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PROPOSITION DE SUJET DE THESE

Intitulé : Adaptive Optics and Multi-Aperture Diversity for Ground-Space Optical Communications

Référence : **PHY-DOTA-2024-18**
(à rappeler dans toute correspondance)

Début de la thèse : A partir d'octobre 2024	**Date limite de candidature :** Mars 2024

Mots clés :

Turbulence, adaptive optics, aperture diversity, digital communications, optical telecommunications

Profil et compétences recherchées :

Master 2 or Engineering schools with majors in Physics, Optics, Telecom, Physics or Signal Processing.
Skills : Optics, digital communications, modeling tools

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 satellite, so-called GEO-Feeder links, aiming at about one Terabit/s, are currently under development, while feasibility of LEO feeder links is still under investigation. The strong requirements in performance of such systems imply the development of innovative solutions on all the segments of the transmission chain: high power sources, modulation/demodulation format, coding/decoding schemes and handling of the propagation channel. The latter segment concerns mainly the modeling and management of atmospheric turbulence effects that induce not only a mean loss on the optical signal but also the 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. It relies both on optical and digital communication deployed strategies that will be the heart of the present research subject.
Two competing optical strategies, to be deployed on the groundside, are currently studied for turbulence mitigation: Adaptive Optics (AO), and multi-aperture diversity. Focusing on the uplink, AO pre-compensation on a single large aperture is limited in performance due to point-ahead anisoplanatism [Lognoné-2023a]. Hence the multi-aperture diversity alternative that consists in averaging out turbulence effects via multiple emitters on small apertures and at different wavelengths with the drawback of a reduced spectral efficiency. We believe however that recent developments in these two fields are about to change the overall system optimisation. Indeed, our current PhD student has found a very innovative approach that significantly reduces AO point-ahead anisoplanatism [Lognoné-2023a,b], while, in the meantime, new techniques using polarisation, phase and spectral division [Fuchs-2022] are progressively improving the spectral efficiency of multi-aperture diversity.

Research project:
The PhD work is triggered by these recent developments and aims at a joint optimization of optical and digital communication strategies so as to take advantage of the overall channel diversity by exploiting all the degrees of freedom of the channel: spatial, spectral and polarization domain. We aim to investigate in particular hybrid solutions consisting of multiple AO corrected medium size apertures together with smart telecom modalities (modulation format, channel coding, interleaving, MIMO (Multi-Input Munti-Output) coding/decoding...). Reaching this objective implies addressing various research topics:

- study and optimization of the uplink channel with AO assisted multi-aperture configurations in the presence of point ahead anisoplanatism: impact of aperture number and diameter, means to obtain incoherent beam summation while keeping good spectral efficiency,
- study of the diversity of the uplink channel with AO assisted multi-aperture configuration, theoretical assessment of performance limits (channel capacity),
- optimization of the digital signal processing (DSP) modules as modulation format, channel coding/decoding and MISO (Multi-Input Single-Output) schemes.

In summary, the PhD work will provide innovative concepts allowing unprecedented high performance and high data rate optical links from ground to LEO/GEO satellites. Novelty is based on the co-design of optical and digital communication strategies exploiting channel diversity and all physical degrees of freedom of the channel at hand. This work should have a strong impact on the design of future operational systems.

Environment:
The PhD student will have access to ONERA simulation tools (semi-analytical models and end-to-end code TURANDOT-AOST) [Canuet-2018, Lognoné-2023a,b]. The PhD student will also benefit from unique experimental results coming from: FEEDELIO, the first experimental demonstration of uplink pre-compensation on a slant line of sight relevant of the ground-GEO scenario [MontmerleBonnefois-2022] ; and complemented recently by the VERTIGO terrain demonstration of high data rate optical links, obtained in July 2022 on a 53 km line of sight, in the framework of a EC H2020 funded project [Horst-2023]. The PhD student will therefore also benefit from this international collaboration environment.
Besides, this PhD work will be performed in close collaboration with Ghaya Rekaya (Professor at Telecom Paris) who is expert in digital communication and more particularly in MIMO systems. She has also several contributions on DSP for Space-Division Multiplexing Optical fiber communications, and is CEO of MIMOPT, a recently created startup working in this field.

*L. **Canuet**, N. Védrenne, J.-M. Conan, C. Petit, G. Artaud, A. Rissons & J. Lacan, "Statistical properties of single-mode fiber coupling of satellite-to-ground laser links partially corrected by adaptive optics," JOSA A, 35(1), 148-162 https://doi.org/10.1364/JOSAA.35.000148 (2018).*

*C. **Fuchs**, D. Giggenbach, R. Mata Calvo & W. Rosenkranz, "Optical Transmitter Diversity With Phase-Division in Bit-Time." 2022 IEEE International Conference on Space Optical Systems and Applications (ICSOS). IEEE, https://doi.org/10.1109/ICSOS53063.2022.9749729 (2022).*

*Y. **Horst**, B. I. Bitachon, L. Kulmer, J. Brun, T. Blatter, J.-M. Conan, A. Montmerle-Bonnefois, J. Montri, B. Sorrente, C. B. Lim, N. Védrenne, L. Pommarel, D. Matter, B. Baeuerle, J. Leuthold, "Tbit/s Line-Rate Satellite Feeder Links Enabled by Coherent Modulation and Full-Adaptive Optics ", Light Sci Appl 12, 153 https://doi.org/10.1038/s41377-023-01201-7 (2023).*

*P. **Lognoné**, J.-M. Conan, G. Rekaya Ben Othman, and N. Védrenne, "Phase estimation at the point ahead angle for AO pre compensated ground to GEO satellite telecoms", Optics Express https://doi.org/10.1364/OE.476328 (2023a).*

*P. **Lognoné**, J.-M. Conan, G. Rekaya Ben Othman, L. Paillier, and N. Védrenne, "Two aperture measurements for GEO feeder adaptive optics pre compensation optimization", Optics Lett. https://doi.org/10.1364/OL.495200 (2023b).*

*A. **Montmerle Bonnefois** et al. "Feasibility demonstration of AO pre-compensation for GEO feeder links in a relevant environment," Opt. Express 30, 47179-47198 https://doi.org/10.1364/OE.470705 (2022).*

Collaborations envisages:

Beyond the collaboration ONERA / Telecom Paris, the project will benefit of our contacts with the following partners: CNES, ESA, ADS, TAS, ETH Zürich…

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