# Defining the constraints of an adaptive optics system applied to free-space optical satellite and aircraft data downlinks

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## Summary

Adaptive Optics (AO) applied to free-space optical (FSO) communications aims to maximize either the power coupled into a single-mode fiber (SMF) or the heterodyne efficiency in coherent-based communications. LEO satellites and aircraft downlinks have to deal with low elevation angles because of the link geometry and short contact time. Due to strong scintillation and phase singularities, below 20°, traditional Shack-Hartmann sensors perform poorly. GEO satellite downlinks have to deal with very low received power levels. Here, we briefly explain the challenges to be addressed by an AO system for communication purposes.

## Introduction

Coupling into an SMF allows connecting the fiber network infrastructure to satellites or aircrafts through the atmosphere. Although a perfect correction is not required like in imaging applications, coupling losses may limit the feasibility of communication due to link budget limitations and strong fading. A partial correction of the wavefront distortions leads to a trade-off between power coupled to an SMF and complexity of the AO System. The reception of a LEO satellite downlink, as compared with astronomy, deals with high phase distortions, singularities and strong scintillation due to the low elevation angles ($\theta$). The time required for the wave-front correction is defined by the smallest auto correlation time (ACT) of the received power, and it ranges between 2.5ms and 0.5ms for $\theta$ from 5° to 60°, respectively [1]**Error! Reference source not found.**. These values include the effect of slew rate of the satellite and the atmospheric wind. For GEO satellite communications an important limiting factor is the low received power level. Traditional AO systems based on least-square estimation are not suitable, since below 20° **Error! Reference source not found.**the phase estimation leads to errors and the performance deteriorates due to strong turbulence [1][2][6]. Thus, an AO system for optical communications must be robust under strong fluctuations and it should demand low received power to reconstruct the phase. It is then necessary to define the requirements of the AO system based on the attainable coupling efficiency (η) and set a trade-off between the amount of power coupled into the SMF and the degree of correction.

## Discussion

Following a modal compensation approach, the number of Zernike modes to be corrected ($Z_j$) sets a trade-off between η and system complexity. Based on equations from [3][7][8] and using the phase residual error $\Delta_j$ from Noll table (considering $\Delta_j \approx 0.2944 j^{-\sqrt{3}/2}(D/r_0)^{5/3}$ from mode j=10 onward), an analysis of η vs. $Z_j$ was performed modifying η with a generalized Fried parameter $\rho_G$ derived from a Strehl Ratio after modal correction ($SR_c$) [8][5]. The saturation effect of the structure function for partially corrected wavefronts is not analyzed in this paper. For the analysis,

$1.3 < D/r_0 < 13.3$ is associated to $r_0$ values of 30cm ($> 40°$) to 3cm (7°), respectively and an OGS telescope diameter of 40cm, see Fig. 1 (left). The values of $r_0$ where obtained from satellite downlink measurements, performed by DLR in 2006 and 2009 from OICETS LEO satellite [4] and scaled to 1550nm.

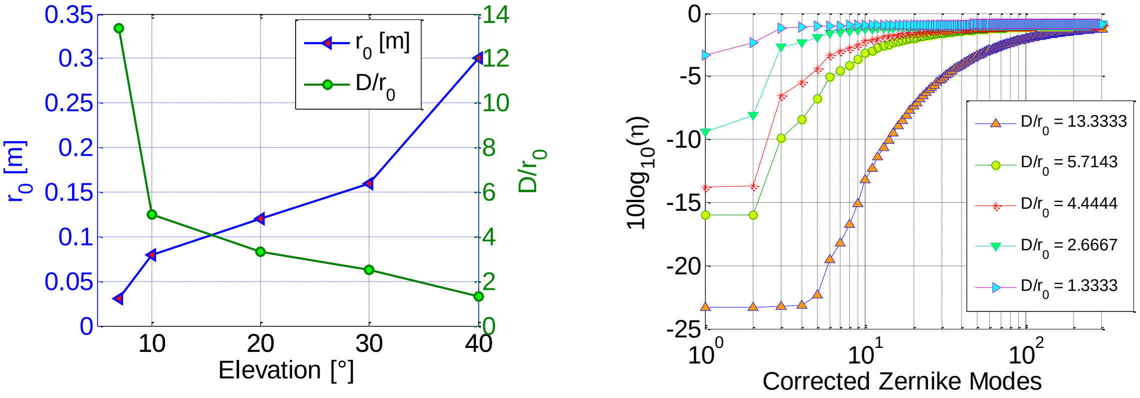

Fig. 1. Values of $\boldsymbol{r_0}$ and $\boldsymbol{D/r_0}$ for LEO sat. λ=1550nm (Left). Curves of η [dB] vs. $\boldsymbol{Z_j}$ for $\boldsymbol{D/r_0}$ (Right).

The Fig. 1 (right) shows that in absence of correction the $\eta < -20dB$ and, at low elevation angles (7°), correcting 30 modes result in coupling losses reduced to 4dB. The same performance is reached by correcting 10 modes under lower turbulence conditions. Also, under strong turbulence ($D/r_0 = 13.3$), improvement is seen after $Z_j > 5$ since the spot power is widely spread around the SMF core position. The $\eta$ values represent an expected mean to achieve a coupling power between 37% and 87% of diffraction limit. Finally, while the coupling losses are a constraint of the link budget, the number of corrected modes impacts on the system complexity, i.e. correcting 30 modes requires a DM with $(j^2 + 3j + 2)/2 \geq 496$ actuators.

## Conclusions

Perfect seeing is not required, but instead optimum coupled power and robust system. Up to 30 $Z_j$ assures $\eta \geq 0.3$ within all analyzed turbulence conditions. Further requirements for communications AO are low complexity, short loop time and low power for phase reconstruction. Theory and results will be experimentally verified in the near future.

## References

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