HYDRON: the ESA Initiative towards Optical Networking in Space

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Abstract *The HydRON Project aims at developing innovative optical communication technologies / equipment, including flight opportunities for their in-orbit verification, to validate the "Fibre in the Sky" concept integrated into terrestrial networks at Terabit/sec capacity. This paper will present the current status of the technical and programmatic aspects.*

Introduction

In 2016 the ESA Member States established a new and dedicated SatCom programme framework on "SeCure and Laser communication Technology", called ScyLight[1], [2].

ScyLight 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 innovative concepts to produce leading-edge satcom products and services.

ScyLight addresses the development and evolution of innovative optical communication technologies and, optionally, suitable flight opportunities for their in-orbit verification. As a matter of example, HydRON (High Throughput Optical Network), aims at providing an answer to the trend of integrating space and terrestrial network architectures by means of a Terabit-Optical Network architecture - The "Fibre in the Sky"[3], [4]. The HydRON Project was approved at the ESA Ministerial Council in November 2019.

HydRON Vision: Internet backbone beyond the clouds

Space communications have been a successful player in providing global coverage for different types of services, e.g., TV / radio broadcasting, phone services / internet access in isolated regions, business to business virtual private networks over satellite, etc. In those scenarios, the satellite is the central node in point-to-point/point-to-multipoint star topologies or in multipoint-to-multipoint meshed topologies. In most cases, the satellite is conceived as a standalone communications system, and therefore, different satellites (with typically different ground segments) are serving different missions, with cost and complexity implications.

A shift in the paradigm of satellite communications is considered mandatory, in order to complement (rather than compete with) the continuous performance evolution of terrestrial high capacity networks, which are transporting >99% of the worldwide traffic.

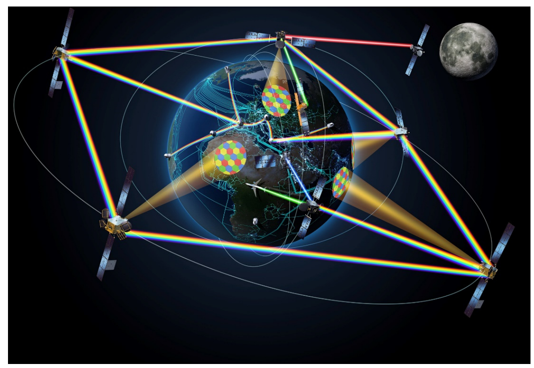

Fig. 1. Artist impression of HydRON vision of an optical space network integrated into terrestrial network infrastructures. HydRON interconnects different satellite assets by means of "The Fibre in the Sky" (image © ESA).

The aim of future telecom satellites is to become inter-operable (in a seamless manner) with terrestrial high capacity networks, providing capabilities not available in terrestrial communication systems (e.g., ubiquity, mobility, multicast / broadcast), rather than continuing the provision of services in an isolated way, or offering satellite bandwidth to internet service providers. Indeed, satellite services are nowadays not (yet) an integral part of the terrestrial network architecture.

For that purpose, the implementation of high data rate bidirectional space / ground links (optical SGL - OSGL) is envisaged, as well as on-board processing capabilities (optical cross-connect, optical add & drop multiplexer) compatible with broadband switching operations. This enables connecting to other satellites with similar payload processing capabilities (via high data rate optical inter-satellite links, optical ISL - OISL), and to transmit traffic back to the terrestrial high capacity network via the ground

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segment. Such an implementation allows the space and ground segments of HydRON to become inter-operable with terrestrial high capacity transport networks, as shown in Fig.1.

HydRON Project objectives

The mission statement of the HydRON Project is to develop and validate the “Fibre in the Sky” technology integrated in terrestrial networks at Terabit capacity demonstrated by European and Canadian Industries by 2025-2026 timeframe.
In order to fulfil such mission statement it is necessary to:

1. Define the full end-to-end architecture of the visionary HydRON System that meets the needs of its identified potential users on the medium / long term;
2. Define and implement a HydRON Demonstration System (HydRON-DS) that allows the demonstration and validation of the essential technologies by European and Canadian industries by 2025-2026.

HydRON Users

The service targeted by HydRON is a ubiquitous optical transport network in space capable of carrying data among the HydRON users at very high throughputs in spite of time-varying network topology. HydRON will provide a seamless integration with other terrestrial high capacity optical transport networks.
Four categories of HydRON users have been identified so far:

- Telecommunication Satellite Operators: operators of telecommunication satellites in either GEO, MEO or LEO orbits, currently feeding their satellites via several dedicated RF band gateways. Those operators, instead of developing their own RF gateways infrastructure, can feed their satellites via the HydRON optical gateways and the HydRON network in space, see Fig.1 (top)
- Terrestrial Network Operators: terrestrial operators can expand their terrestrial network and services with the HydRON space network, seamlessly integrated with the terrestrial network, see Fig.1 (bottom).
- Satellite / Airborne Users: institutional and commercial satellites (e.g. Copernicus, Cubesats, HAPS, deep space/lunar satellite etc.) and airborne systems which need to transfer data to/from ground, in a timely and cost-efficient manner, can use the HydRON space network instead of their own dedicated gateways.
- Private Network Users: users with private networks, for instance due to more

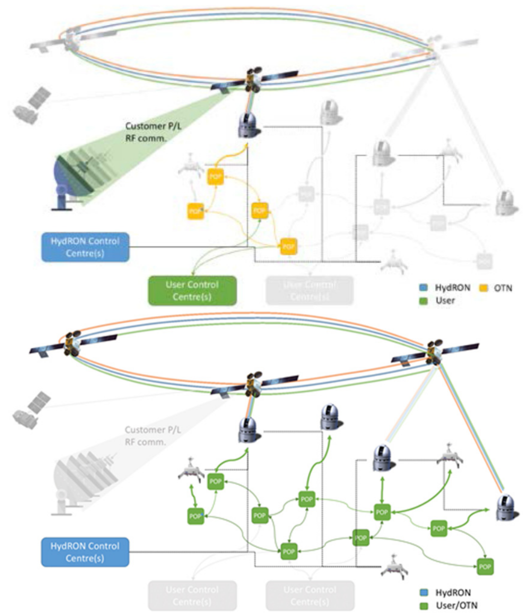

Fig. 2. HydRON Users: (top) Telecommunication Satellite Operators, (bottom) Terrestrial Network Operators.

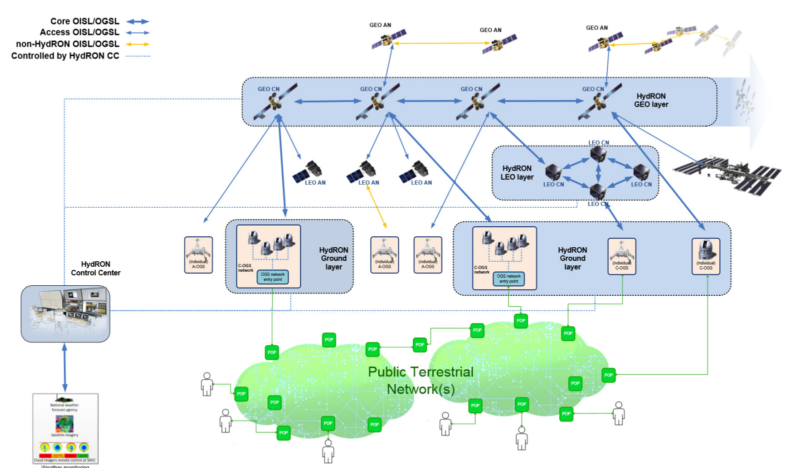

Fig. 3: HydRON System architecture.

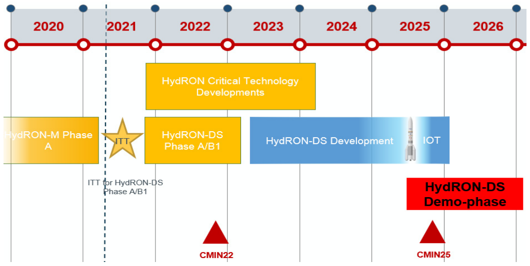

Fig. 4. HydRON Project schedule.

stringent security requirements or high data volumes (e.g. banks, governmental services, oil stations, data centres, etc.) can transfer data from A to B by connecting to the HydRON optical gateways closest to A. Then data is transferred via HydRON space network up to the HydRON optical gateways closest to B, where the user can again pick up the data via an own dedicated network.

HydRON System

The HydRON end-to-end System architecture is composed of the following main elements:

- Space Segment;
- Ground Segment;
- User Segment;
- Network Management, orchestrating Space, Ground and User Segments.

The HydRON Space Segment is constituted by HydRON payloads embarked either on a third-party host platform or on a dedicated platform. The HydRON payloads can be located in GEO, MEO and LEO orbits and encompasses:

- Laser Communication Terminals (LCT) capable of establishing high data rate OISL and OGSL
- elements to implement on-board data routing / switching / forwarding

The HydRON Ground Segment is constituted by network(s) of optical ground stations (OGS) capable of establishing high data rate ground-to-space links.

The User Segment refers to user's equipment interfacing with HydRON. It is implemented across both Space and Ground Segments.

The Network Management guarantees the management and control of the overall HydRON System and network elements, ensuring an effective routing of the user data in the face of time-varying network topology. In particular, in this context, the Network Management covers the set of functions that (i) manages the network topology by configuring LCT and OGS, which allocate capacity by activating lightpaths on each optical link, and (ii) controls network routing by configuring each on-board / on-ground switch.

The various HydRON elements and type of optical links are schematically outlined in the HydRON System architecture depicted in Fig 3.

Activity Ref.	Activity Title
	SPACE SEGMENT – PAYLOAD
	1. Optical Repeaters and Photonics
5F.018	WDM Laser Sources at 1064nm
5F.019	Low-noise optical pre-amplifier at 1064nm
5F.020	WDM High-Power Optical Amplifier at 1064nm
5F.021	WDM High-Power Optical Amplifier at 1550nm
5F.022	LEO/GEO Optical Switch Matrices 25x25
5F.024	100 Gbps free-space experiment using fibre optical transceivers
	2. Optical Communication Terminals and Equipment
5G.019	Optical technologies for next generation high throughput optical inter-satellite links
	3. GROUND SEGMENT
6C.006	Reliable GEO Optical Feeder Link demonstration
6C.007	Reliable LEO Optical Feeder Link demonstration
6C.008	Aircraft detection system for Optical Ground Stations
6C.009	Turbulence monitoring equipment
6B.090	Machine learning in optical communication systems

Fig. 5. Preliminary list of HydRON CTD.

HydRON Demonstration System

The implementation of the full HydRON System is considered beyond the scope of the current HydRON Project, taking into account estimated financial envelope and effort. Instead, the HydRON Project will define, develop and validate a representative HydRON Demonstration System (HydRON-DS) reducing the complexity of a full system to key elements and targeting the provision of a minimum viable service.

HydRON Project schedule

Fig.4 presents the schedule of the HydRON Project. The HydRON System described above has been investigated during the HydRON-M Phase A study.

The HydRON-DS Phase A/B1 study is planned to start in 3rd quarter 2021. The HydRON-DS Development phase will expand from 2023 until 2025 (including launch and in-orbit testing), after which the Demonstration phase will follow in 2025-2026.

Critical Technology Developments

In parallel, ESA has initiated / will initiate several activities to investigate the state of the art of optical and digital technologies of relevance to the HydRON-DS and to start early breadboard and space assessment of critical technology developments (CTD), to achieve the required maturity levels essential for the system architecture trade-offs. The current list of CTD to be implemented within the ScyLight programme is summarized in Fig.5.

Conclusion

ESA has recently concluded the assessment of the HydRON System presented in this paper towards the (medium / long term) HydRON Vision. Next, the "Fibre in the Sky" concept will be validated by implementing the HydRON-DS in the 2025-2026 timeframe.

References

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

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

[3] H. Hauschild et. al., “HydRON: High thRoughput Optical Network”, in *Proceedings SPIE 11272, Free-Space Laser Communications* XXXII, 112720B (2 March 2020).

[4] H. Hauschild et. al., “HydRON: High thRoughput Optical Network”, in *Proceedings of SPIE 10910, Free-Space Laser Communications* XXXI, 109100K (4 March 2019)