the last years an improvement of the climate control was necessary. The safe operation modes had to be adjusted. Especially humidity was an influential factor, here additional support and control equipment was installed to keep the hole OGS facility at a more constant level. In Addition to that, also the limit values for safe operations were adopted to project and new technical requirements. This includes an update of the dome control system, which will enable a more flexible opening and dynamic ranging, in order to deal better with sun, wind and rain influences.

Weather Monitoring

The OGSOP has several weather and climate monitoring systems in its peripheric space. The overall systems are regularly extended with new sensors and are registered in a periodic calibration cycle. The extension comes from a regular evaluation of the data and needs of information around and inside the ground station.



Figure 11 Miratlas Integrated Sky Monitor



Figure 12 C-Dimm with Alt-Azimuth Mount at OGS-NZ

Currently it includes climate monitoring inside the dome and lab as well as observation stations outside. There is a calibrated Reinhardt MWS 55VY expanded with additional sensors for the operational Data (temperature, humidity, air pressure, wind direction and speed). The operational ranges of the OGSOP changed and adopted from the construction requirements, over project request to experienced insights. E.g. operational temperature could be reduced to -15°C from -5°C by a slowly cooling down procedure. Operations during high humidity phases needed to be reduced, a save operational condition could only be achieved by being under 90% of humidity. Wind speed and gusts are highly dependent on the wind direction compared to the OGS operational trajectory. The operational conditions are also improved with the integration of a new flexible dome shell control provided by Baader Planetarium. Rain sensors around the OGSOP trigger the closing of the dome to protect the receiving antenna from damage through rainwater.

OGSOP operates a fully Integrated Sky Monitor (ISM) System from Miratlas. The system is able to characterize cloud cover and turbulence at night and during the day[16]. It generates several additional measurement values, like temperature, humidity, wind speed and direction, seeing and more. Additionally, to the classical ISM, DLR is supposed to install a second double C-Dimm for collecting fried parameter, isoplanatic angle, scintillation and seeing not only static from measuring Polaris, also into the planned link direction. Therefore, the new C-Dimm will be mounted on an Alt-Azimuth Mount, like it is currently used at OGS-NZ (Optical Ground Station New Zealand).[5] This will gain data along the planned link trajectory, it will be possible to get a prediction of the turbulence and light propagation through the atmosphere[16]. Final implementation and first tests are planned for Q4 2026 including first usage in Key Experiment 4 (SE4) QuNET.

Fibernetwork

A dedicated research fiber network is placed at the KN institutes building, see QuKomIn description page 8 below. Fiber coupling of the QKD and communication signals is either directly at the OGS or in the Coudé laboratory.[11]

QKD - Reciever

In the frame of Eagle-1, QuNET and QuKomIn DLR develops systems for QKD receiving and transmission, it generates the quantum pulses and provides the control, monitoring and operations as well as a hacking protection unit. The hardware of the QKD Transmitter consists of electronics, optics and a field programmable gate array (FPGA). In order to generate the signals states, a cascade of lasers, modulators, amplifiers, attenuators and PIN diodes are mounted on a main board.[4] The control of all hardware elements is shared by the FPGA and a softcore embedded microcontroller unit. In this way, weak and bright laser pulses can be generated on demand according to the QKD protocol specifications with the desired signal quality. DLR-KN develops the software package running on the microcontroller unit. It contains all code for the calibration algorithms, monitoring, control flow logic, software updates and maintenance, command and control (telemetry and telecommand), data storage (volatile and non-volatile) and data processing[4].

4. PROJECT UPDATES RELATED TO OGSOP

The following points will give an overview of the most relevant projects and missions with high impacts on OGSOP in 2026. It will give an insight on the QKD OGS research topics at DLR OSL related to OGSOP.

QUBE

QUBE is a 3U sized CubeSat (30cm X 10cm X 10cm), built by the Center for Telematics (ZfT) in Würzburg, with contributions from DLR, LMU, MPL/FAU and OHB as an industrial partner.[3] It is designed and developed to demonstrate technologies in preparation for QKD from CubeSats. It was launched on Transporter Mission 11 on 16th of August 2024. Since first light in May 2026, QUBE is a permanent ongoing experiment at OGSOP, link possibilities are spread over the consortium partners and DLR to gain scientific knowledge and data about QKD and the linking technology and its technical transfer into demonstration experiments.[2] The mission goal of achieving QKD signals from a CubeSat is about to be realized. The QUBE links are one of the main operational projects of OGSOP in 2025 and 2026.

QUBE-II

The satellite QUBE-II is the follow up mission from QUBE-I and is aiming for a full QKD exchange between satellite and ground station. It was successfully launched on May 3rd 2026. It is an 8U sized CubeSat. Currently in Q3 2026 it is in its LEOP (launch and early orbit phase) phase and will get into full operations soon. The consortium includes again DLR, LMU, MPL/FAU and OHB as an industrial partner. Main Mission goals are to demonstrate real quantum key generation and distribution and the exchange with OGSOP. For that the optical aperture at satellite site got improved compared to QUBE-I, as well as the pointing accuracy and the payloads from the project partners. [12][13]

Eagle-1

The EAGLE-1 mission aims to develop Europe's first sovereign, end-to-end space-based quantum key distribution system. The mission is multi-European, led by the European Space Agency and SES.[7] DLR is one of the contributing partners, on the one side for the QKD terminal on the other hand will the OGSOP be the IOT (in orbit testing) ground station. The EAGLE-1 project represents a major step for next-generation quantum communication infrastructures, delivering valuable technical results and mission data, as well as contribute to the development of the EuroQCI program.[7] For the space segment, DLR-KN is in charge of the design of the QKD transmitter, including the development of the software and firmware.[7] This transmitter generates quantum states which are used to implement a QKD protocol based on an optical signal, that will be transmitted to ground.[7]. The main developments of OGSOP for the mission is the implementation of an upgraded adaptive optics system to correct for atmospheric distortions and optimize the coupling of the incoming light into a single mode optical fiber monitoring.[7] Additionally a new compatible uplink beacon system is developed and integrated by the ground station group at DLR. Operational test procedures and processes are developed and scheduled to aim OGSOP for high availability and stability of links for key exchanges.

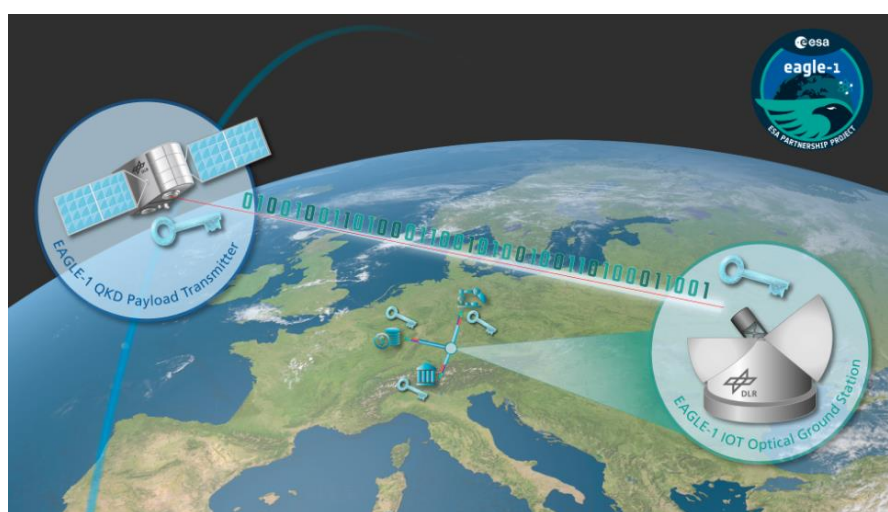


Figure 13 The DLR-KN participation in the EAGLE-1 mission. OGSOP serves as the IOT ground station[7]

QuKomIn

The project QuKomIn is to establish a hybrid quantum communication network consisting of fiber-optic links and free-space channels, along with an application laboratory for satellite-based quantum communication. This test network is intended to demonstrate secure quantum communication under realistic conditions and to evaluate the practical suitability of QKD systems.[10][11]

The OGSOP serves as key part ground station inside the application laboratory to receive and transmit free space optical QKD signals, from satellites as well as from ground-based terminals (e.g. QKD terminal at Testlink tower).[10] The OGSOP is also part of the institutes internal QKD network as one of the core points for receiving and transmitting signals from/to outside. OGSOP will be at the interface between fiber based and free space communications. Via the QuKomIn fiber network several DLR laboratories will be connected directly to the OGS (e.g. Quantum-Lab for QKD exchange, Clock-Laboratory for time transfer experiments including atomic clocks and frequency stabilizing demonstrations).[11]

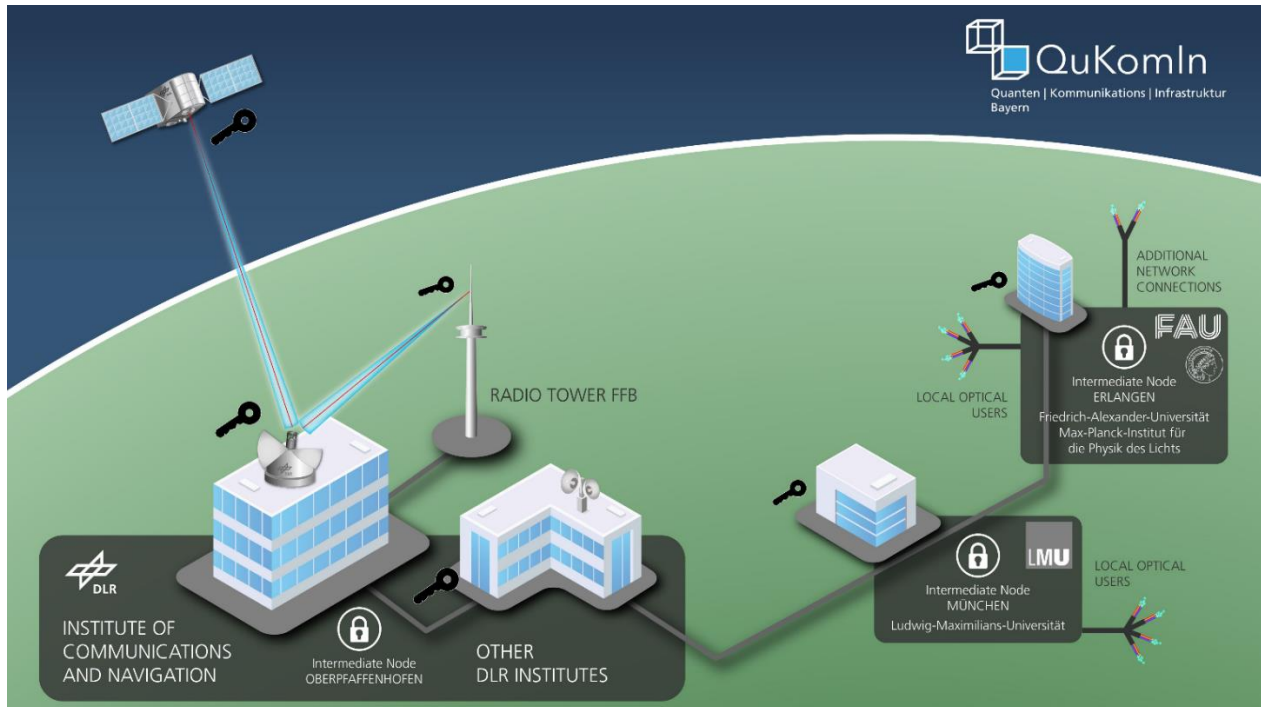


Figure 14 QuKomIn Network Bavaria, Application Laboratory for Satellite-Based Quantum Communication[10]

QuKomIn aims to create a test infrastructure for quantum communication under real-world conditions, enabling the trial and further development of tomorrow's secure communication technologies, with a particular focus on the requirements of government agencies and industrial users.[10]

QuNET

The mission of QuNET is to make the communications of the future secure against eavesdropping and tampering.[15] Its goal is to use various technologies to create the foundations and in-house expertise for tap-proof, quantum-based communication networks in Germany and Europe, thus laying the foundation for secure communications of the future.[15] DLR is working on practical solutions for satellite-based quantum communication to securely and efficiently distribute keys over long distances.[15] In optical fiber, this is only possible over a few 100 kilometers. Quantum encryption via satellite, on the other hand, enables arbitrarily larger distances on Earth.[15]

OGSOP is a central element in the final key experiment (SE4) in the QuNET project frame. It will conduct in Q4 2026 and complete the big project experiments. Additionally Channel measurement campaigns, to characterize the link channels on scientific bases are supported by the ground station. In Figure 15 the currently installed QuNET Channel Measurement Setup is shown. It is placed after the Coudé Path on the optical Table and has its one configuration and can be used as

Ongoing and Future Developments at OGSOP

OGSOP is currently extended to increase the performance in link opportunities. A drone tracking capability is implemented in August 2026 and will be tested in September 2026. This also includes an upgrade of the possibilities of aircraft tracking. In the frame of QuNET a Ballon tracking test is planned to happen in Q3 2026. The tracking options also allow experiments with fast moving systems. The Felt-II Terminal is under supervision to be part of a Car based QKD experiment to be conducted in 2027. DLR project VERONIKA is currently focusing on semi- and full-automation processes for OGSOP operations.

5. CONCLUSION

In 2025 and 2026 OGSOP could proof its capability to provide multi-mission support. Optical links with QUBE-I, the preparation of first experiments with QUBE-II, the QuNET channel measurement campaigns, and QuNET Key Experiment 4 can be declared as full chain experiments in optical communication. The additional upgrades, pre-experiments and infrastructural updates at OGSOP will continue the way to establish the possibility to serve even more projects in parallel and change setups quickly. The preparation for Eagle-1 as the European QKD mission as well as implementing capabilities and capacities for Hydron Element 1 and 2 will continuously take place at OGSOP towards the end of 2026 and will be conducted in 2027. QuNET will be finished by 2026 and QuKomIn will go from infrastructural upgrades to an experimental phase. OPTIMUS will be fully implemented at OGSOP and come into demonstration service by next year.

ACKNOWLEDGEMENTS

This research and upgrades towards QKD were conducted within the scope of the project QUBE and QUBE II, funded by the German Federal Ministry of Education and Research (former BMBF, now BMFTR) under the funding codes 16KIS0767 and 16KISQ051.

The OGSOP topics were made possible by support from the Eagle-1 Team at DLR, funded by European Commission, through SES and ESA.

We acknowledge the project QuNET, funded by the German Federal Ministry of Education (former BMBF, now BMFTR) in the context of the federal government's research framework in IT-security "Digital. Secure. Sovereign.", with funding code 16KIS1265, partly participated and contributed on the Ground Station side.

Building and upgrading of the infrastructure related towards quantum key distribution were funded by the project QuKomIn by the Bavarian Ministry of Economic Affairs, Regional Development and Energy.

OPTIMUS project founded by ESA and lead by DLR GfR as prime contractor for building a European optical communication network.

DLR internal projects Further Developments OGS and VERONIKA.

This work wouldn't be possible without the contributions of the team at the Optical Satellite Links department within the German Aerospace Center's Institute of Communications and Navigation (DLR – OSL). The authors would like to extend our sincere thanks to the team members for their relentless dedication and outstanding efforts. Especially we want to mention the working assignment from the Optical Ground Stations Group and the Mitigation of Atmospheric Impairments Group.

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