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PROPOSITION DE SUJET DE THESE

Intitulé : Adaptive optics with predictive control for space to ground optical telecommunication : towards on sky validation with FEELINGS

Référence : **PHY-DOTA-2024 -15**
(à rappeler dans toute correspondance)

Début de la thèse : Octobre 2024	**Date limite de candidature :** Mars 2024

Mots clés:

Optique adaptative, Télécommunications optiques, observation de l'espace, turbulence, contrôle-commande, validation expérimentale

Profil et compétences recherchées :

profil ingénieur, écoles généralistes, ou master, compétences automatique, optique, traitement du signal

Présentation du projet doctoral, contexte et objectif :

Context:

The exponential growth of the needs in data transfer drives 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 ground / satellite optical links, or feeder links. Links with GEO satellites, so-called GEO-Feeder links, aiming at about one Terabit/s, are currently under test, while feasibility of LEO feeder links is still under investigation. Links with LEO are thus mostly downlinks today.The strong requirements in performance of such systems imply innovative developments on all the segments of the chain: high power sources, modulation/demodulation format and handling of the propagation channel. The latter segment concerns mainly the management of atmospheric turbulence effects that induce not only a mean loss on the optical signal but also deep fadings (>15 dB) with long durations (few milliseconds) compared to the symbol time. The mitigation of these effects is therefore essential to reach the required data rates.

In LEO as in GEO, Adaptive Optics (AO) is used to correct for the downlink beam. In the LEO case however, as the satellite scrolls quickly through the sky, the adaptive optics has to face fast evolving turbulence and should correct for the perturbations some angle in advance.

The reciprocity principle allows showing that the downlink correction is also relevant to pre-compensate the uplink beam. However this principle is partly valid due to the point-ahead angle, this angle between down and uplink beams is imposed by the differential dynamics 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 [Conan-2019]. This is a current limitation in GEO and a true challenge in LEO here again due to its fast evolution in the sky meaning large point-ahead-angle.

On the whole, a similar problem of turbulence prediction and correction some angle in advance limits the communication performance either on the dowlink or uplink, with some differences in cinematics between GEO and LEO, and AO shall include some predictive scheme to reduce this effect. Such a prediction could represent a game changer in the development of feeder-links.

ONERA has developped for more than 20 years predictive control approaches, and more recently has proposed solutions for LEO and GEO cases : a real-time dynamic control solution based on Linear Quadratic Gaussian approach and Vector AutoRegressive Models to perform temporal prediction for LEO downlinks [Robles-2022], a static Minimum Mean Square Error reconstruction approach based on angular correlation of phase and scintillation for GEO uplinks [Lognoné-2022]. These approaches share some common ground and now need to be developped and coupled towards effective implementation on a real system to be confronted to the experimental issues. In particular these approaches rely on models of the turbulence statistics that needs to be estimated.

In that prospect, ONERA has developped an optical ground station, FEELINGS [Petit-2022], located close to Toulouse, including a telescope and an optical set-up embedding adaptive optics to test GEO and LEO dowlinks and demonstrate GEO-feeder links with AO pre-compensated uplink beam.

The proposed work focuses on effective implementation and experimental testing of the control strategy developped for LEO dowlinks, as well as its evolution to address the GEO uplinks.

Such implementation relies on specific calibrations of AO components, in particular of the wavefront sensor, as well as identification of turbulence statistics. The student shall investigate preliminary strategies to calibrate the wavefront sensor response and identify the turbulence models. Performance brought by the predictive control with respect to the telecom criteria will be assessed and compared to numerical simulation. Comparison with other control strategies shall be considered, in particular comparison of the current modal approach with zonal approaches. The student shall evaluate the sensitivity of the performance to the calibrations and identification steps, and assess strategies to populate the necessary models from telemetry and turbulence identification.

Based on analytical and numerical analysis, the student shall consider the experimental implementation, first in the lab using a turbulence emulator, PICOLO [Robles-2023], and the LISA AO bench [Lim-2018], before real implementation on the FEELINGS optical ground station for on sky testing.

In summary, the PhD work will provide in situ demonstration of predictive control as well as innovative concepts associated to it, for downlinks and feeder links. This PhD is positioned right in between the theoretical concepts and their on sky validation and offers the possibility to access to one of the few Adaptive Optics assisted optical ground station in the world.

This PhD will be directed by B. Neichel (LAM) and co-supervised by C. Correia. It is funded by the European PEPR Origin program.

[Conan-2019] J.-M. Conan et al., "Adaptive Optics for GEO-Feeder Links: from performance analysis via reciprocity based models to experimental demonstration," COAT-2019 (2019).

[Lim-2018] Lim, C. B.,et al. "Single-mode fiber coupling for satellite-to-ground telecommunication links corrected by adaptive optics". In SF2A-2018: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics.

[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-2022] P. Robles et al, "Predictive adaptive optics for satellite tracking applications: optical communications and satellite observation", SPIE Astro. Tel. and Instr. Proceeding, (2022).

[Robles-2023] Pablo Robles et al, "Emulating and characterizing strong turbulence conditions for space-to-ground optical links: The PICOLO bench". JATIS, 2023. To be published.

Paper can be provided on request.

Collaborations envisagées : LAM

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