

On The Optimal Number of Relays for Nanosatellite Swarm Downlink

Nicolas Gresset-Bourgeois, *TéSA*

Riadh Dhaou, *Toulouse INP*

Emmanuel Lochin, *ENAC*

David Pradas, *Viveris*

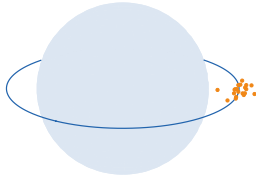
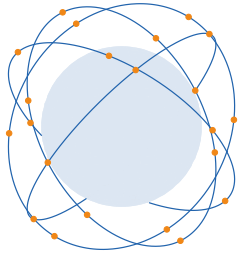
Bernard Pontet, *CNES*

2026-10-12



Motivation and context

- ▶ Nanosatellite swarms in LEO are increasingly popular for Earth / Space Observation, generating large volumes of data

	Swarm	Constellation
Geometry		
Use cases	Space / Earth observation, collaborative & autonomous missions	Earth Observation, Internet access
Examples	Starling, S-NET	Starlink, Planet Labs, IRIS ²

- ▶ How can large volumes of data be downlinked from such swarms within a few orbits?

Outline

Why is it even tricky to downlink from a LEO swarm?

What does the swarm look like from a network perspective?

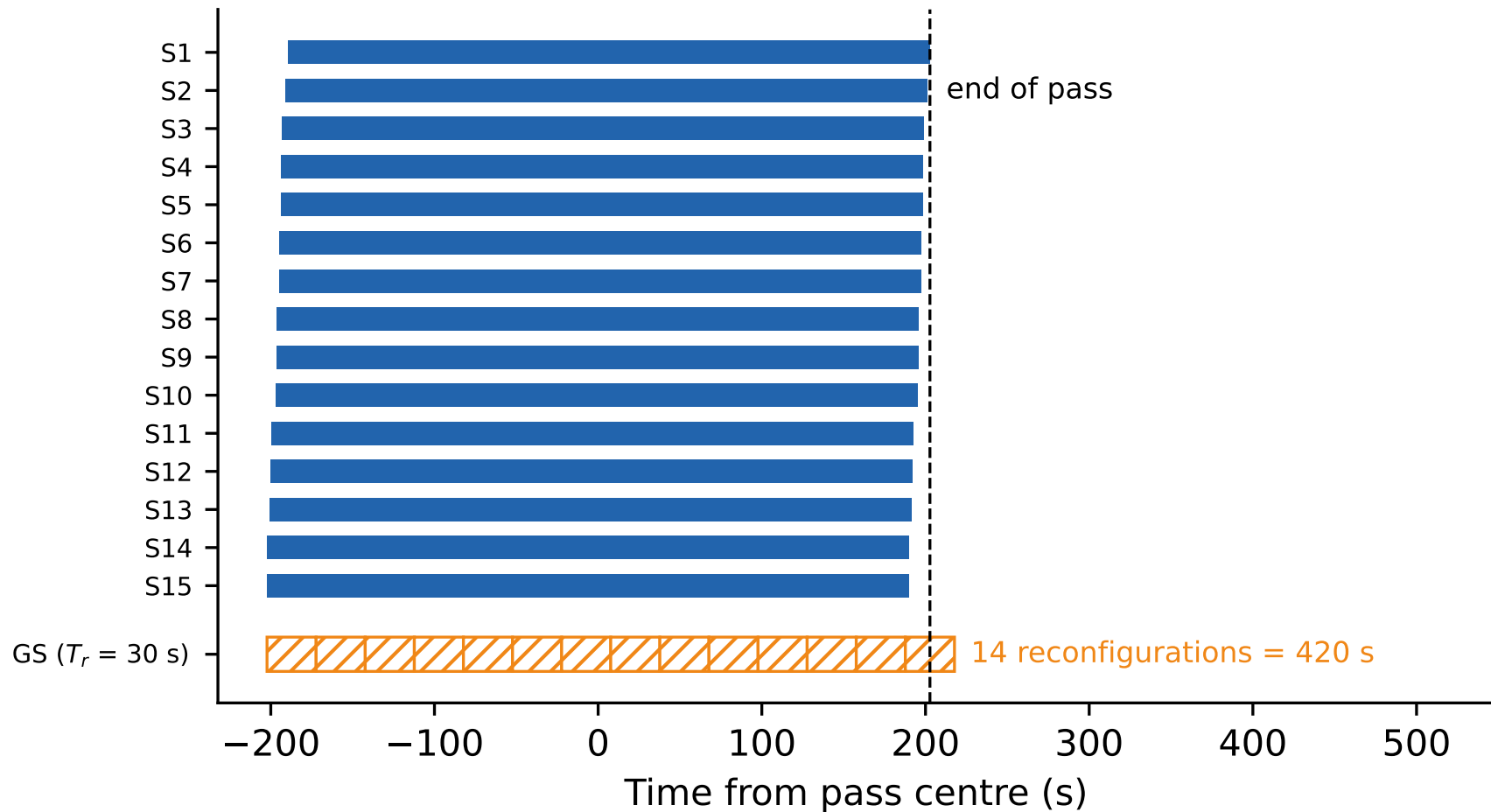
Under what circumstances is it worth using relays?

The ground segment is constrained...

- ▶ **H1** : The GS can only track a single satellite at a time (out of $N \geq 15$)
- ▶ **H2** : It must reconfigure between successive transmissions (up to 70 s !)



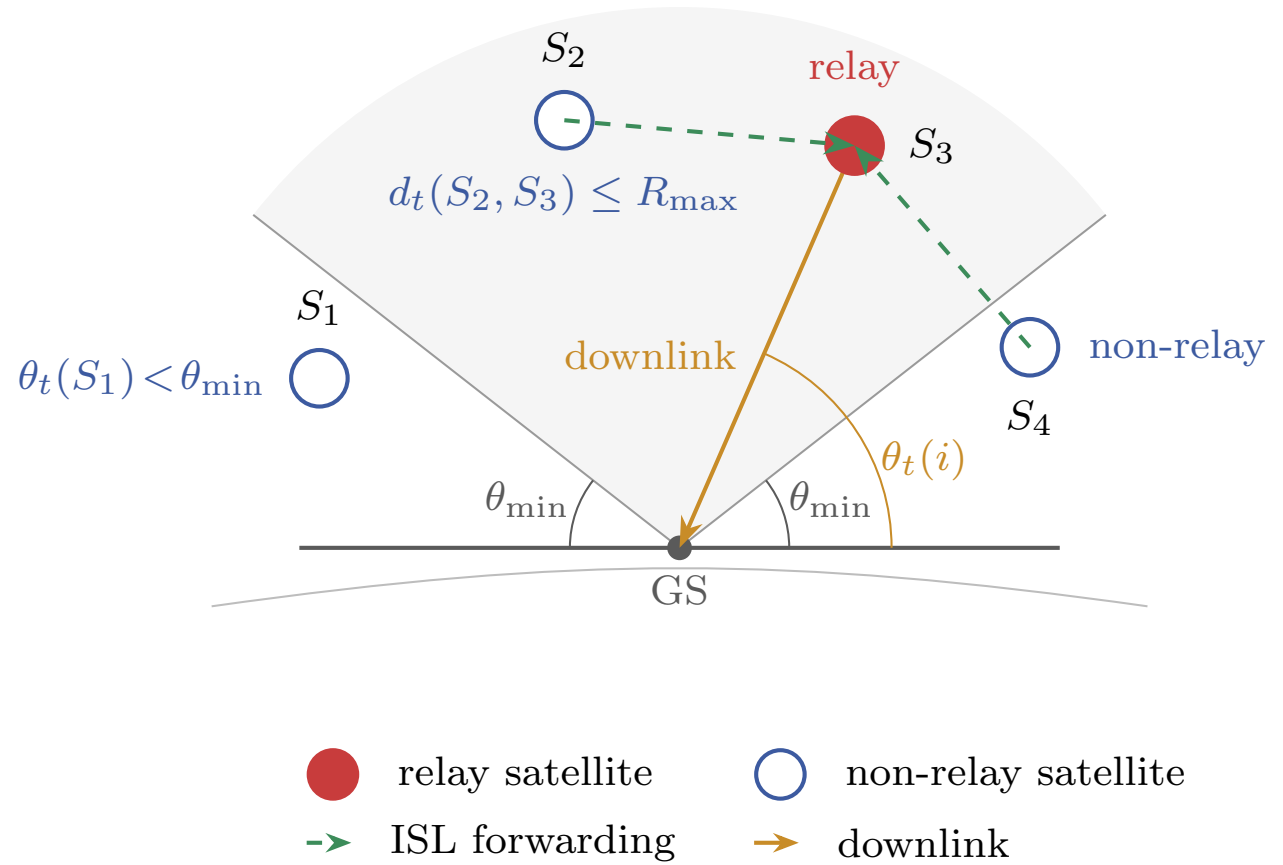
... and the swarm is compact



All 15 satellites compete for access during 94% of the pass

Solution : relay-based offloading

- ▶ **Goal** : maximise data delivered to the GS before deadline: the completion ratio r
- ▶ Investigation of relay-based offloading



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Frequent visibility conflicts & a constrained GS

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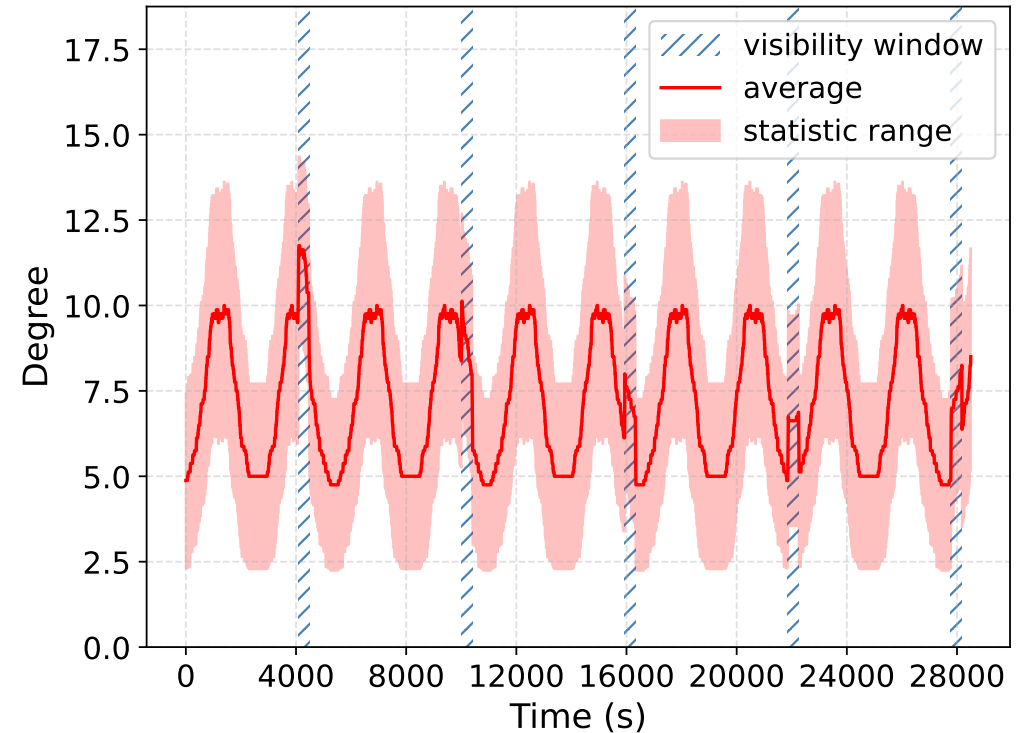
System parameters

- ▶ N orbital parameters sampled from a diagonal multivariate Gaussian
- ▶ Equatorial orbit, GS placed on the equator accordingly

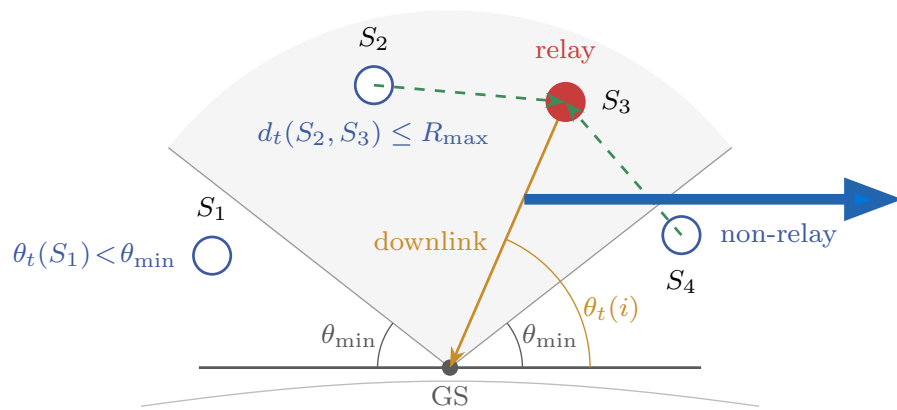
Parameter	Value
Semi-major axis	6770.5 km
Eccentricity	0.001095 ± 0.0015
Inclination	$0 \pm 0.1^\circ$
R_{ISL}	30 km
θ_{min}	10°

Dynamics in action!

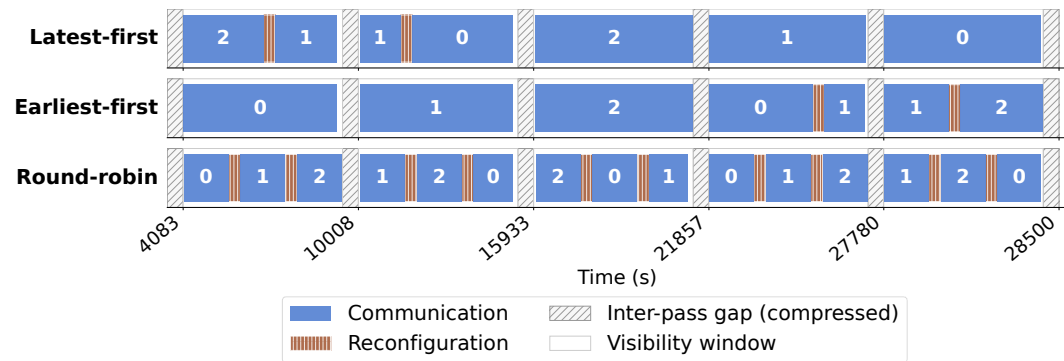
- ▶ Swarm remains confined in a 100 km diameter sphere
- ▶ Alternates between **dense** and **sparse** connectivity phases
- ▶ Duty cycle remains low ($\approx 6\%$)



Downlink scheduling : how to enforce H1 (single-access) and H2 (reconfiguration)?



● relay satellite ○ non-relay satellite
-> ISL forwarding -> downlink



- ▶ 3 different scheduling algorithms tested to remove artefacts (similar results obtained !)
- ▶ Static: computed before the mission starts → load-aware scheduling as a perspective

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What does the swarm look like from a network perspective?

A highly dynamic graph with sparse GS opportunities

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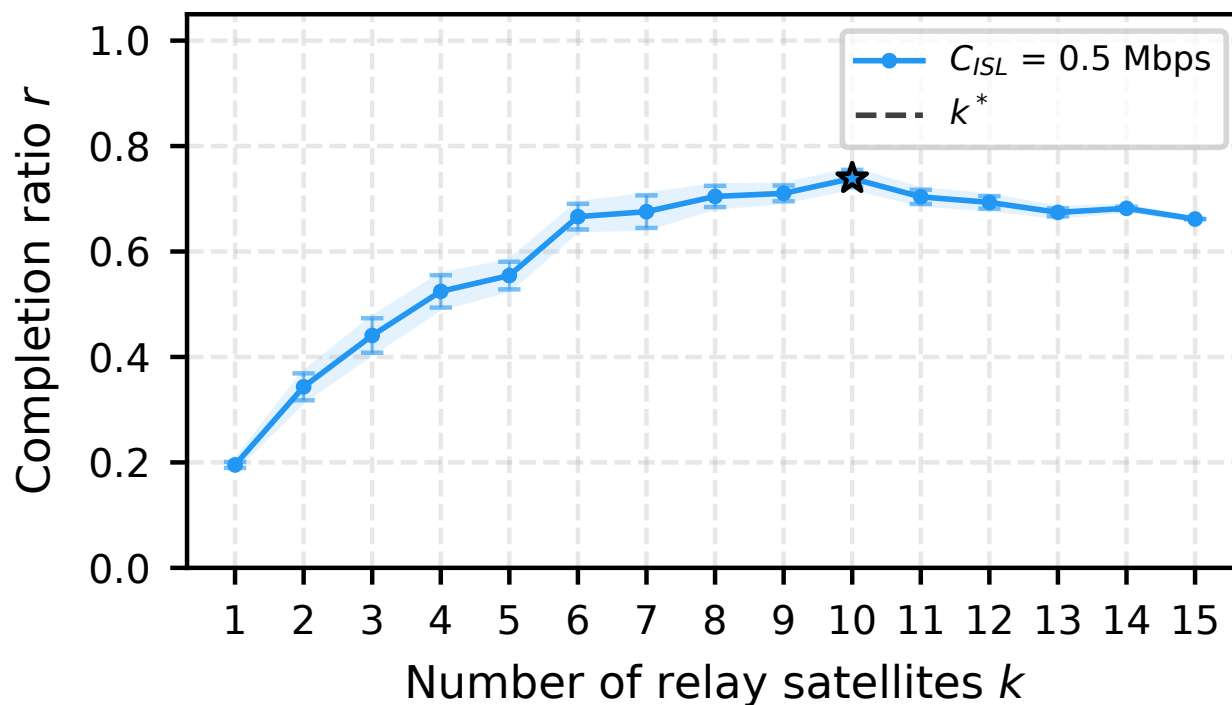
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Overview (reconfiguration time = 70 s)

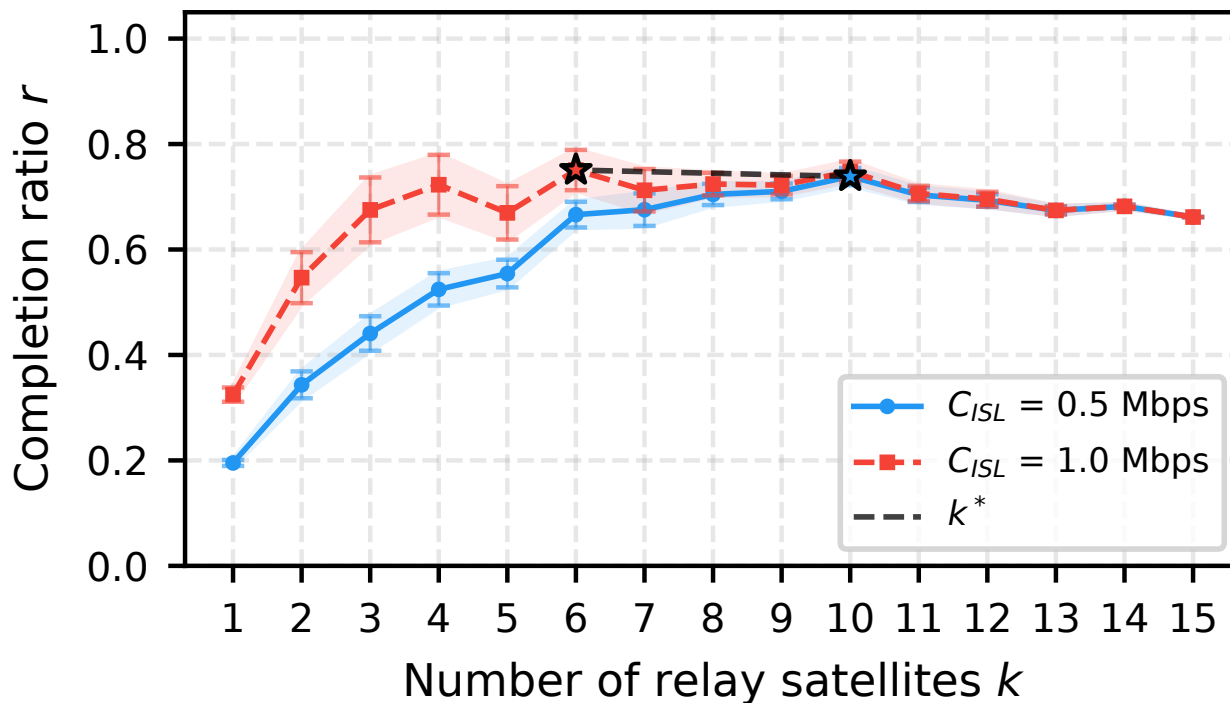
- ▶ Presence of an optimum k^*
- ▶ $k < k^*$: downlink slots **under-utilised**
- ▶ $k > k^*$: **reconfiguration overhead** dominates



$$k^* = \arg \max(r(k))$$

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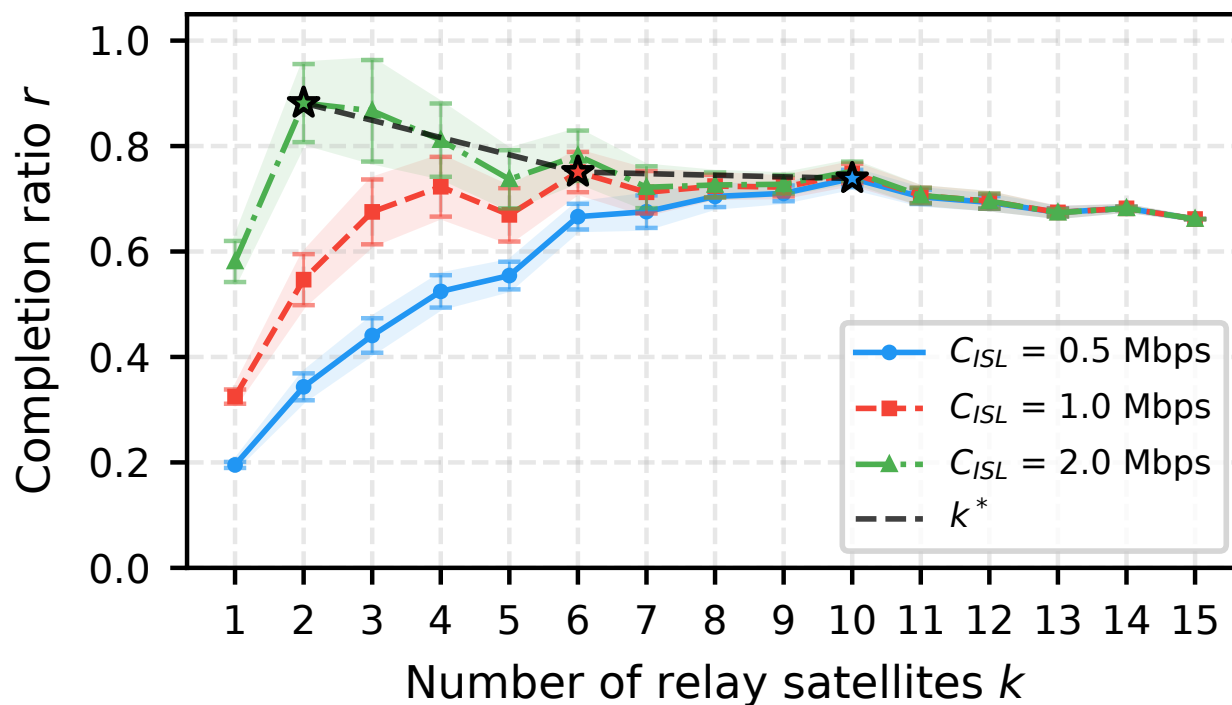
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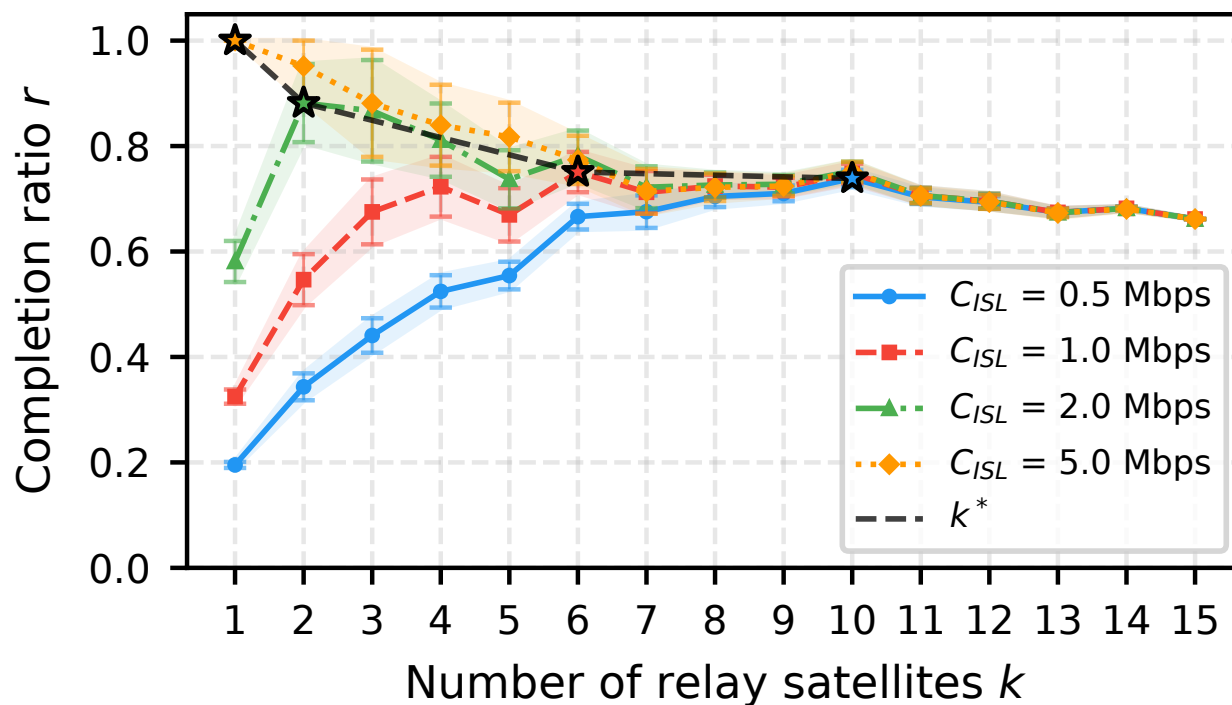
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Efficient ISLs & long reconfiguration times

Conclusion & Perspectives

Contributions

- ▶ Formulation of the problem
- ▶ Actionable framework determining the optimal relay count k^* as a function of ISL data rate and reconfiguration time.
- ▶ Open-source code available at <https://github.com/NicolasGresset/optimum-relay-nanosatellite-swarm>

Perspectives

- ▶ Extension to other swarm geometries (train, different sizes, level of connectivity)
- ▶ Collaborative offloading: joint optimization of ISL and downlink (MILP)
- ▶ Smarter selection of relays