POST-DOCTORATE PROPOSAL

Title : Development of unsupervised predictive control approach for optical GEO feeder links, through model identification. Analysis of the extension to LEO-feeder links.

Reference: **PDOC-DOTA-2025-10**
(to be recalled in all correspondence)

Start of contract: 2026	**Application deadline: 2025**

Duration: 18 months

Keywords : Adaptive Optics, Telecommunication, predictive control, unsupervised control approach.

Profile and skills required:

The candidate shall demonstrate skills in adaptive optics, control and data processing. Experience in experimental testing not required but may be a plus.

Presentation of the post-doctoral project, context and objective:

Onera is a world leader in Adaptive Optics, and its various applications including astronomy, optical telecommunication, biomedical imaging. In the recent years, Onera has developped a full optical ground station FEELINGS (see picture), in addition to in lab optical set ups, to investigate space-to-ground laser communication and associated research topics.

Indeed, the fast development of satellite constellations and saturation of radio-frequency based communication lead to an increasing interest for high capacity optical links between the ground and telecommunication satellites, either in Low Earth Orbit (LEO) or Geostationnary Earth Orbit (GEO). Currently the most appealing configuration relies on bidirectional links : links with GEO satellite, so-called GEO-Feeder links, aiming at about one Terabit/s, are currently under development, while feasibility of the more challenging LEO-Feeder links is still under investigation. The strong requirements in performance of such systems imply mitigating the impacts of atmospheric turbulence. These effects not only lead to an average attenuation of the optical signal but also cause severe and prolonged fading events (exceeding 15 dB) that last for several milliseconds, significantly outlasting the symbol duration of less than a nanosecond. The mitigation of these effects is therefore essential to reach the required data rates.

In GEO as well as in LEO case, Adaptive Optics (AO) is used on the ground side to sense and correct for atmospheric turbulence effects on the downlink beam, before injection in a single mode fiber. According to the reciprocity principle, the same corrective measure applied to mitigate atmospheric turbulence effects on the downlink can also be effective for the uplink, if used as a pre-compensatory technique. Specifically, this involves pre-deforming the uplink beam with the identical correction before its emitted from the ground station. However, in practice, the effectiveness of this approach is limited due to the inherent point-ahead angle. This angle between downlink and uplink beams is imposed by the differential velocity between the ground station and the satellite on its orbit. This point-ahead angle limits the efficiency of the uplink pre-compensation (anisoplanatism effect) and therefore the uplink performance [Bonnefois-2022], in particular in the LEO case.

In GEO as in LEO, specific control laws shall be considered to ensure proper optimisation of the uplink precompensation. Linear Quadratic Gaussian predictive control has been investigated at Onera and a specific strategy proposed, presently under experimental validation in the lab and on sky [Robles-2023, Lognoné-2022]. The control strategy relies on turbulence statistics and AO components models that need to be identified. This identification shall be performed quickly and regularly. Indeed, turbulence conditions will quickly evolve along time, particularly in the LEO case due to the evolution of turbulence conditions along the pass of the satellite in the sky, which is only a few minutes. Still, telecommunication stations shall be designed in the perspective of autonomous commercial use, ensuring the highest throughput any time. As a consequence, to ensure optimal

control strategy along time, real-time identification strategies associated to on-line adjustment of the control parameters (models) shall be considered, with minimum computation load.
The work will thus focus on developping and evaluating unsupervised predictive control, meaning without human intervention, by extension of the proposed control strategy to integrate on-line identification of turbulence statistics, and possibly AO system drifts.
Different strategies shall be considered :

- First it can be based on the identification of current turbulence or system conditions, possibly focusing on well chosen integrated parameters and performing direct recomputation and adjustment of the models. This can take opportunity of the measurements and priors on the observation conditions such as the satellite trajectory.
- Second, direct assessment of the aforementioned models from the data (data-driven modelling) can be considered. AI approaches shall also be considered, either to evaluate integrated parameters of models.

In each case, performance shall be balanced with computational burden. The student shall first focus on the GEO feeder link case, and evaluate the possible extension to future LEO feeder links.

This work will first rely on the numerical simulation tools developed at ONERA, covering both LEO and GEO communcation feeder links. But this work shall aim at experimental validation using the ONERA optical ground station FEELINGS [Petit-2022]. This OGS is located close to Toulouse, includes a telescope and an optical set-up embedding adaptive optics to demonstrate and investigate GEO-feeder links with AO pre-compensated uplink beam. It offers the possibility of in situ validation and first hand data, with clear evolution of turbulence conditions along time. For validation of concepts in well understood conditions, a lab plateform based on a turbulence emulator, PICOLO, coupled to an AO system LISA is also available. This post-doc participates to pioneering works on feeder links, as no demonstration in lab and on-sky of unsupervised precompensated feeder links have been reported yet.

This post-doctorate position is funded through the PEPR ORIGIN project.

[Bonnefois-2022] Aurélie Montmerle Bonnefois, et al. "Feasibility demonstration of AO pre-compensation for GEO feeder links in a relevant environment." Optics express 30.26 (2022): 47179-47198

[Petit-2022] C. Petit et al. "FEELINGS : the ONERA's optical ground station for Geo Feeder links demonstration", ICSOS conference Proceeding, (2022).

[Lognoné-2022] P. Lognoné et al. "Phase Estimation at Point-Ahead Angle for AO Pre- Compensated Ground to GEO Satellite Telecoms". Optics Express, December 2022.

[Robles-2023] P. Robles. "Optique adaptative pour la communication optique LEO-sol :

Modélisation, optimisation et expérimentation", PhD, 2023

Papers can be provided on request

Feelings optical ground station at Fauga Mauzac.

External collaborations :

University of Durham, Laboratoire d'Astrophysique de Marseille

Host laboratory at ONERA:

Department: Optics and Associated Techniques

Location (ONERA center): Châtillon

Contact: Cyril Petit

Phone: +33 1 46734754 Email : Cyril.petit@onera.fr