Available online at www.sciencedirect.com
ScienceDirect
Electronic Notes in DISCRETE MATHEMATICS
Electronic Notes in Discrete Mathematics 64 (2018) 255–264 www.elsevier.com/locate/endm

Ground stations networks for Free-Space Optical communications: maximizing the data transfer

Mikaël Capelle[a,b] Marie-José Huguet[b] Nicolas Jozefowiez[b] Xavier Olive[a]

[a] *Thales Alenia Space France, Toulouse, France*[1]

[b] *LAAS-CNRS, Université de Toulouse, CNRS, INSA, Toulouse, France*[2]

Abstract

Free-space optical communications are becoming a mature technology, but unlike current radio-frequency technologies, they are strongly impacted by clouds. In this paper, we aim to find a network of optical ground stations maximizing the amount of data that can be sent from a low-earth orbiting satellite to the Earth during its missions, taking into consideration cloud information. We present a Mixed Integer Linear Program (MILP) and a hierarchical method based on an exhaustive enumeration of the sets of ground stations and on a dynamic programming algorithm and compare them on real scenarios based on archived years of cloud data. Even if the MILP can solve scenarios over small time horizons in less than one hour, experiments show that the hierarchical approach outperforms it in term of CPU time while achieving optimality.

Keywords: Free-Space Optical Communications, Optical Ground Station Network Optimisation, Dynamic Programming, Mixed-Integer Linear Programming.

[1] Email: `firstname.lastname@thalesaleniaspace.com`

[2] Email: `firstname.lastname@laas.fr`

https://doi.org/10.1016/j.endm.2018.01.027
1571-0653/

1 Introduction

Free-Space-Optical (FSO) communications are seen as a key technology [6] [8] [11] to cope with the needs of higher data-rate payloads for future low-earth orbiting (LEO) observation satellites in replacement to the current radio-frequency (RF) technologies. Current RF technologies use X-Band for download which can currently provide up to a few Gbps [3]. These are not impacted by weather or atmospheric turbulences. Their main drawbacks are limited data-rates and a need for frequency licensing which will become a major issue in the upcoming years due to increases in the number of operational satellites and constellations. *FSO* communications offer data-rate order(s) of magnitude higher than current RF technologies: targeted data-rates go from some tens of Gbps to some Tbps. They do not require frequency licensing and are hard to intercept by malicious observers. However, *FSO* communications are strongly impacted by weather, cloud, and atmospheric turbulences. To evaluate the impact of FSO communications for spatial imagery systems, we aim to find a subset of optical ground stations in order to maximize the percentage of data downloaded from satellites taking cloud information into account using archived data from previous decades.

The optimization of an *Optical Ground Stations Network* taking into account the influence of clouds was first studied by [7] and [13]. Their objective was to find a network for a deep-space probe in order to reach a given temporal availability using an approximation algorithm with a high-resolution database as input. In [12], a probabilistic approach was used to analyze the availability of ground station networks: one in Japan for a geostationary satellite and one worldwide for a low-earth orbiting satellite (LEO) satellite. In [10] and [9], a greedy algorithm was used to find a network in Europe for a geostationary satellite based on data from the *SAF-NWC* cloud database and using an hypothetical substrate network.

In 2012, the *Optical Link Study Group (OLSG)* published a report in which the impact of FSO communications on various space systems (LEO observation satellite, geostationary relay) was evaluated using the *Lazercom Network Optimization Tool (LNOT)*[7].

In Section 2, we will characterize more formally the problem under study and propose a Mixed Integer Linear Program. In Section 3, we will present a hierarchical method based on a dynamic programming algorithm to solve this problem. We will then present our experimental context and the results of our experimentations in Section 4.