International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

ESAs ScyLight Programme: activities and status of the high throughput optical network "HydRON"

Harald Hauschildt

Carlo Elia

Andrew Jones

Hermann Ludwig Moeller

et al.

International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 111800G · © 2018 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2535935

ESAs ScyLight Programme, Activities and status of the High thRoughput Optical Network "HydRON"

Harald Hauschildt, Carlo Elia, Andrew Jones,

Hermann Ludwig Moeller, Josep Maria Perdigues Armengol

European Space Agency, ESA-ESTEC

***Abstract*— ESA's Telecommunications and Integrated Applications Directorate (TIA) runs a dedicated programmatic framework to Optical Communication Technologies, called ARTES ScyLight (SeCure and Laser communication Technology, pronounced "skylight").**

ScyLight supports the development and deployment of innovative optical technologies for satellite communication as well as assisting industry to develop new market opportunities for optical communication technologies.

The ScyLight programme focuses the efforts of European and Canadian industry on optical communication technologies in the following areas:

- **Optical Communication Technology at System Level**
- **Optical Communication Terminal Technology**
- **Intra-Satellite Photonics/Optical Payloads**
- **Quantum Cryptography Technologies in Space and initial services demonstration**

The paper will give an overview of the programme status and an outlook on its evolution.

The paper will inform about the status of a new proposed ESA project on optical communications called “High thRoughput Optical Network” (HydRON), which aims to demonstrate European and Canadian capabilities in all fields of optical communications and with the seamless integration into terrestrial network structures, via a dedicated mission.

Key Words: ESA ARTES ScyLight; Optical Communication Technology; Laser Terminals; Photonics; Quantum Cryptography Technologies, Optical Payloads, HydRON, ESAs High Throughput Optical Network

I. INTRODUCTION

In December 2016 the ESA Member States established at their Council-Meeting in Lucern (CH) a new and dedicated SatCom programme framework on “*SeCure and Laser communication Technology*”, called “*ScyLight*” (pronounced "skylight").

The new framework was created as a new element by ESA’s *Telecommunications and Integrated Applications Directorate* (TIA) within its “*Advanced Research in Telecommunications Systems (ARTES)*” programme. The ARTES programme enables European and Canadian industry to explore, through research and development (R&D) activities, innovative concepts to produce leading-edge satcom products and services. ARTES offers varying degrees of support to projects with different levels of operational and commercial maturity [1].

In order to stimulate the developments on optical communication technologies and to give European and Canadian industry additional opportunities to prove their technologies in orbit, ESA is preparing a new project called *“HydRON”* standing for “*High Throughput Optical Network”*. HydRON aims to provide an answer to the trend to integrate Space and terrestrial network architectures by the means of a Terabit-Optical Network architecture - The “Fibre in the Sky” .

II. EUROPES ROLE IN OPTICAL COMMUNICATION TECHNOLOGY

Europe is leading the field of optical space communication technology and optical data relay services. Some European technology today is in a very advanced state, especially in the field of high data rate optical space terminals as implemented by EDRS and the Sentinel 1 and 2 satellite fleet of the Copernicus programme. However, around the world multiple development programmes, scientifically and commercially driven, aim to catch-up.

Other areas of Optical Communication Technologies and especially its commercial usage, e.g. on payload components, are still at an early implementation phase – not only in Europe.

In general optical communications are considered to be one of the next major revolutions in satellite communication, bringing unprecedentedly high levels of transmission rates, data security and resilience in the next decade.

The commercial take-up of optical technologies is believed to be the next breakthrough in the satcom market arena, addressing the need for the ever-increasing data rate and secure communication. Today's developments and early implementations cannot demonstrate its full capabilities, as the optical solution is mainly used in non-optimized systems, focusing on one particular area only (e.g. high data rate transmission from one point to another).

Over past decades, the evolutionary market development process worked in the area of (Space/Ground) RF-equipment, triggered by many commercial/institutional satcom missions. This process is still the motor for technology evolutions from C, Ku, Ka and U/V/W Band. However, the technology gap for optical solutions is still large, and today's economy is requiring a swifter approach.

In order to support industry across different market segments a close loop between the identification of market trends, system and sub-system design, technical developments, manufacturing technics, service needs and their demonstration as well as standardization is required. Cutting edge solutions in each area also requires a close interaction between industry, research institutes, operators, service providers, standardization bodies and experts in the Agency to jointly define the development roadmaps to demonstrate the full capabilities of optical communication technologies and finally to support industry in capturing the upcoming market opportunities.

Therefore, Europe and Canada concentrate their capacities on optical technology developments for all applications covering terminal developments communicating between space assets, space and ground as well as space and airborne platforms, but also covering photonics equipment on-board satcom satellites and secure optical communication technologies.

III. ScyLight - SeCure and Laser communication Technology

Figure 1: ScyLight Logo

ScyLight is designed to focus on the support of European and Canadian industry by [8]:

- identifying the requirements addressing upcoming market opportunities;
- translating the market requirements and results of the system studies into technology roadmaps, deriving technical specifications on system, sub-system and equipment level for optical technologies;
- triggering ESA-initiated developments on critical but commonly required components;
- implementing, in parallel, technology developments and evolutions, especially if already well defined (niche) markets exist which might be complemented by a long-term view provided by activities described in a) and b);
- performing early in-orbit verification and service demonstration; and
- coordinating the European and Canadian interests in worldwide standardization efforts on optical communication technologies for space applications (free space communication and optical payload components).

Optical technologies cover the entire value chain, which is also seen as an opportunity for small and medium-size enterprises, as well as research institutions.

ScyLight Programme Objectives

The objectives of ScyLight are to:

- address, in a coherent programmatic framework, the development and use of innovative optical technologies for satellite communication, as well as, new market opportunities for optical communication technologies; and
- demonstrate the maturity of optical communication technology to the end user community also by means of early in-orbit demonstrations; and
- support industry to develop capabilities and competitiveness in the field of optical technologies, enabling seize related emerging market opportunities for products based on the newly developed technologies.

Thus, ScyLight will cover the development and evolution of optical communication technologies and, optionally, suitable flight opportunities for their in-orbit verification.

Quantum Cryptography and other new applications will be addressed by ScyLight, inter alia by allowing in-orbit and end-to-end/service demonstrations, for example in the form of Optical Technology Demonstrator Payloads (OTDPs).

ARTES SCYLIGHT FRAMEWORK

To support the programme objectives, ScyLight is structured as 4 thematic lines (see Figure 2):

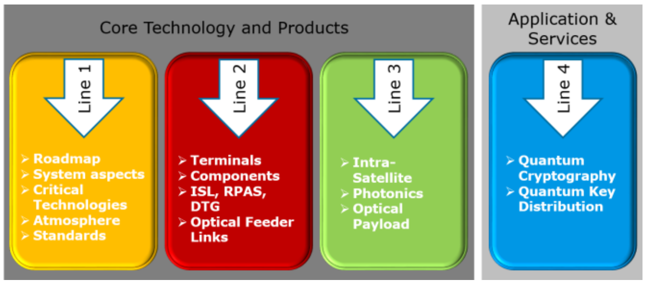

Figure 2: ScyLight thematic lines and examples of related technology areas to be addressed

Line 1 - Common System and Technologies Activities

In order to cover the system aspects required for optical communication technologies, this line covers ESA-initiated market and system studies including optical transmission/propagation, as well as ESA coordination of user and expert groups (i.e. satellite primes, operators, service providers, industry and international partners) to define the roadmap and derive ESA Tenders. The line also covers ESA-initiated development activities on critical and commonly required components and their validation, evaluation and in-orbit verification, and supports coordination efforts with standardization bodies.

Line 2 - Optical Communication Terminals and components

This line covers industry-initiated market and system studies, developments, in-orbit validation and/or demonstration of Optical Communication Terminals and/or its components, including developments for inter-satellite, direct-to-ground and airborne communications. The line also covers developments related to optical user ground stations, required for example for direct-to-ground and high-data-rate uplinks.

In particular, the activities will address:

- Intersatellite Links and Data Relay Services
- Direct to Ground Links
- Optical feeder links
- Airborne to Space/Ground Links
- Optical User-Ground Stations

Featuring

- High Data rates;
- Extremely high communication link distances;
- Atmospheric Transmission Systems and Methods;
- Cost and mass optimization activities/measures;
- Multi-Wavelength/Wavelength Multiplexing Technologies;
- Innovative thermal and reliability concepts supporting optical payloads.

From a technical point of view, the activities will encompass innovative developments in the field of e.g.:

- Laser and amplifier assemblies;
- Space Optics and Adaptive Optics techniques;
- Pointing, acquisition and tracking (PAT) systems;
- High performance data and power electronics and control electronics/ software;
- Modulation and coding schemes;
- Terminal structure elements;
- Thermal control systems;
- Calibration systems for Optical Ground Stations; and
- Ground network and diversity aspects.

Line 3 - Intra-Satellite Photonics / Optical Payloads

This line covers industry-initiated market and system studies, the development as well as in-orbit and service demonstration of enabling technologies required for intra-satellite photonics (commanding/data transfer/data handling) and optical payloads for the satcom market.

In particular, activities will aim for e.g.:

- extremely high bandwidth equipment;
- optical fiber/harness at spacecraft level;
- technologies resulting in lightweight, low volume, mechanically flexible equipment.

The activities will encompass innovative developments in the field of e.g.:

- Amplifiers;
- Lasers;
- Fibre optics cable assemblies;
- Passive components (such as optical connectors);
- Image sensors (CCD/CMOS).

Line 4 - Quantum Cryptography Technologies

This line is dedicated to Quantum Cryptography technologies, and covers the related development as well as in-orbit and service demonstration, including Quantum Key Generation and Distribution systems, and the demonstration of related end-to-end systems.

Activities under ScyLight

Industrial proposals under Line 2, 3 and 4 are initiated by an "always open call for proposals" [3]. The information on the activities themselves however is commercially confidential and cannot be disclosed here.

For the ESA lead activities under Line 1 and 4 the workplan [4], has been approved by ESAs Member States and the Tender Process has been kicked off.

The current budgetary allocation is approx. 60 MEuro. Additional subscriptions by ESA Member States are expected in the course of the coming months. The next phase of ScyLight will be for decision at the next ministerial council in 2019, were Member States will define ESAs forthcoming budget allocation.

Table 1: Selected activities under the current Scylight Workplan (ESA initiated activities only)

ID	Title
SL.003	Optical communications for scientific missions and the Moon village
SL.006	Uninterrupted handover for optical earth-space links using site diversity
SL.007	Assessment of analogue optical links through the atmosphere
SL.008	Space assessment of optical amplitude modulators
SL.011	Quantum key distribution protocols for space applications
SL.013	Assessment of reliable high data rate optical links under strong atmospheric turbulence conditions
SL.014	Fast switching for Optical Inter-Satellite Data Transmission and Ranging for Satellite Radionavigation Systems
SL.015	Demonstration of reliable high data rate optical links under strong atmospheric turbulence conditions

Table 2: Selected Scylight Workplan activities currently running or open (ESA initiated activities only)

ID	Title
SL.001	Optical technologies for next generation communication satellites
SL.002	Optical technologies for next generation optical inter-satellite links
SL.004	Guidelines for the safe use of laser technology
SL.005	Atmospheric monitoring to assess the availability of optical links through the atmosphere
SL.009	Photonics phased array for optical feeder links
SL.010	Use of secure optical communication technologies to protect European critical infrastructure

IV. HydRON – High Throughput Optical Network

Figure 3: HydRON Logo

Optical Communication Technologies is one of the major disruptive solutions that need to be developed to address the changes in the satcom market.

Today VHTS Satellites & Mega-Constellations are competing with high capacity terrestrial fibre networks (in terms of throughput and latency), but the payloads or system aspects get more and more complex and the implementation is reaching its limits with today's satcom technology.

Optical Communications can provide high capacity and a flexible space network needed to cope with the high data demands, together with satellite fleet operations, which will benefit from high capacity intersatellite links.

Extremely high throughput and flexibility in space are required in the future to cope with those demands.

Optical communication technology can serve flexible/scalable multi-network (terrestrial, XEOs, HAPS, RPAS, NAV, EO) intrinsically Safety and cyber-secured.

It will enable the shift from partitioned ground and space segments into a full integrated system and therefore a drastic reduction in ownership costs of Satcom solutions.

Once the optical communication technology, space to/from ground, intra- and inter satellite, is mastered it will provide the highest growth potential.

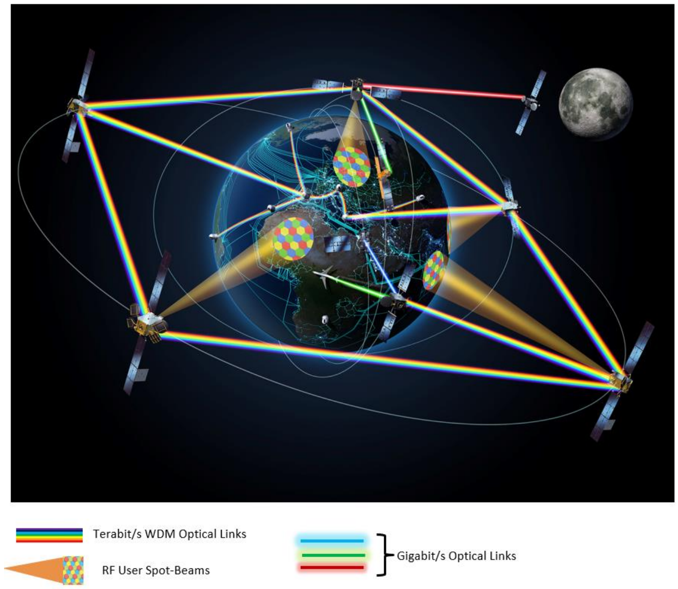

Figure 4: Artist Impression of HydRON Vision of an all optical space network integrated into terrestrial network infrastructures.

In order to answer the demands of the network requirements and to include satellites as an integral part, the HydRON System Concept (see also Figure 4 and 5) aims to demonstrate that:

- All-Optical Satellite Nodes (GEO/NON-GEO) can produce extremely high data throughput .
- Space Laser Networks, featuring Terrabit (>>100 Gbit/s) link capabilities and enabling optical re-routing/switching of data streams can perform likewise standard fibre concepts commonly applied in terrestrial systems.
- The impact of atmospheric conditions can be reduced by making use of the HydRON network capabilities to re-distribute data in-orbit, because:
  - The dedicated HydRON Terabit optical up/downlink stations can be located at geographical areas with high link availabilities (good weather conditions) or
  - the distributed optical ground station networks can serve more than one satellite in parallel and avoid expensive “stand-by” times

- The intrinsic data distribution capabilities of

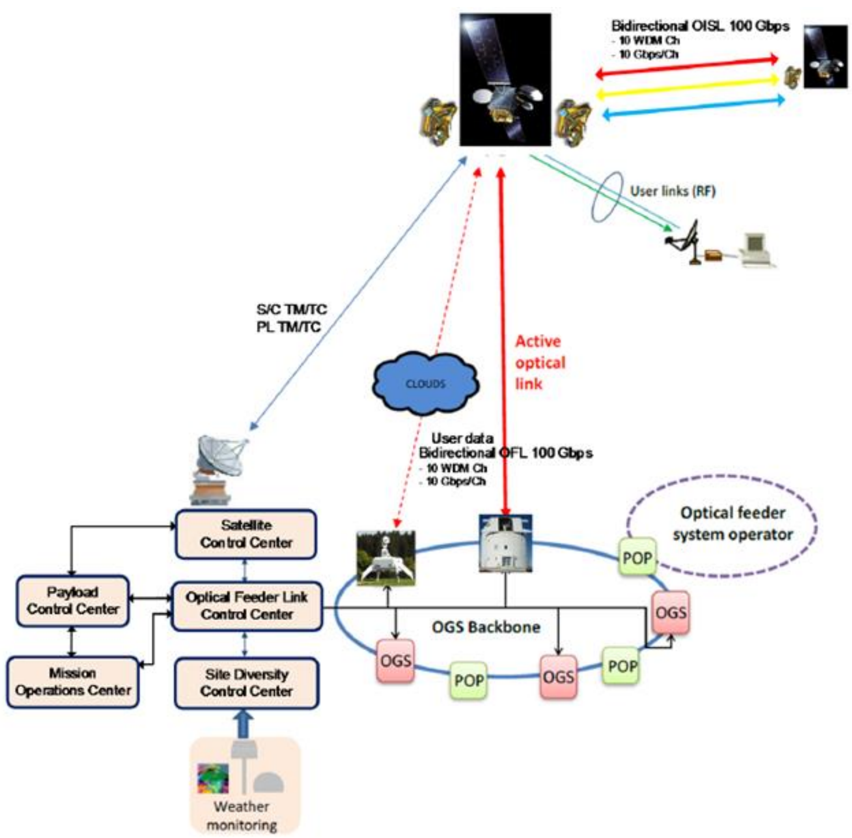

Figure 5: Overall System Concept. HydRON Nodes interconnected via WDM Laser Terminals as well as connected to ground via its optical ground stations, which serve at the same time as Points of Presence (PoP) within the terrestrial network.

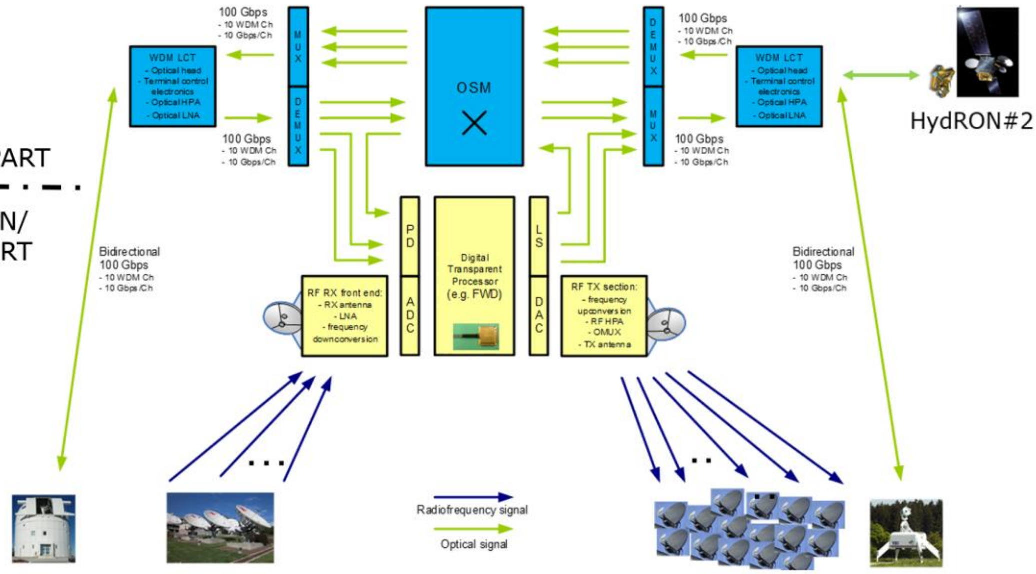

Figure 6: High Level sketch of a potential HydRON payload block diagram

HydRON will allow also the collection and distribution of user data within the network architecture, similar to the terrestrial fiber network.

- The new Network Concepts with a dedicated focus on the space segment and its specific operational constraints (e.g. station keeping manoeuvres or remaining weather conditions) while at the same time aiming for a high integration into terrestrial networks, will benefit from Artificial Intelligence Processes to optimise and provide a highly flexible and integrated network.

HydRON Objectives

HydRON demonstrations shall:

- Give a frame to demonstrate the capabilities of multiple industry players and to prepare for the future. HydRON aims to be a SHOW CASE on Optical Comms.
- Be implemented as a series of dedicated but self-standing Technology Demonstrators (e.g. hosted payloads), which can be implemented in GEO or non-GEO orbits.
- Foster Developments and Technology Demonstrations towards the HydRON vision and will actively push the industrial competences to master the technology gap, whilst preparing industry to compete worldwide.

In line with ScyLight Objectives, HydRON shall:

- Foster the implementation of the Optical Roadmap to ensure European and Canadian industrial capabilities in the areas of:
  - Intra-Satellite Photonics
  - Optical terminals (Space and Ground)
  - Optical Network Concepts
  - Platform-Enhancements
- Provide Framework for Developments up to PFM/FMs
- Provide End2End Flight Opportunities to demonstrate maturity of technology
- Integrate end users (primes, operators)

HydRON Payload Concept

As an analogy to terrestrial networks the HydRON Payload Concept distinguishes between a network part and a user/application part on-board the satellite (see Figure 6):

- The network part (shown as blue items in Figure 6) includes all the elements required to "plug and play" with the rest of the HydRON Network. Those elements will feature laser communication terminals (intersatellite and up/down links), optical routing/switching matrices/equipment, potentially data processing equipment and it will include the interface components to the main mission payload to allow its connections to the network.

- The user/application part (shown as yellow items in Figure 6) is serving the user/satellite owner needs and it provides the required capabilities. Satellites benefiting from high capacity network connections are for example VHTS or satellites gathering time critical data. Applications providing a backbone to the terrestrial submarine cable networks would also benefit from the extremely high bandwidths available with HydRON.

HydRON Mission Schedule

HydRON will be an ESAs proposal to Member States for their next approval cycle end 2019, while preparatory activities can be started already within the existing ScyLight Programme.

Within the next couple of months ESA will detail the plans for the mission implementation and its space-, ground- and network segments design.

It is planned to split HydRON across multiple hosted payloads and the related missions (space, ground and network segment implementations) are called HydRON#1, #2 to #n.

The current project planning is addressing the preparation of HydRON#1, its implementation and its in orbit demonstration phase for a first set of equipment to be ready in 2022 timeframe for in-orbit and on-ground demonstrations.

Equipment (or manufactures) that can for technical or schedule reasons not comply with this aims, will become the opportunity to be embarked on HydRON#2.

The schedule of HydRON#2 will depend on the readiness of this additional equipment.

The overall planning is depicted in Figure 7.

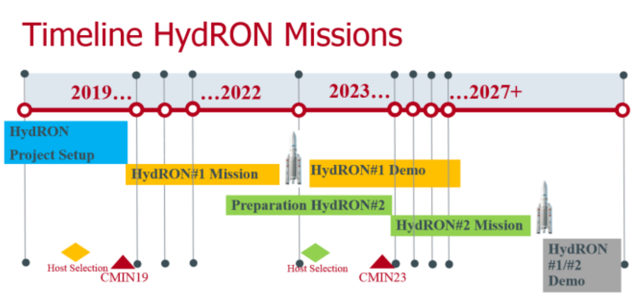

Figure 7: Tentative Overview on HydRON Missions Timeline and Decision Milestones

V. CONCLUSIONS

The ARTES programme element dedicated to "SeCure and Laser communication Technology", called ScyLight has implemented the vision by ESA Member States and is supporting Industry in areas like:

- Optical Communication Technology at System Level
- Optical Communication Terminal Technology
- Intra-Satellite Photonics/Optical Payloads
- Quantum Cryptography Technologies in Space and initial services demonstration

At the next approval cycle (end 2019) it is planned to extend ScyLight and to create in addition a new project aiming for a High throughput optical network implementation, called HydRON and its means to seamlessly integrate the "Fibre in the Sky" into the terrestrial fibre network.

REFERENCES

[1] ARTES Programme : https://artes.esa.int/about-artes

[2] ESA ARTES ScyLight Program, https://artes.esa.int/artes-scylight-secure-and-laser-communication-technology

[3] ESA ARTES ScyLight Call for proposals, https://emits.sso.esa.int/emits/owa/emits_online.showao?typ1=7222

[4] ESA ARTES ScyLight Workplan, https://artes.esa.int/artes-scylight-–-work-plan

[5] Josep Perdigues et al., "Status of the European Data Relay Satellite System", Proc. International Conference on Space Optical Systems and Applications (ICSOS) 2012, 8-1, Ajaccio, France, October 9-12 (2012)

[6] Harald Hauschildt, Francois Garat, Heli Greus, Khalil Kably, Jean-Pascal Lejault, Hermann Ludwig Moeller, Andrew Murrell, Josep Perdigues, Michael Witting, Bas Theelen, Matthias Wiegand, Akos Hegyi, "European Data Relay System – one year to go," Proceedings of ICSOS 2014 (International Conference on Space Optical Systems and Applications), Kobe, Japan, May 7-9, 2014

[7] Harald Hauschildt, Willem Admiraal, Edoardo Benzi, Martin Born, Marina Diaz Martin, David Evans, Francois Garat, Heli Greus, Khalil Kably, Jean-Michel Lautier, Jean-Pascal Lejault, Nicolas Le Gallou, Silvia Mezzasoma, Ludwig Moeller, Josep Maria Perdigues, Juan Rivera Castro, Cedric Salenc, Pablo Sarasa, Dr. Michael Witting, TimWatterton," European Data Relay System – Operational Service using Optical Communications Technology", Proceedings of ICSOS 2015 International Conference on Space Optical Systems and Applications), New Orleans, USA, October 27/28, 2015

[8] Harald Hauschildt, Carlo Elia, Ludwig Hermann Moeller, Dietmar Schmitt, „ESA, "ScyLight – ESA's Secure and Laser Communication Technology Framework for SatCom", Proceedings of ICSOS 2017 (International Conference on Space Optical Systems and Applications), Naha, Okinawa (Japan), 14-16 November 2017