

Mitigating the impact of pointing errors in a 1 Tbps OWC link through PCS and AGC-amplification

Marco A. Fernandes, Paulo P. Monteiro, and Fernando P. Guiomar

Instituto de Telecomunicações and University of Aveiro, Campus Universitário de Santiago, 3810-193, Portugal.

marcofernandes@av.it.pt



instituto de
telecomunicações

10th November 2022
The 3rd Optical Wireless Communication Conference

Who are we?



Paulo Monteiro – Group Leader / Senior Researcher / Associate Professor
<https://www.it.pt/Members/Index/448>



Fernando Guiomar – Senior Researcher
<https://www.it.pt/Members/Index/4556>



Gil Fernandes – Post-Doc Researcher
<https://www.it.pt/Members/Index/5475>



Marco Fernandes – PhD Student
<https://www.it.pt/Members/Index/27781>



Manuel Freitas –MSc Student



Leonardo Nascimento – Former MSc Student

It is becoming real ...

Free Space Optics Communication Market to reach \$2 Bn by 2027; Global Market Insights Inc.

Major players operating in the free space optics (FSO) communication market are AVDA Optical Networking SE, Airlinx Communications Inc, Collinear Networks, Excellence Networks, Fsona Networks, and Mostcom JSC.

December 08, 2021 07:30 ET | Source: Global Market Insights Inc.

Space Communications And Navigation Program

Terabyte Infrared Delivery 200Gb/sec Laser Communications System for LEO Direct-to-Earth Missions (TBIRD)

Completed Technology Project (2017 - 2021)



Project Introduction

Satellites in low-Earth orbit (LEO) have on-board sensors that can generate large amounts of data to be delivered to a ground user. Direct-to-Earth delivery from LEO is challenging because of the sparse contact with a ground terminal, but the short link distances involved can enable very high data rates by exploiting the high bandwidth of the optical link.



Carillon Awarded DARPA Contract for Next Generation Satellite-to-Satellite Free Space Optical Communication (FSOC)

Effort exemplifies Carillon's mission to provide DoD secure access to cutting-edge commercial technologies

September 23, 2021 02:00 AM Eastern Daylight Time

WEST HARTFORD, Conn.--(BUSINESS WIRE)--The Defense Advanced Research Projects Agency (DARPA) has awarded Carillon Technologies a \$6.4M contract to prototype next generation satellite-to-satellite communication systems derived from cutting edge commercial Holographic Optical Beam Steering (HOBS) technology.

Alphabet's X tests Free Space Optical Communications in Congo, beams 700TB across 5km

Partnership with Liquid Intelligent Technologies comes out of failed Loon project

September 16, 2021 By: Sebastian Moss Comment



Alphabet sent nearly 700TB across 4.8 kilometers using beams of light.

The Project Taara initiative, spun out of the [failed Loon effort](#), relies on Free Space Optical Communications to send data in free space - that is, not through a medium like fiber.

Taara's FSOC can create a 20Gbps+ broadband link from two points that have a clear line of sight.

In this experiment, the Google sister company set up the system between Brazzaville in the Republic of the Congo and Kinshasa in the Democratic Republic of Congo.

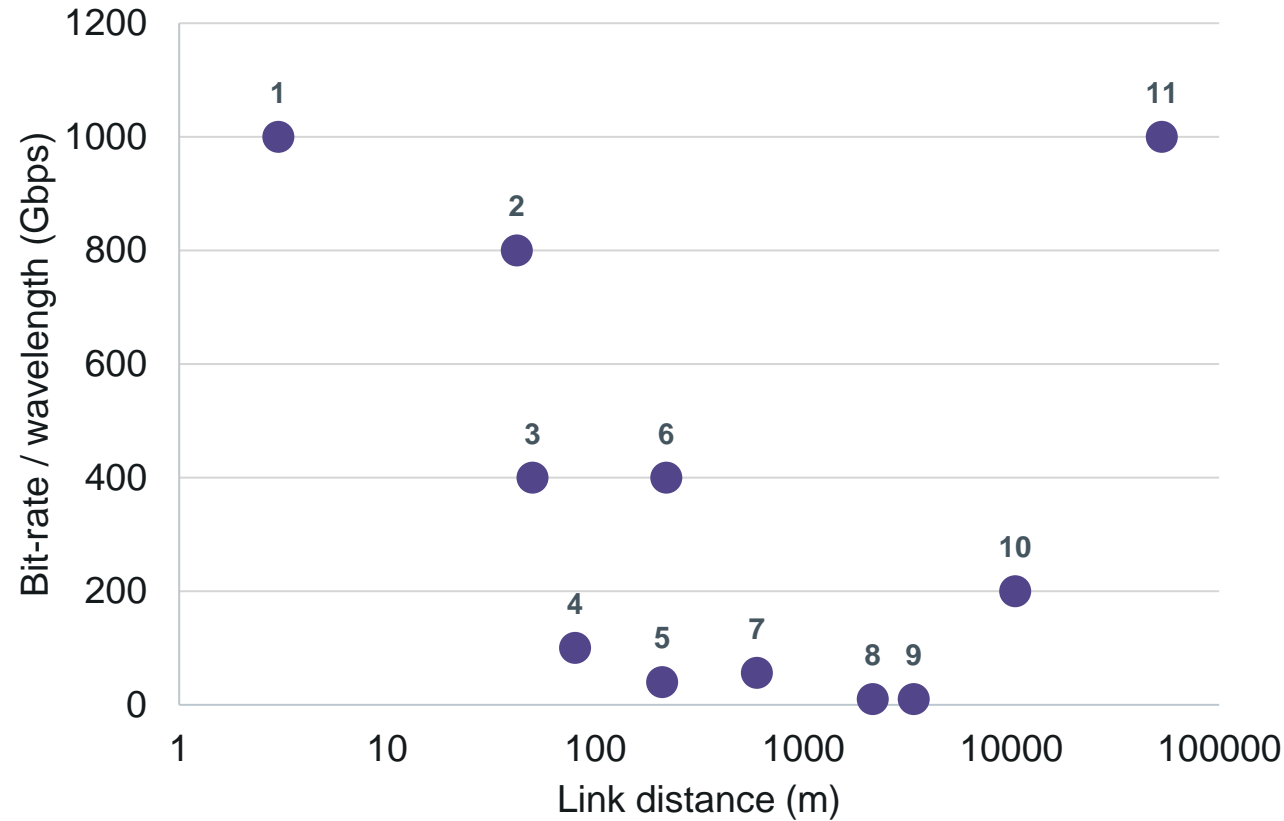
chose the location because it was the only place to travel more than 400kms to the Congo River, whereas this just beam data over the river.

it transferred 700TB with 99.9% reliability.



— Alphabet/X

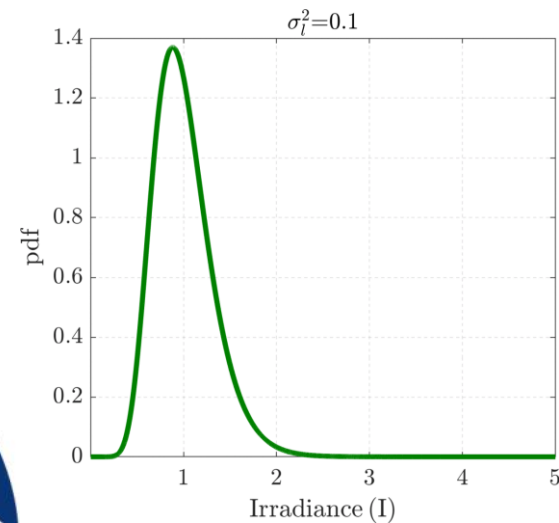
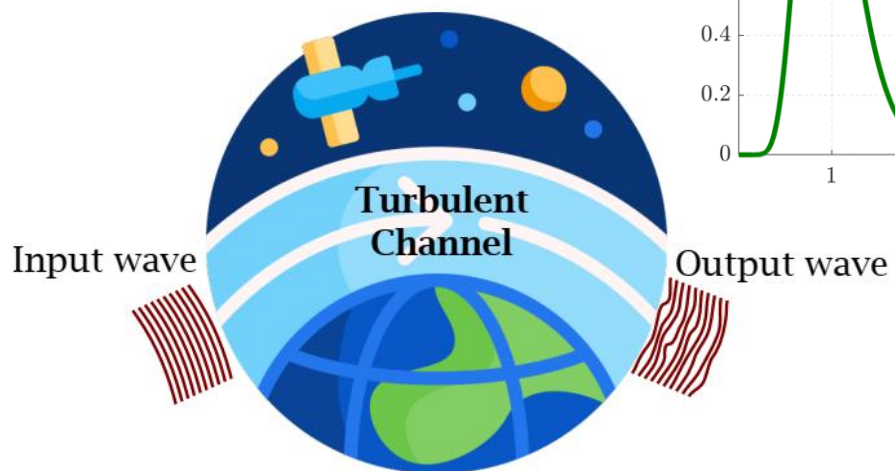
It is going further (and faster) ...



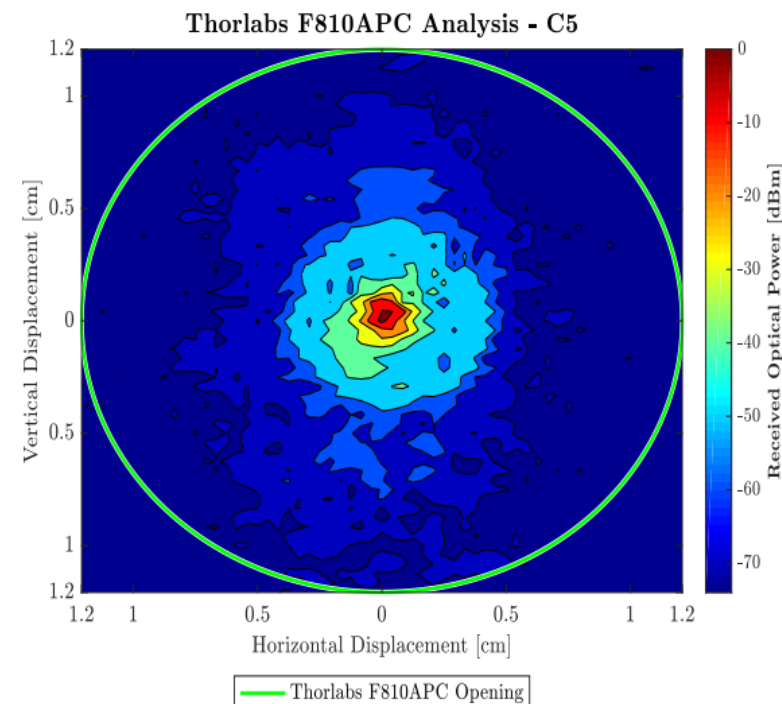
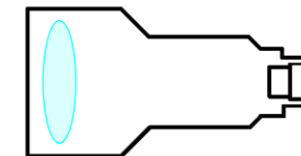
1. M. A. Fernandes, *et al*, "Free-Space Terabit Optical Interconnects," in Journal of Lightwave, 2022.
2. F. P. Guiomar, *et al*, "Coherent Free-Space Optical Communications: Opportunities and Challenges," in Journal of Lightwave Technology, 2022.
3. M. A. Fernandes, *et al*, "Highly Reliable Outdoor 400G FSO Transmission Enabled by ANN Channel Estimation," 2022 Optical Fiber Communications Conference, 2022.
4. Giorgia Parca, *et al*, "Optical wireless transmission at 1.6-Tbit/s (16x100 Gbit/s) for next-generation convergent urban infrastructures," Optical Engineering, 2013.
5. E. Ciaramella, *et al*, "1.28 terabit/s (32x40 Gbit/s) WDM transmission system for free space optical communications," in IEEE Journal on Selected Areas in Communications, 2009.
6. K. Matsuda *et al*, "Field Demonstration of Real-time 14 Tb/s 220 m FSO Transmission with Class 1 Eye-safe 9-aperture Transmitter," Optical Fiber Communications Conference, 2021.
7. H. -W. Wu *et al*, "A 448-Gb/s PAM4 FSO Communication With Polarization-Multiplexing Injection-Locked VCSELs Through 600 M Free-Space Link," in IEEE Access, 2020.
8. Pei-Lin Chen *et al*, "Demonstration of 16 channels 10 Gb/s WDM free space transmission over 2.16 km," IEEE/LEOS Summer Topical Meetings, 2008.
9. Moon-Cheol Jeong *et al*, "8 x 10-Gb/s terrestrial optical free-space transmission over 3.4 km using an optical repeater," in IEEE Photonics Technology Letters, 2003.
10. A. Dochhan, *et al*, "13.16 Tbit/s Free-space Optical Transmission over 10.45 km for Geostationary Satellite Feeder-links," Photonic Networks, 2019.
11. B. I. Bitachon, *et al*, "Tbit/s Single Channel 53 km Free-Space Optical Transmission Assessing the Feasibility of Optical GEO-Satellite Feeder Links," European Conference on Optical Communication, 2022.

Is it easy?

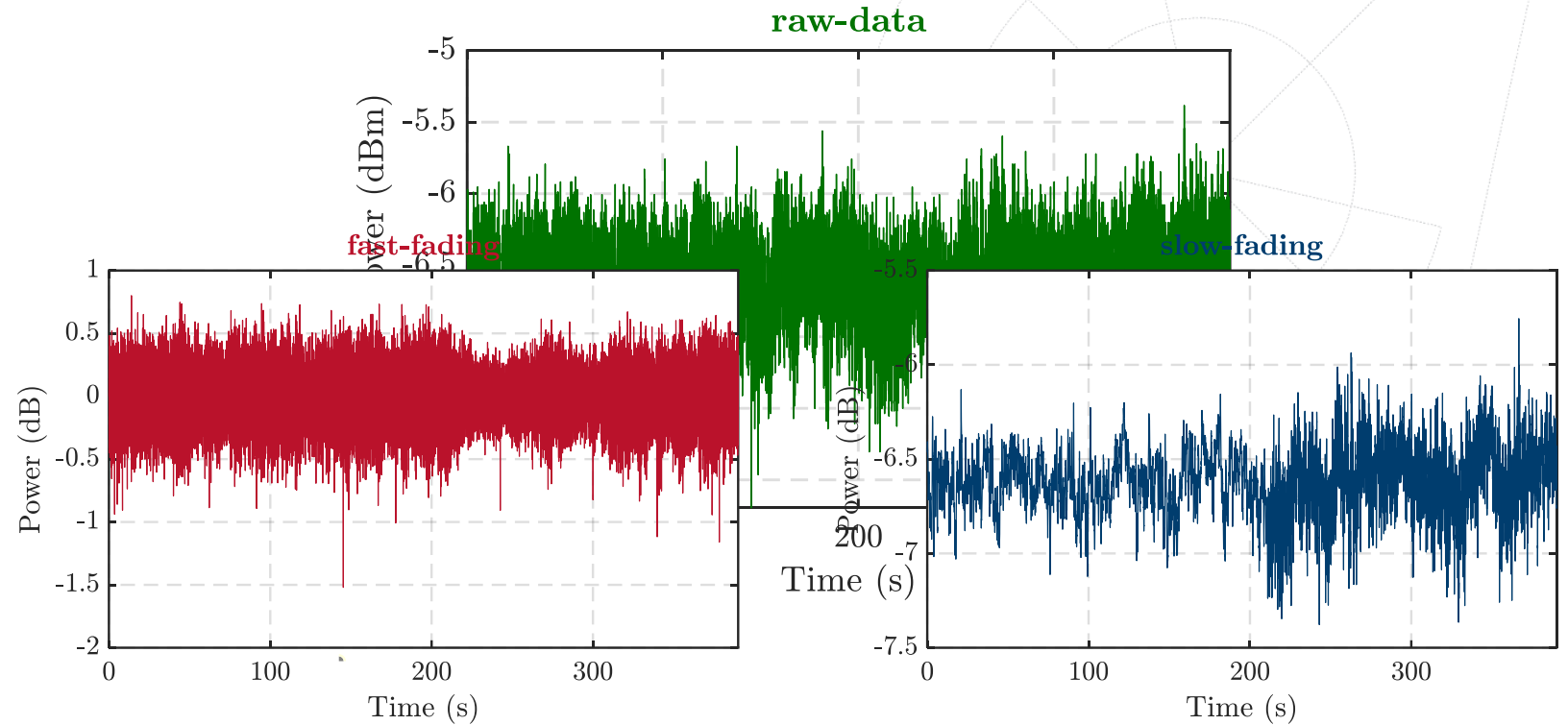
Atmospheric turbulence



Pointing errors



Adapting to the FSO channel



Resulting mainly from atmospheric turbulence, with coherence times between 1 – 10 ms.

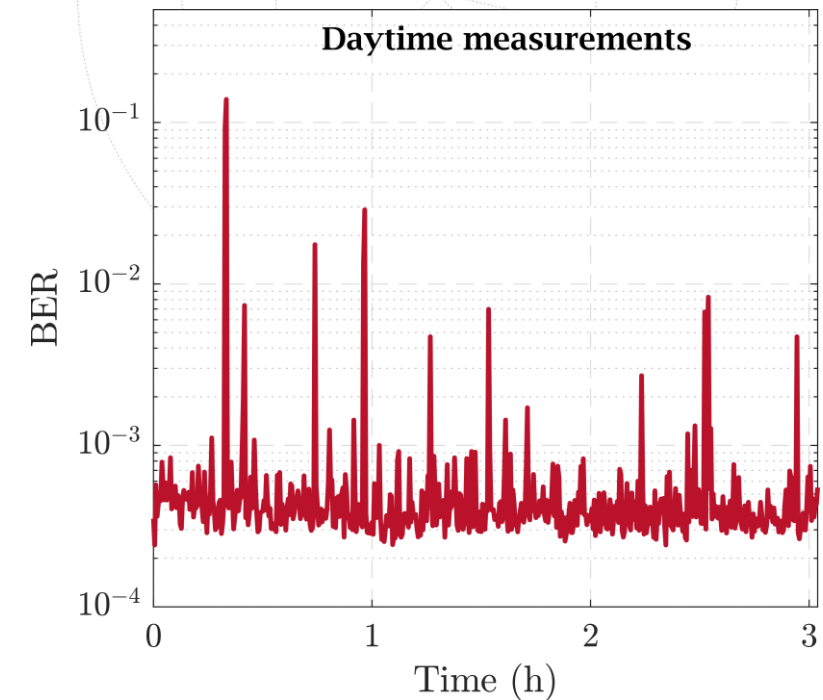
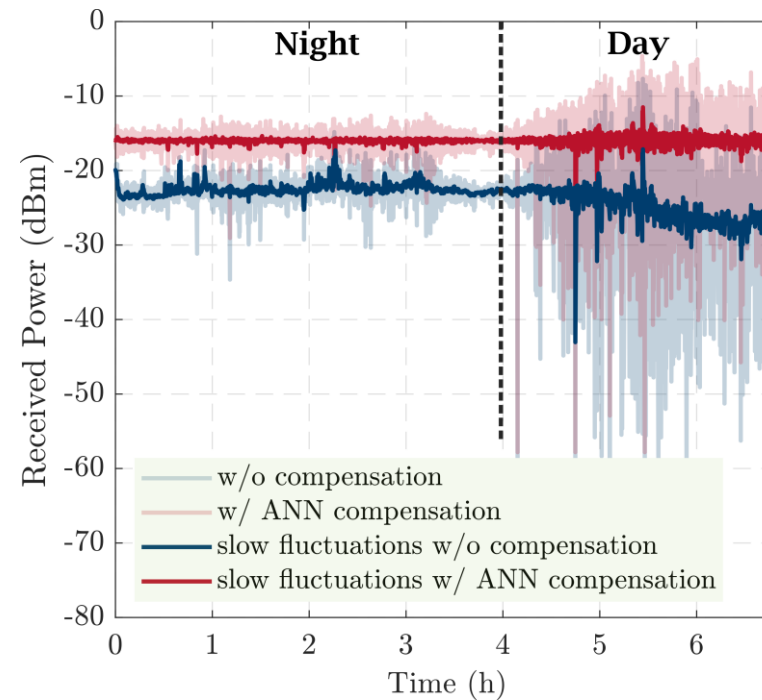
Has a considerable slower impact in the link. Can result from weather changes, pointing errors, ...

Adapting to the FSO channel



400G transmission with NN channel estimation (power control)

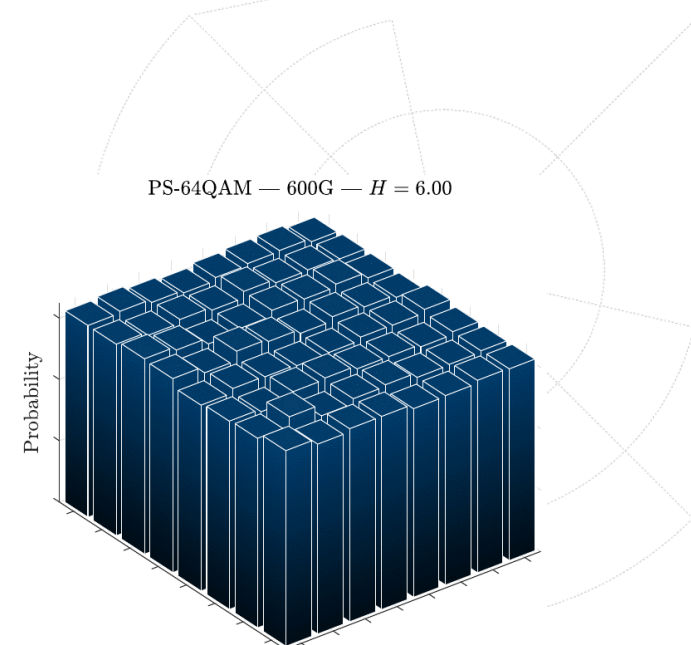
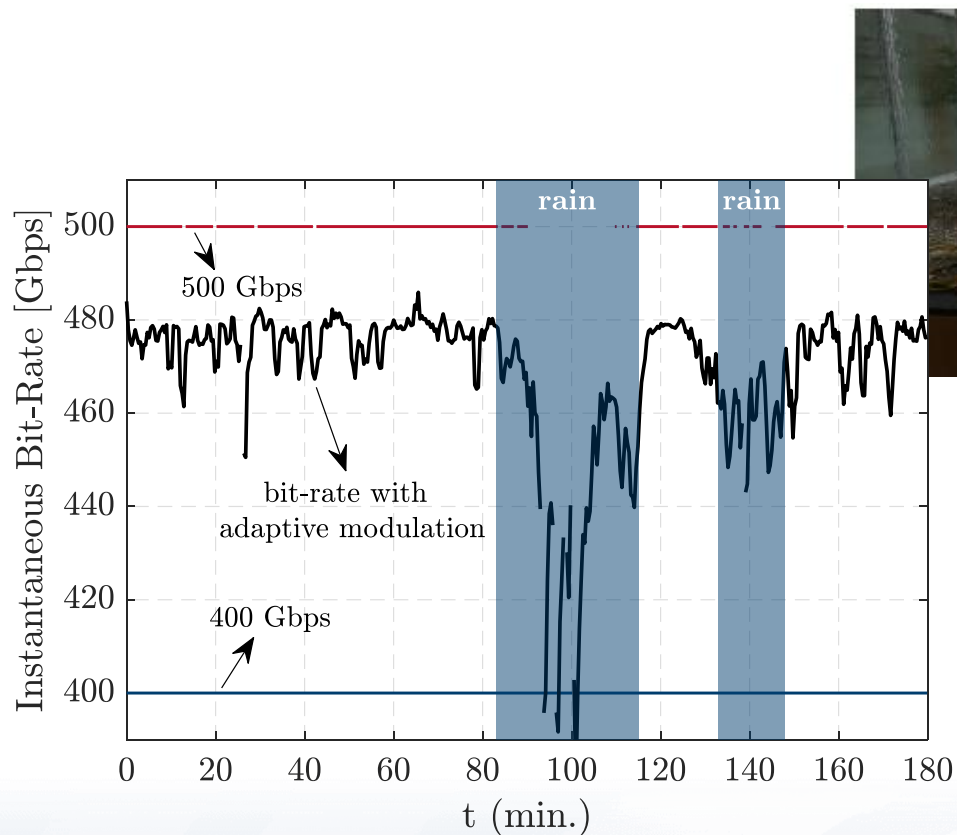
<https://ieeexplore.ieee.org/document/9748439>



Adapting to the FSO channel

400G+ transmission with adaptive bit-rate

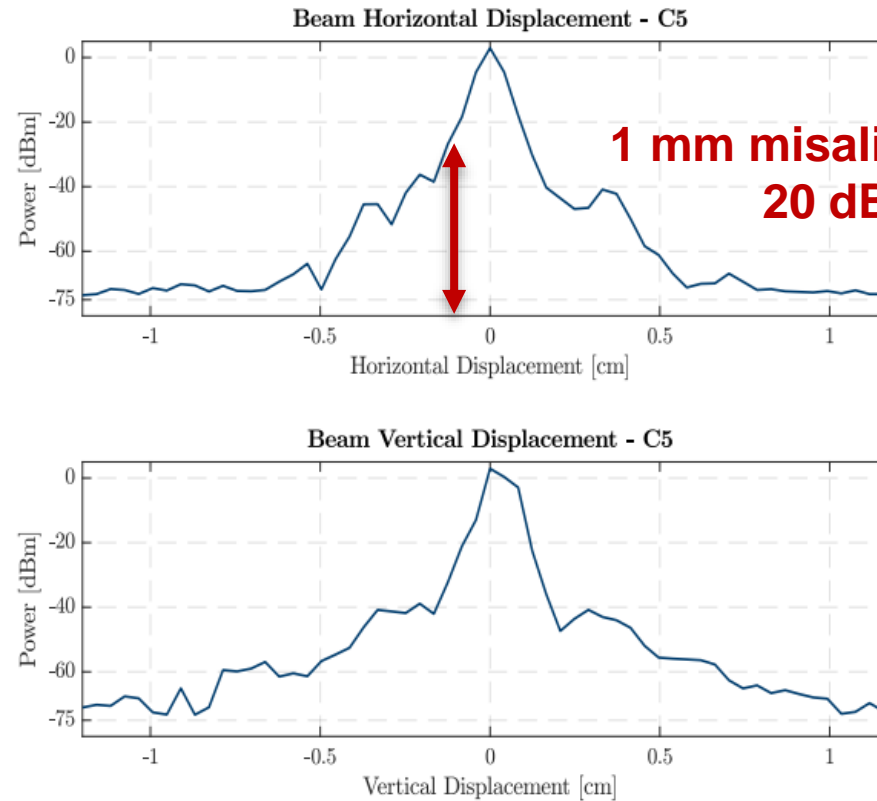
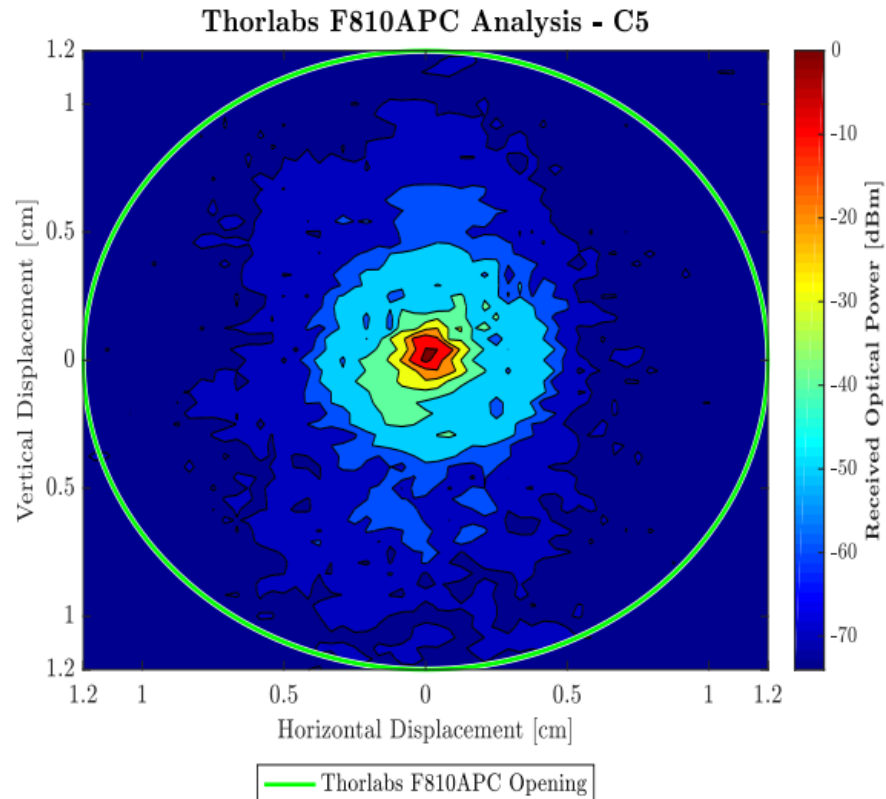
<https://ieeexplore.ieee.org/document/9152099>



- **A little bit more:**

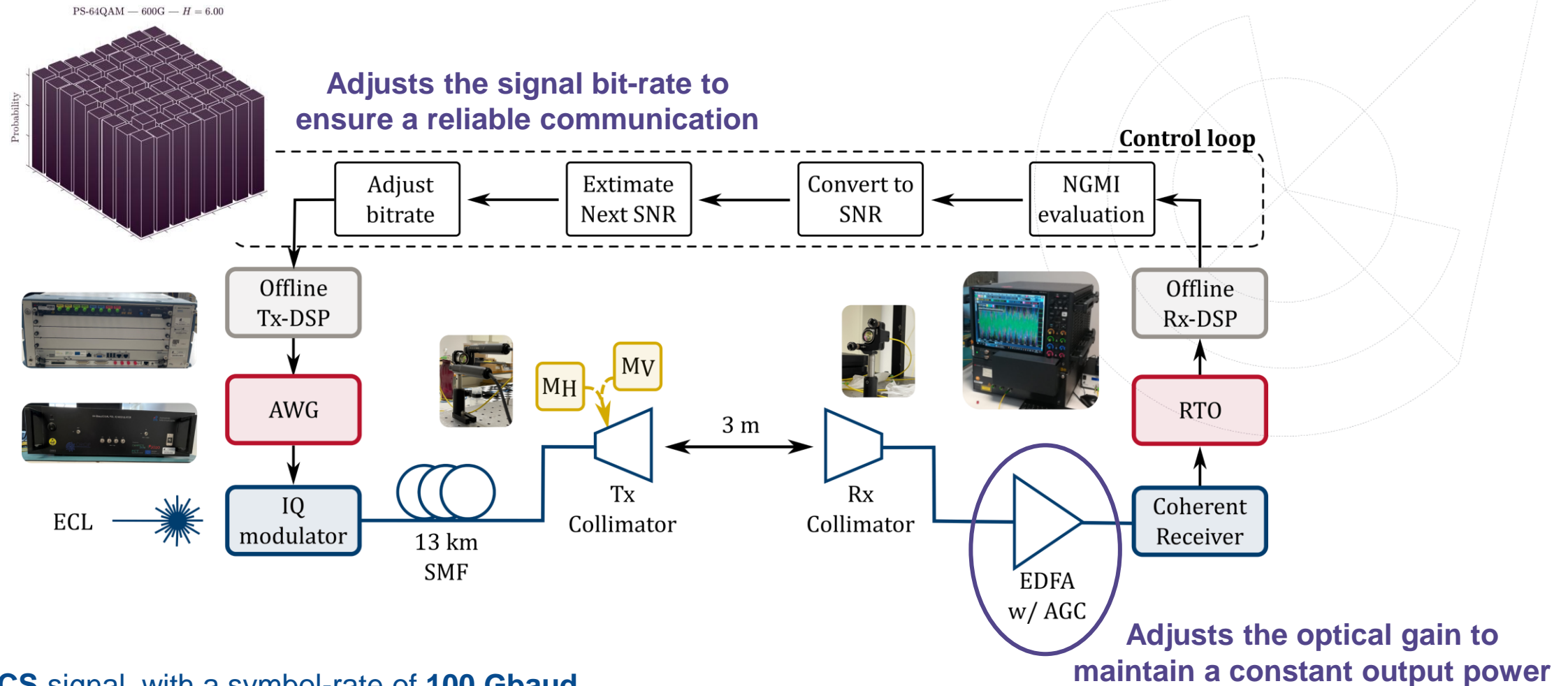
- 200 G outdoor free-space-optics link using a single-photodiode receiver, Abel Lorences-Riesgo *et al* @ JLT
- Adaptive probabilistic shaped modulation for high-capacity free-space optical links, Fernando P. Guiomar *et al* @ JLT
- Single-Wavelength Terabit FSO Channel for Datacenter Interconnects Enabled by Adaptive PCS, Marco A. Fernandes *et al* @ OFC2021
- 400G MIMO-FSO Transmission with Enhanced Reliability Enabled by Joint LDPC Coding, Marco A. Fernandes *et al* @ ECOC2021
- Free-Space Terabit Optical Interconnects, Marco A. Fernandes *et al* @ JLT
- Coherent Free-Space Optical Communications: Opportunities and Challenges, Fernando P. Guiomar *et al* @ JLT

Why do we need a good alignment?



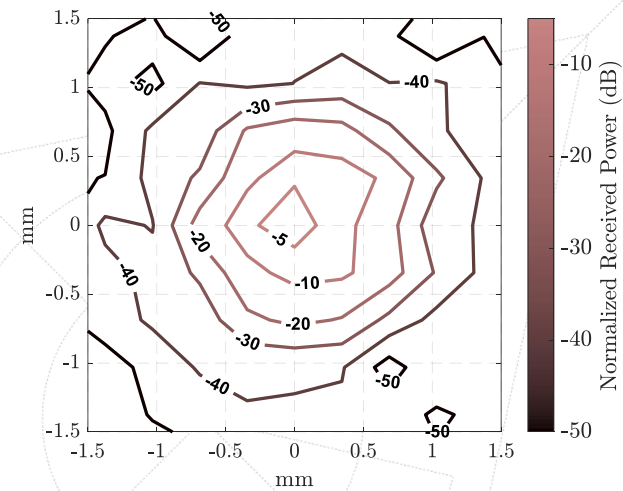
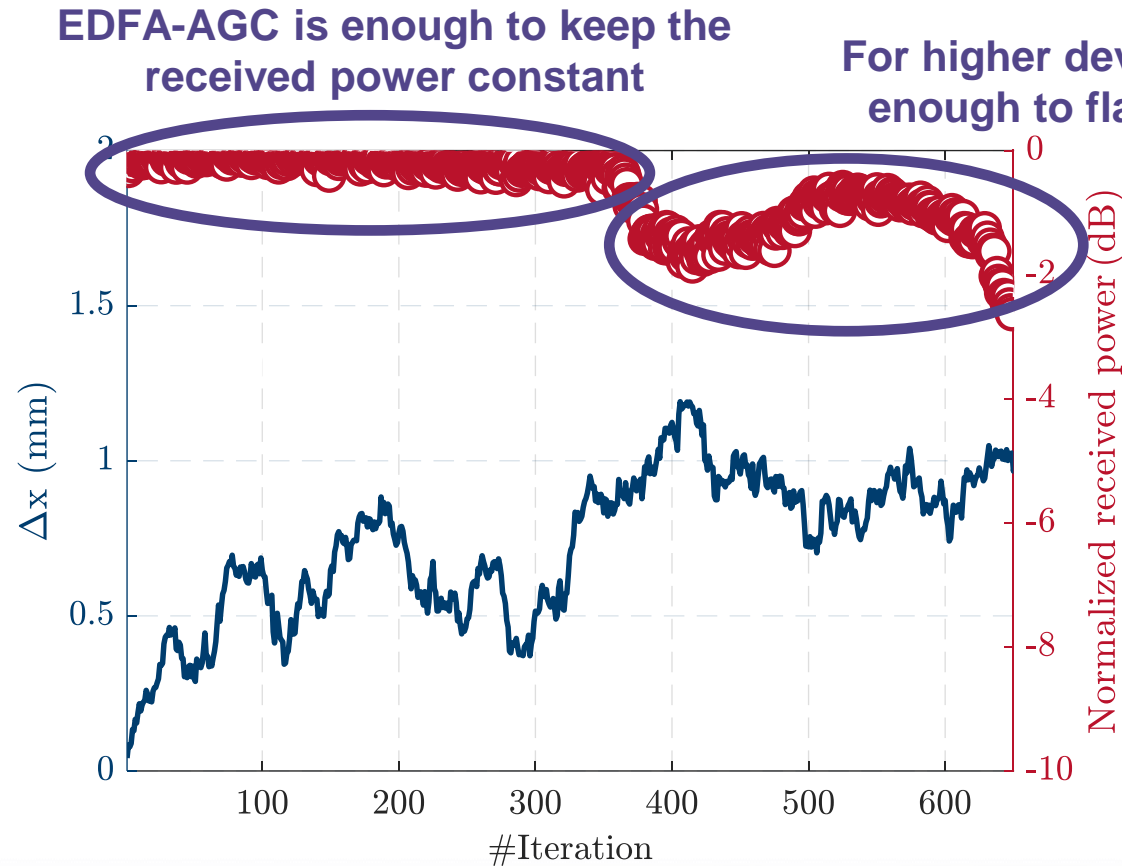
1 mm misalignment corresponds to 20 dB of power losses

Can we go around these requirements?



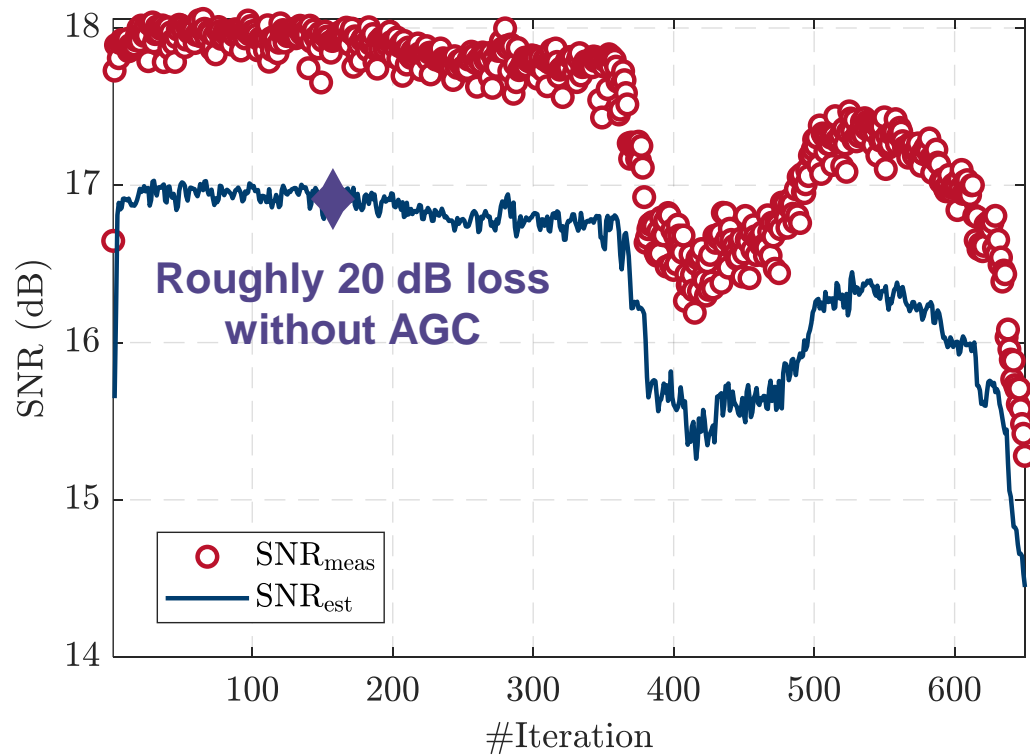
- **64QAM-PCS** signal, with a symbol-rate of **100 Gbaud**.
- **Goal:** Use PCS and AGC to adjust the bitrate to account for sequential beam misalignment.

Is AGC enough?



- As we degrade the link alignment, the losses are too high to be compensated by the EDFA-AGC. In these scenarios, we can exploit PCS to create a dynamic channel while maintaining reliability.

How do we create a dynamic channel?



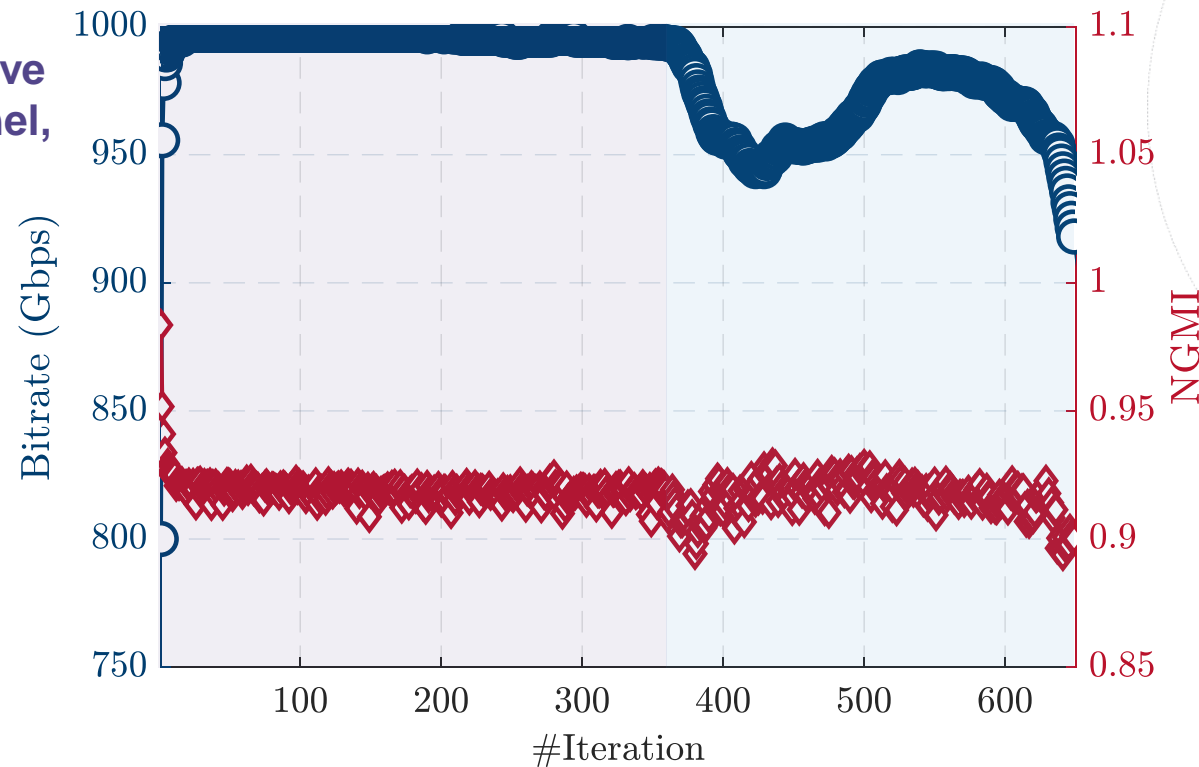
Exploiting the correlation between successive pointing errors we can estimate:

$$\text{SNR}_{\text{est}}(n+1) = \frac{1}{N} \sum_{n-N+1}^n \text{SNR}_{\text{meas}}(n) - \text{SNR}_{\text{margin}}$$

- $N = 2$;
- $\text{SNR}_{\text{margin}} = 1 \text{ dB}$.

Reaching 1 Tbps

If AGC is enough, we have a constant 1 Tbps channel, and a constant NGMI.



If required, we use PCS to decrease the signal bit-rate, achieving a constant NGMI.

- Even in the worst scenario, we demonstrate a FSO channel capable of supporting 900 Gbps, boosted by AGC and PCS.

Conclusions

- ❑ **Free-Space Optics is a reality, with increasing interest by the scientific community and by the industry.**
- ❑ **We showed the seamless FSO capability for ultra high-capacity transmission, with a single optical wavelength carrying a 1 Tbps bitrate.**
- ❑ **We can use AGC at the receiver to mitigate the power losses due to link misalignment.**
- ❑ **PCS is a viable contender for pointing errors mitigation, adapting the transmitted bitrate to the channel quality.**

A little bit more about our work:


- Bruno T. Brandão *et al* “Cooperative FSO and mmWave System for Reliable 200G Wireless Transmission”, IEEE Photonics Letters:
<https://ieeexplore.ieee.org/abstract/document/9916303>
- Fernando P. Guiomar *et al* “Coherent Free-Space Optical Communications: Opportunities and Challenges”, Journal of Lightwave Technology:
<https://ieeexplore.ieee.org/document/9749848>
- Marco A. Fernandes *et al* “Highly Reliable Outdoor 400G FSO Transmission Enabled by ANN Channel Estimation”, OFC 2022:
<https://ieeexplore.ieee.org/abstract/document/9748439>
- Marco A. Fernandes *et al* “Free-Space Terabit Optical Interconnects”, Journal of Lightwave Technology:
<https://ieeexplore.ieee.org/document/9640495>
- Marco A. Fernandes *et al* “400G MIMO-FSO Transmission with Enhanced Reliability Enabled by Joint LDPC Coding”, ECOC 2021:
<https://ieeexplore.ieee.org/abstract/document/9605896>
- Fernando P. Guiomar *et al* “400G+ Wireless Transmission via Free-Space Optics”, ECOC 2021:
<https://ieeexplore.ieee.org/abstract/document/9606136>
- Fernando P. Guiomar *et al* “Adaptive Probabilistic Shaped Modulation for High-Capacity Free-Space Optical Links”, Journal of Lightwave Technology:
<https://ieeexplore.ieee.org/document/9152099>
- Marco A. Fernandes *et al* “Adaptive optical beam alignment and link protection switching for 5G-over-FSO”, Optics Express:
<https://opg.optica.org/oe/fulltext.cfm?uri=oe-29-13-20136&id=451904>

THANK YOU !

marcofernandes@av.it.pt



FCT Fundação
para a Ciência
e a Tecnologia
2020.07521.BD

 "la Caixa" Foundation
LCF/BQ/PR20/11770015

 **ORCIP**
optical radio convergence
infrastructure for communications
and power delivering