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THE FRENCH AEROSPACE LAB

Défis ouverts aux systèmes multi-agents dans le cadre des constellations de satellites d'observation de la Terre

Gauthier Picard[1] Clément Caron[2] Jean-Loup Farges[1]
Jonathan Guerra[2] Cédric Pralet[1] Stéphanie Roussel[1]

[1] ONERA/DTIS, Université de Toulouse
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Context and Motivations

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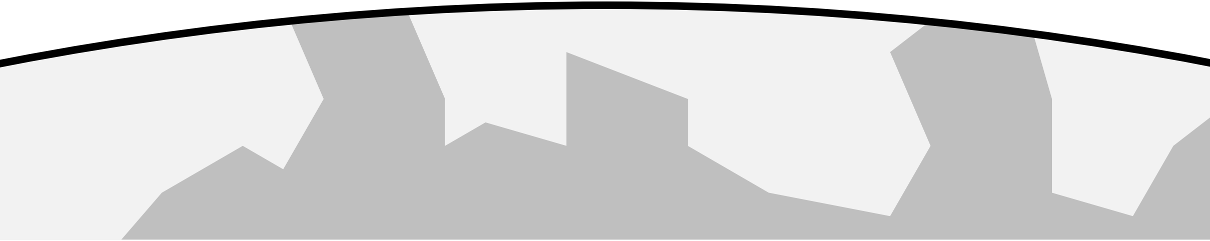
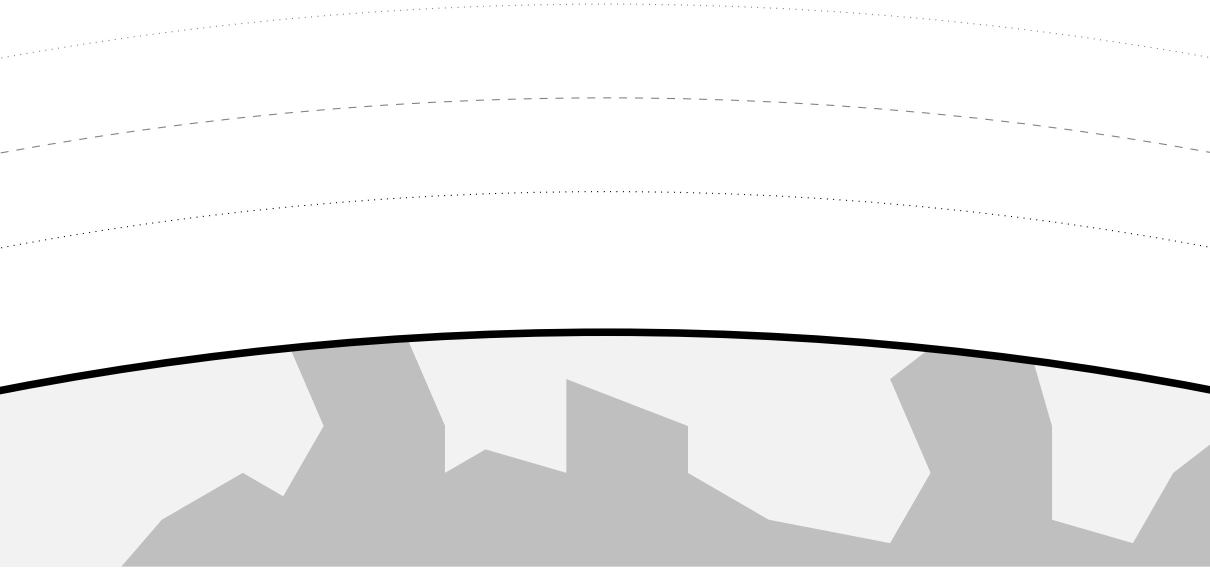
Many open challenges for autonomous agents and multiagent systems and distributed AI

Constellation Design Challenges

How to Design an EOS Constellation?



How to Design an EOS Constellation?
Orbits



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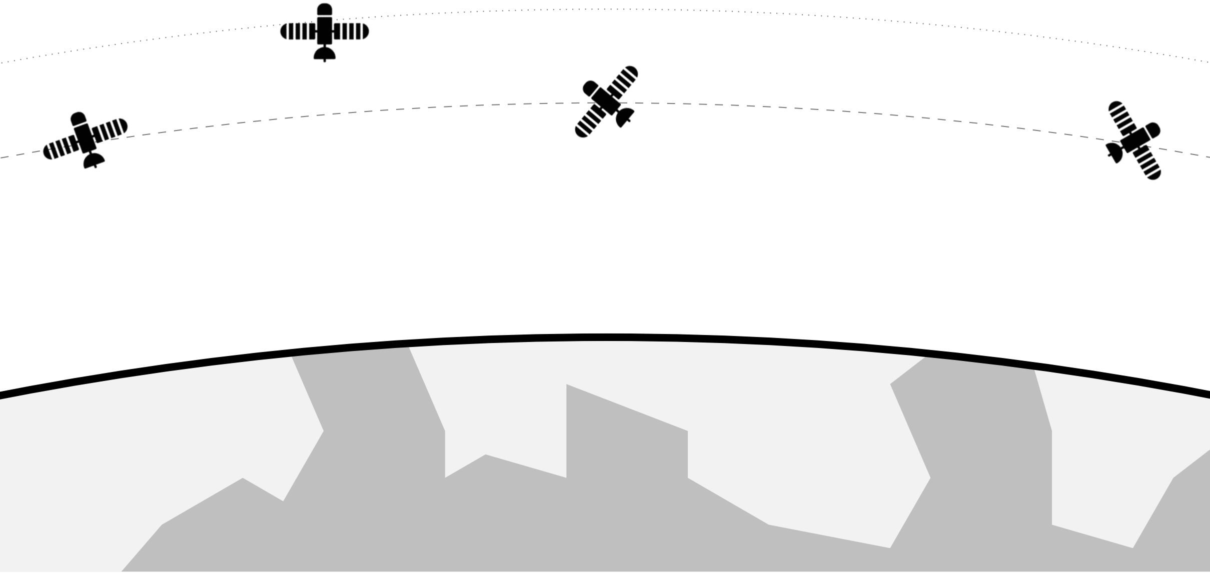
Constellation composition



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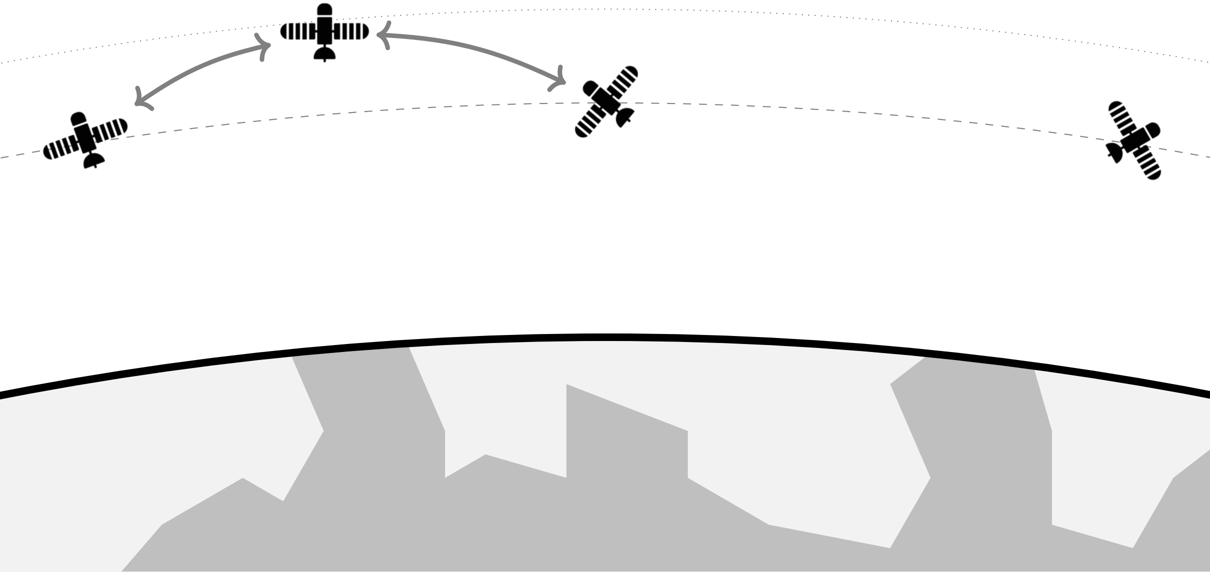
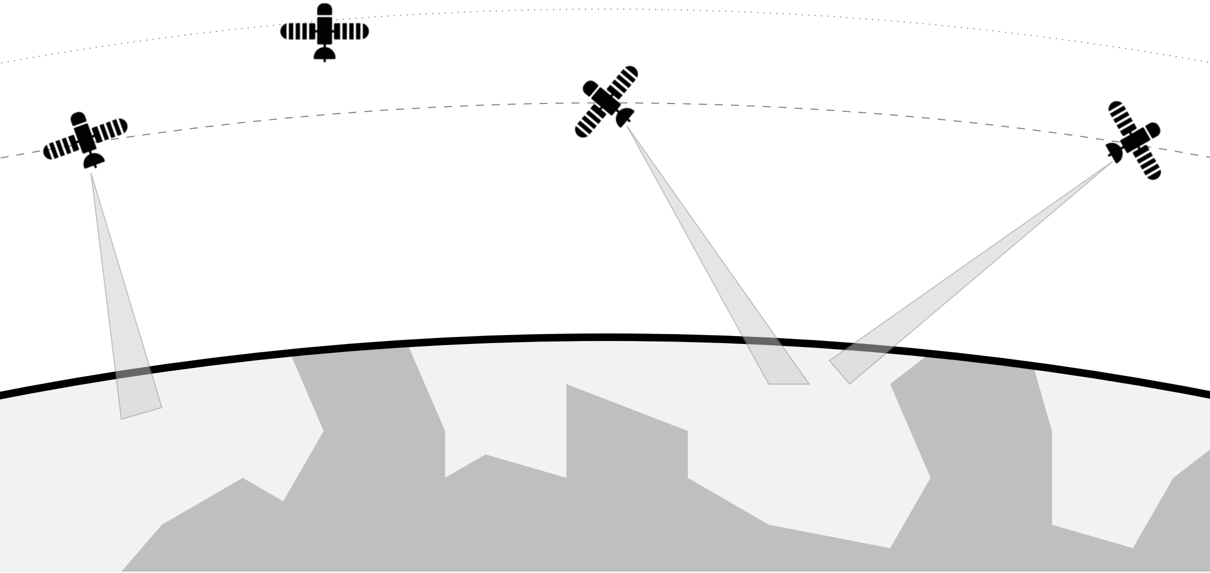


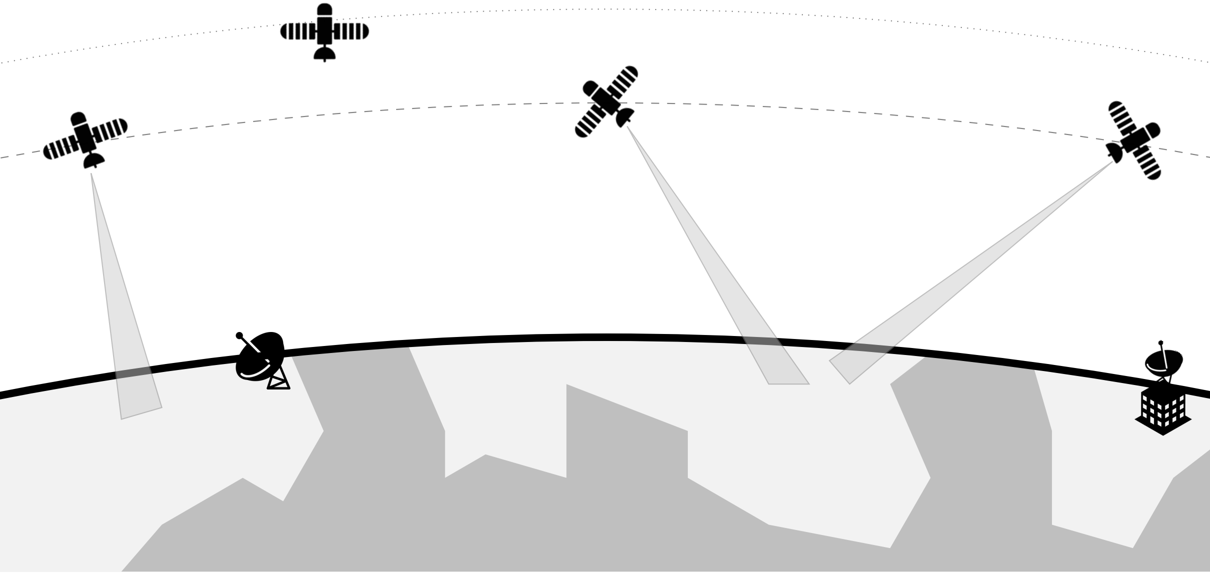
How to Design an EOS Constellation?

Points of interest



How to Design an EOS Constellation?

On-ground communication stations



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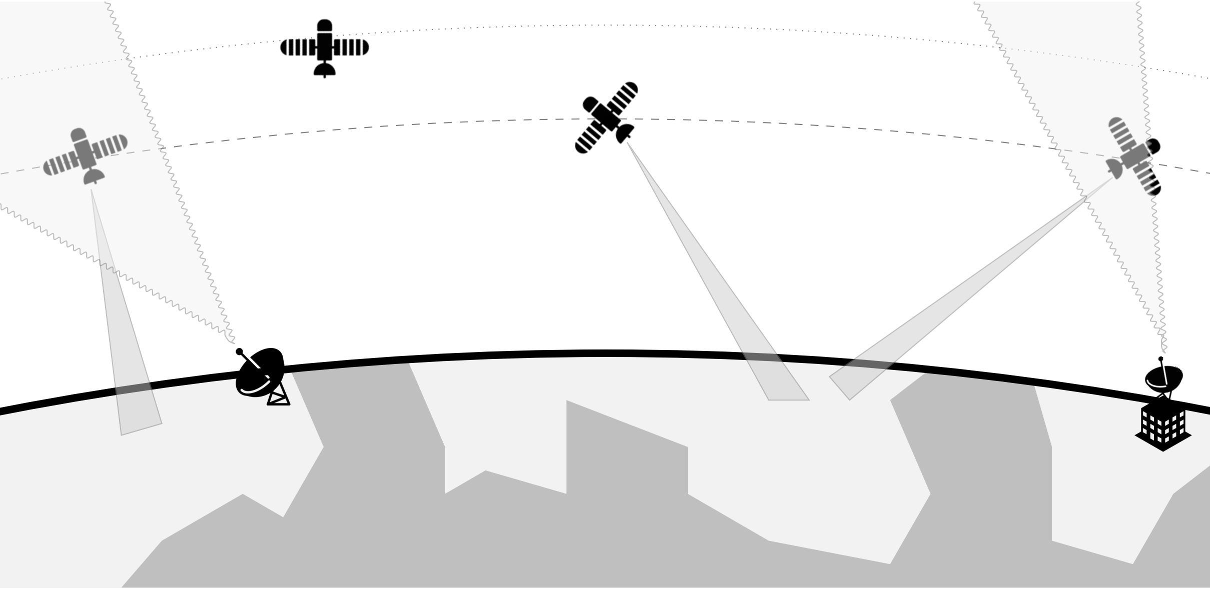
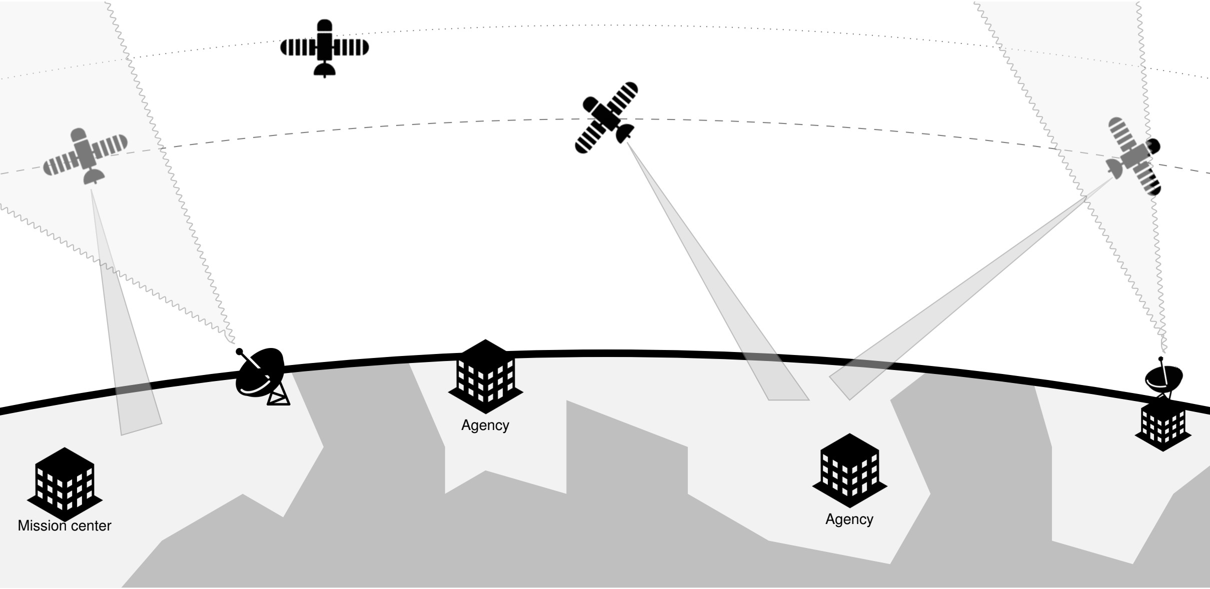
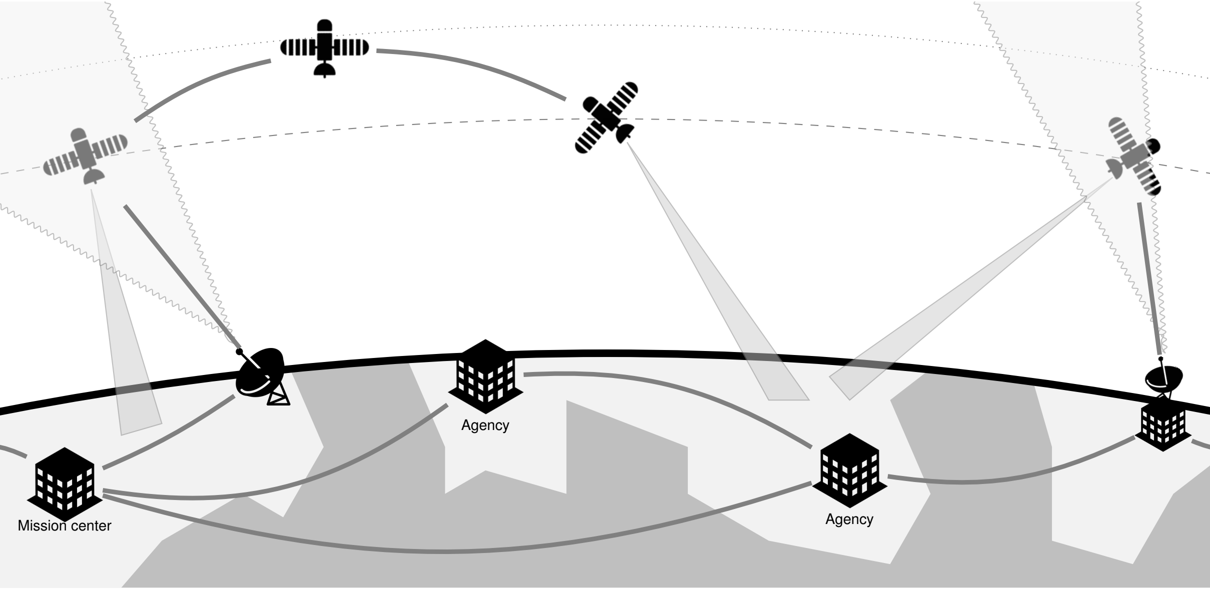
Visibility windows



How to Design an EOS Constellation?
Other actors and stakeholders



How to Design an EOS Constellation?
System organization



Design phase should take into account composite nature, heterogeneity, dynamics, openness, guarantees and safety

Constellation Design Challenges
System Modeling and Simulation

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- *Multiagent modeling and programming*
  - Models (roles, goals, ...) [Boissier et al., 2013; Winikoff and Padgham, 2013]
  - EOS clustering [Chen et al., 2018], team formation [Andrejczuk et al., 2017]
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  - Multi-objective black box optimization vs. MABS fine-grained explanations

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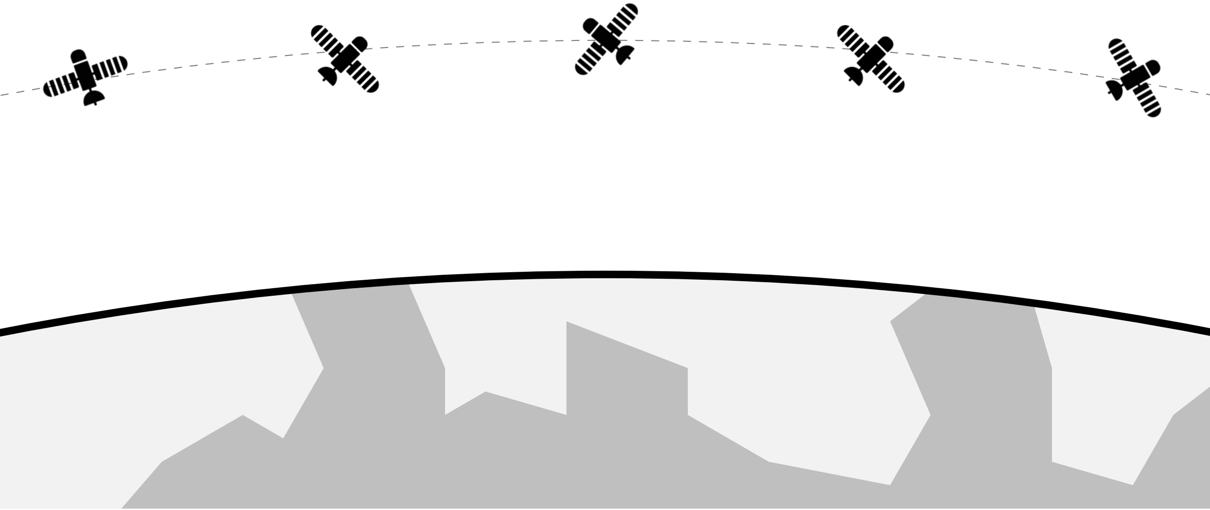
⚠ Models used for assessing performance are different from models used for assessing requirements/safety [Sánchez et al., 2017]

How to Allocate Resources?



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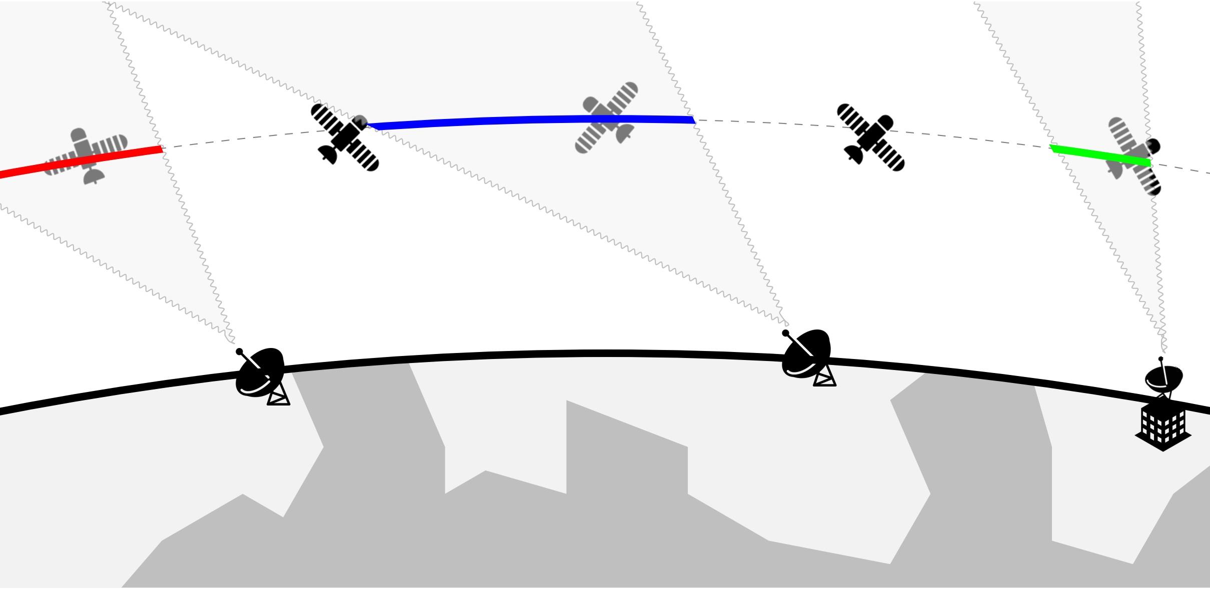

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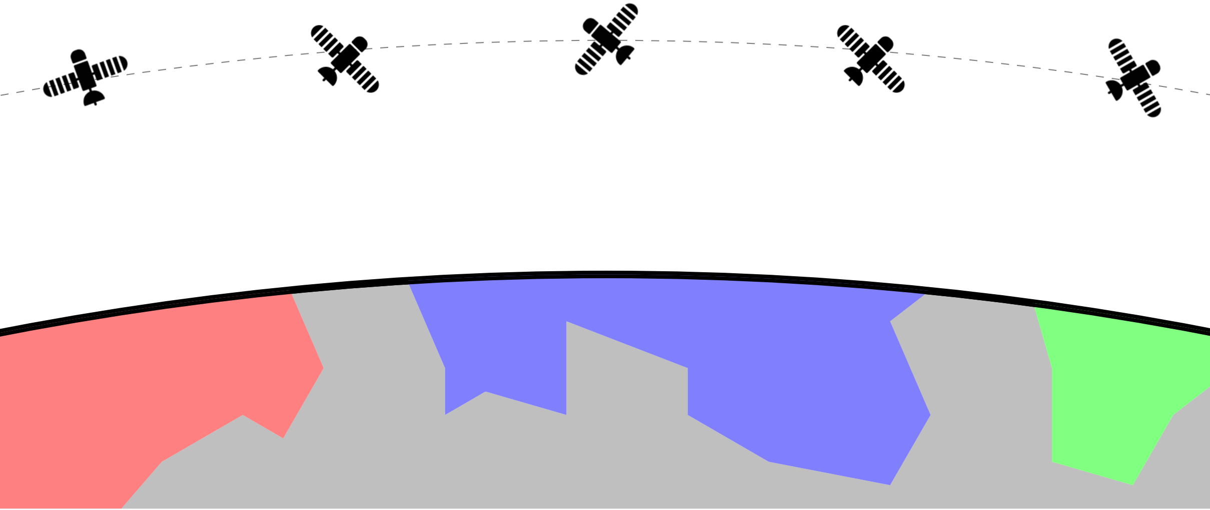

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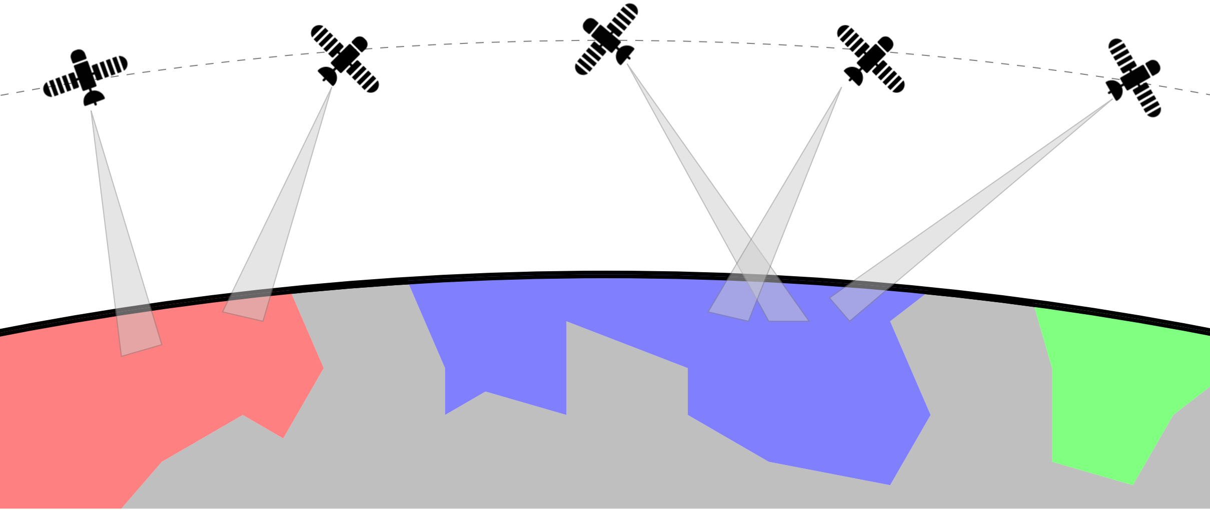

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Resource Allocation and Fair Division

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- *Fair division* [BOUTILIER et al., 2004; BOUVERET et al., 2016]
  - Several *fairness* visions
    - Proportionality wrt. the financial contribution in the funding [LEMAÎTRE et al., 2003]
    - *maxmin* fairness [JOHNSTON, 2020; TANGPATTANAKUL et al., 2015]
  - Trade-off between several criteria is necessary, *e.g.* efficiency vs. fairness
  - ⚠ Complex utility (*e.g.* priority, composite observations, weather) [VASEGAARD et al., 2020]
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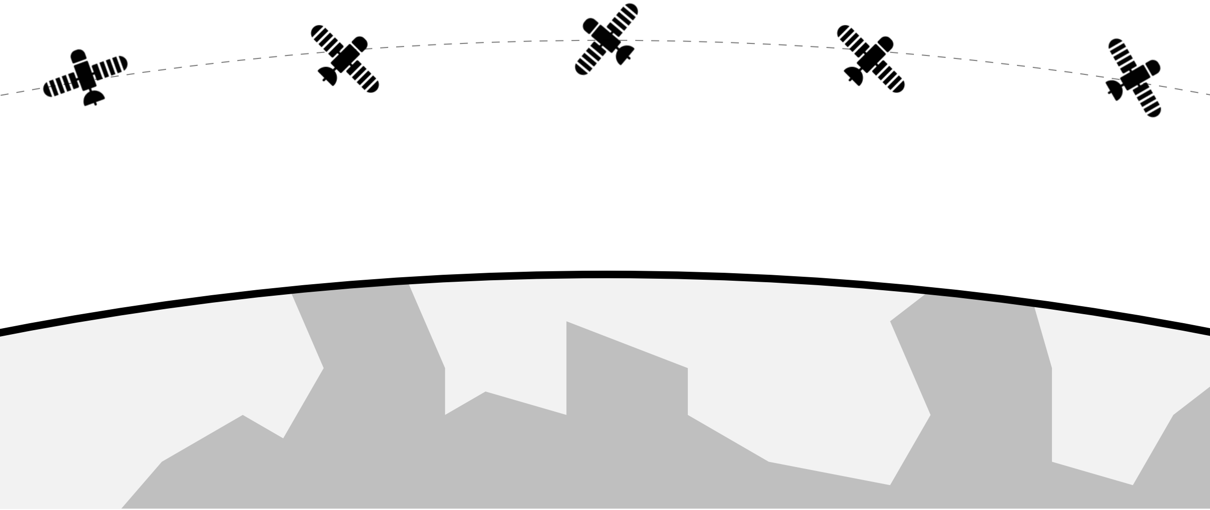
- *Centralized or decentralized procedures*, returning (near) optimal allocations
  - *e.g.* Auctions on orbit portions, geographic zone

Offline Operation Challenges

How to Schedule Tasks in a Multi-satellite and Multi-user Setting?



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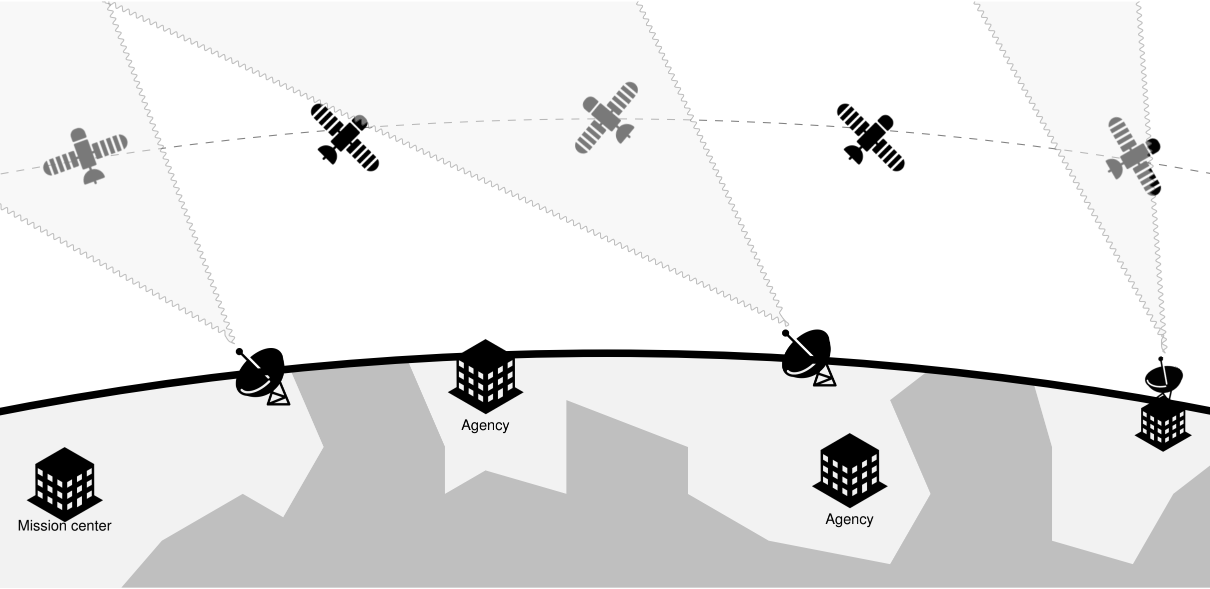

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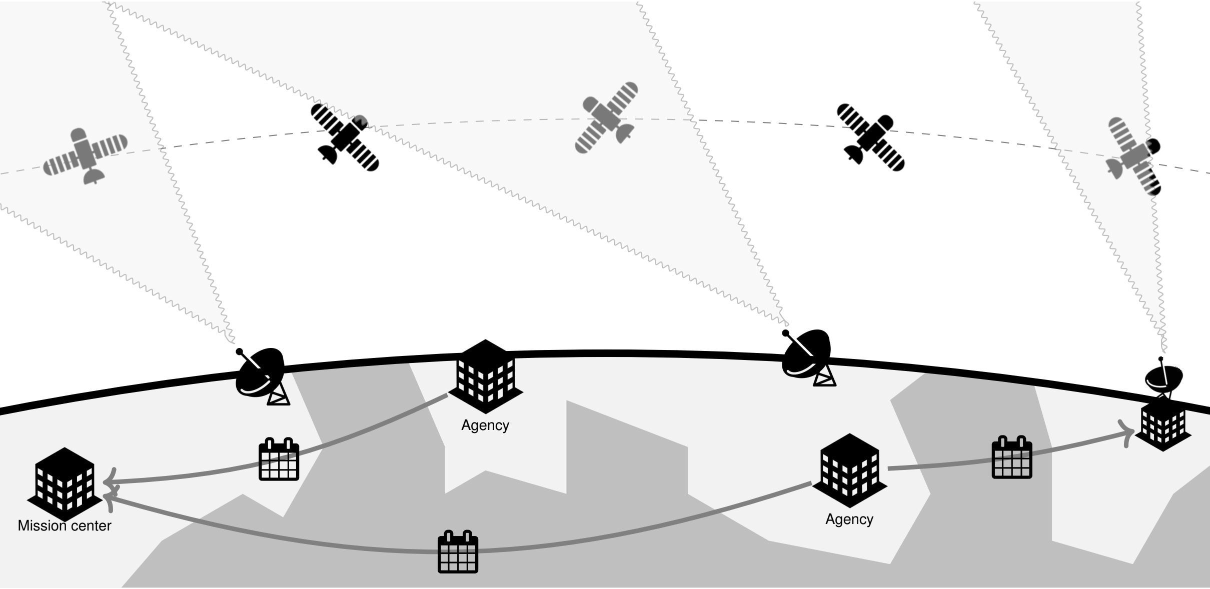

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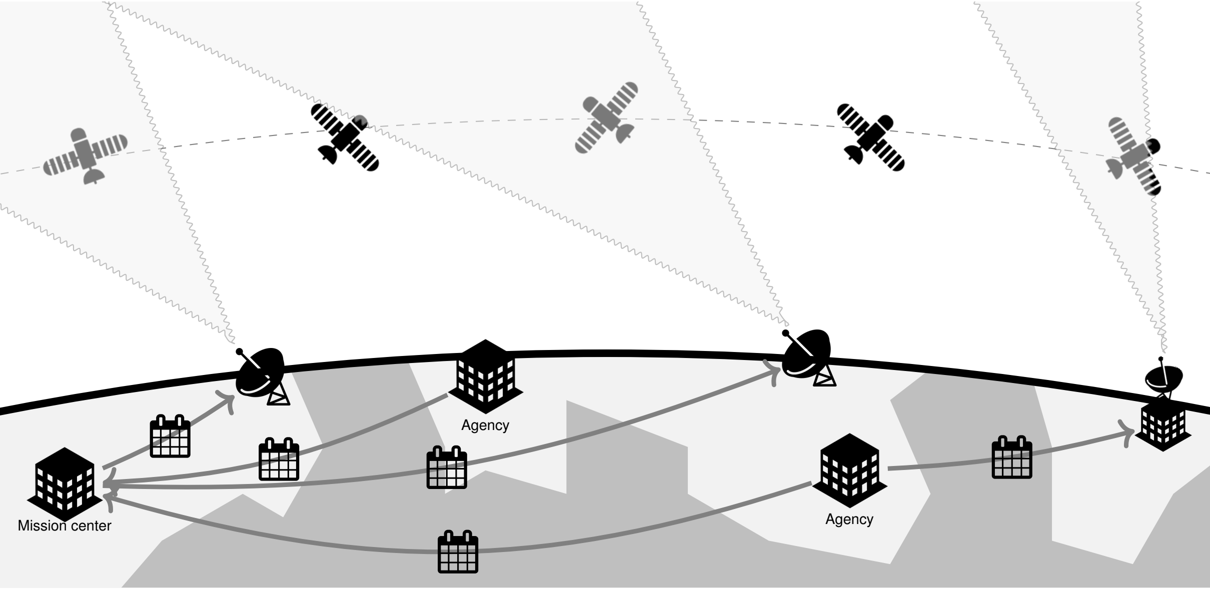

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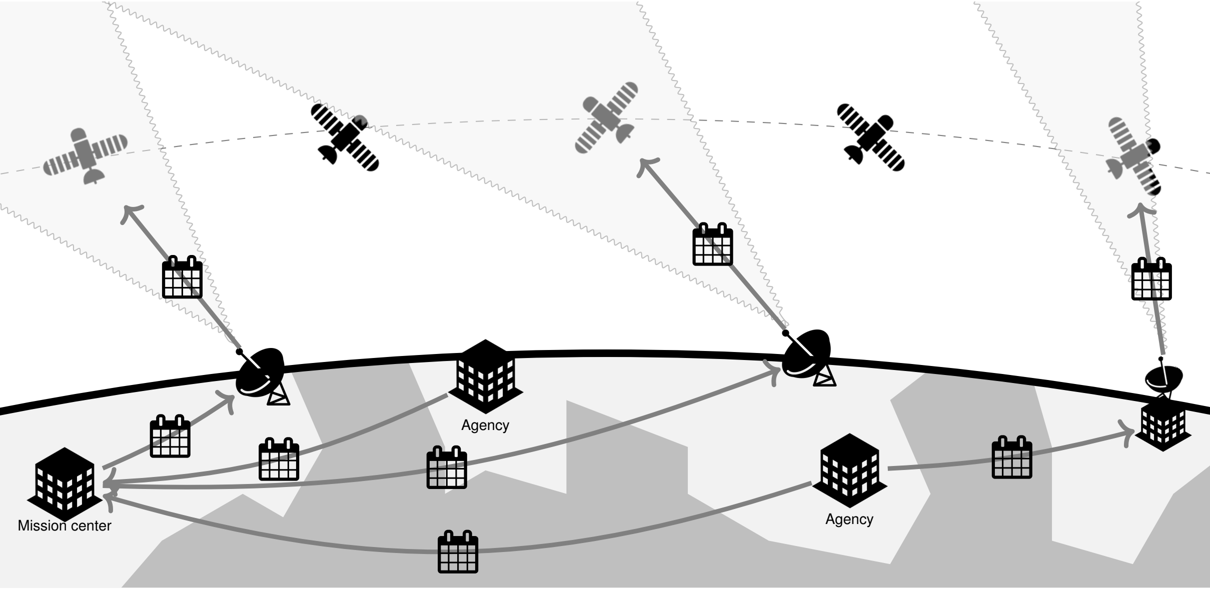

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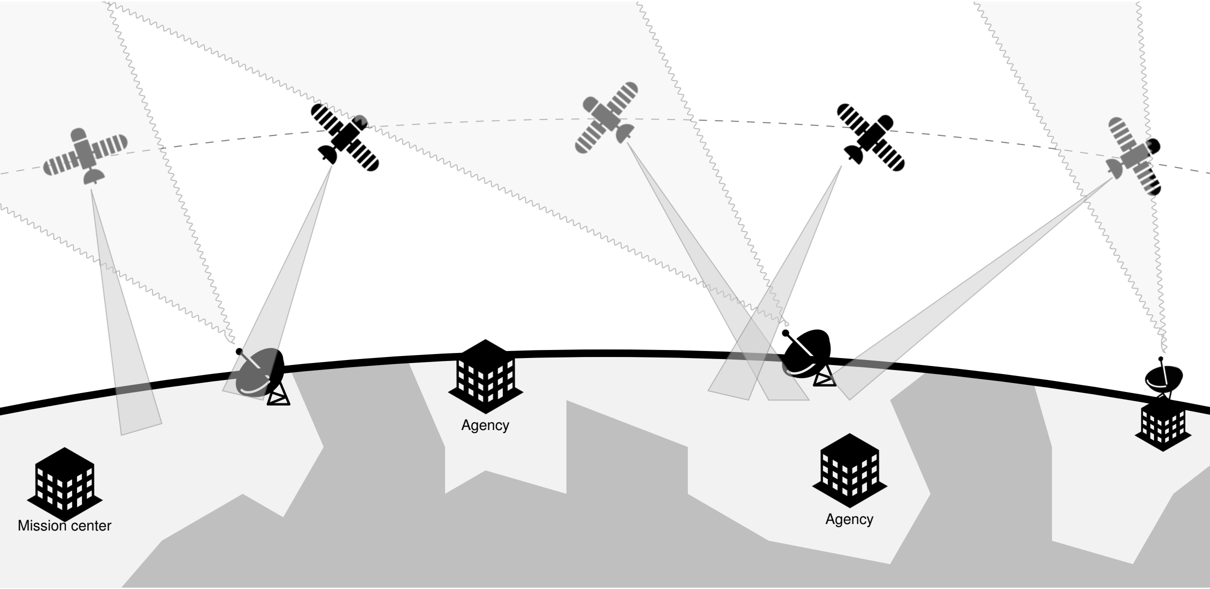

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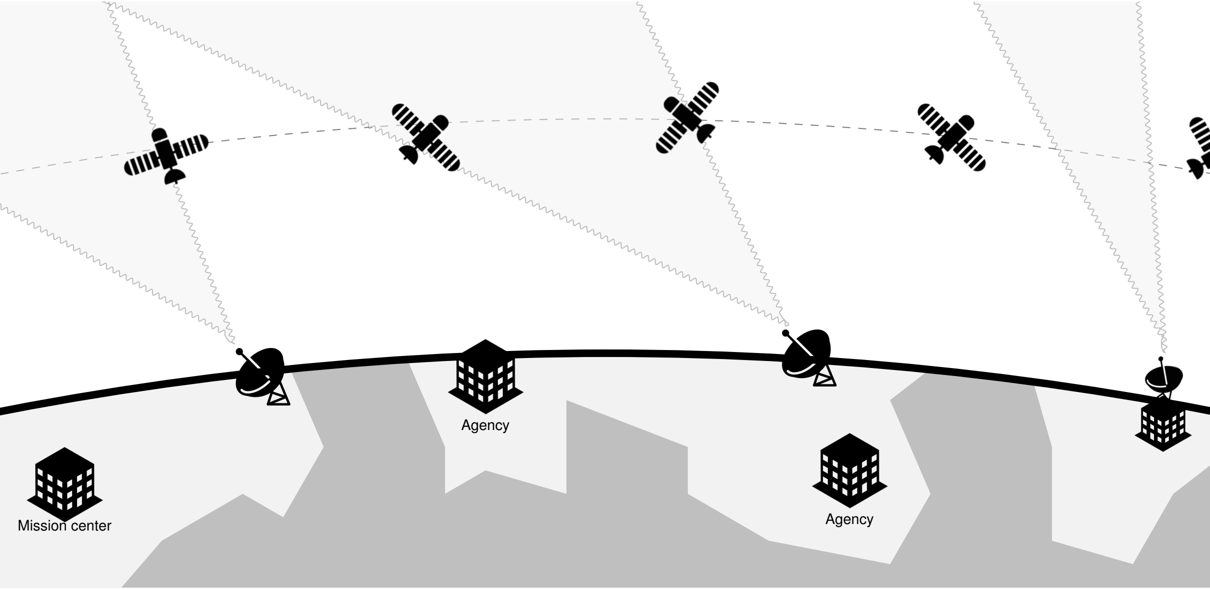

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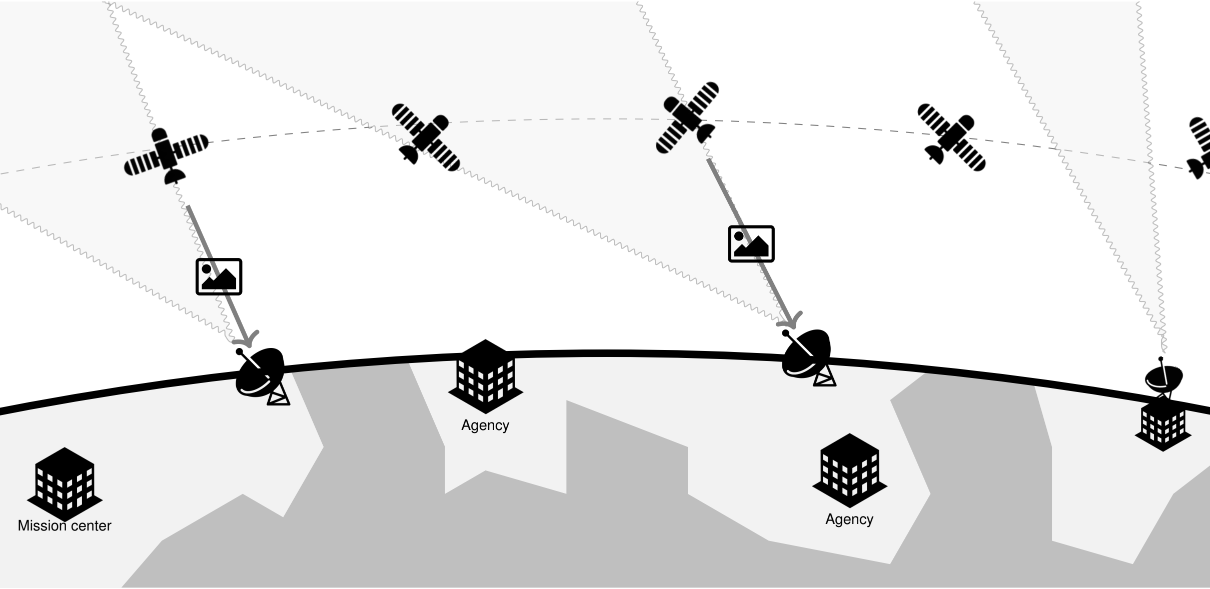

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Distributed by nature $\Rightarrow$ partially or fully decomposable

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  - Distribution to bring *explainability*, *speedup*, and *privacy*
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- *Self-organization and heuristics* for *large scale* schedules [Bonnet et al., 2015]
  - ⚠ No quality guarantees, yet?

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- *Beyond probabilities*
  - *Possibility Theory* [DUBOIS and PRADE, 2014] → increased decision robustness
  - ⚠ How to define deterministic rewards that consider requests of different types and priorities, while being combined into the chosen uncertainty measure?

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⚠ Presence of discrete and continuous decision variables

- *Game Theory* [Sun et al., 2018] and market design [Denis et al., 2017], in more conflicting and non-cooperative settings

Online Operation Challenges

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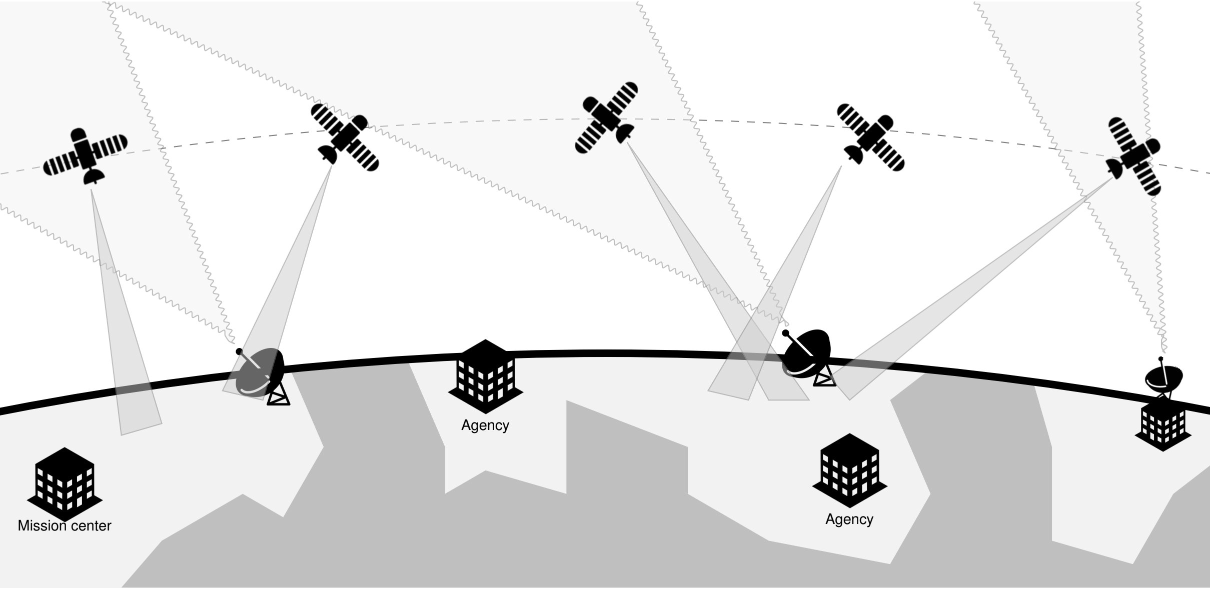

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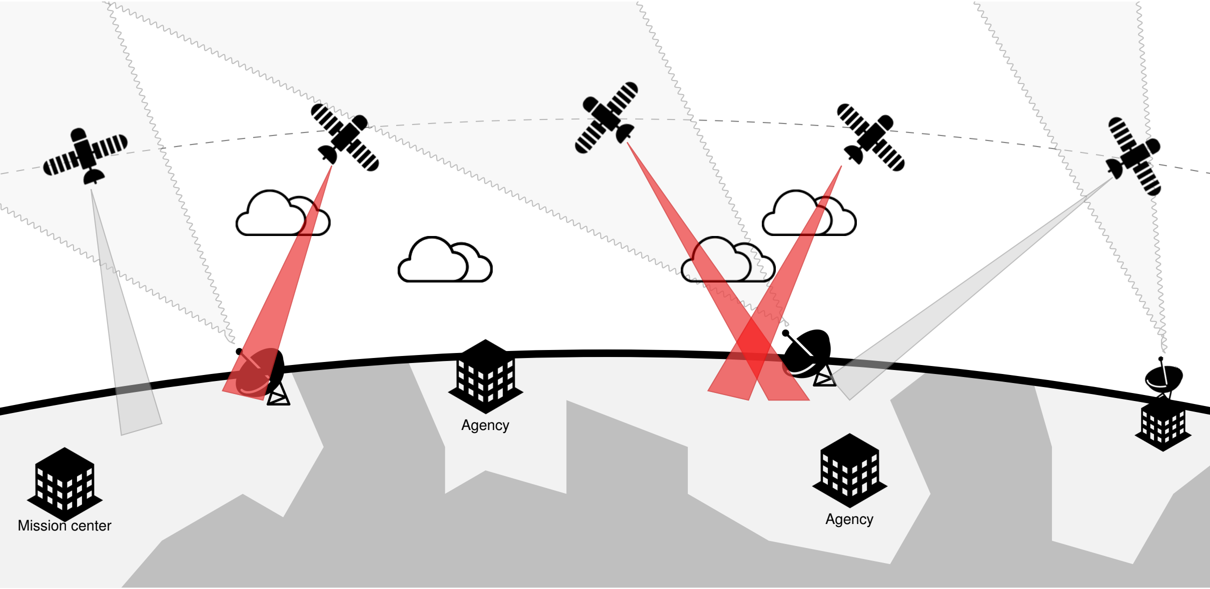

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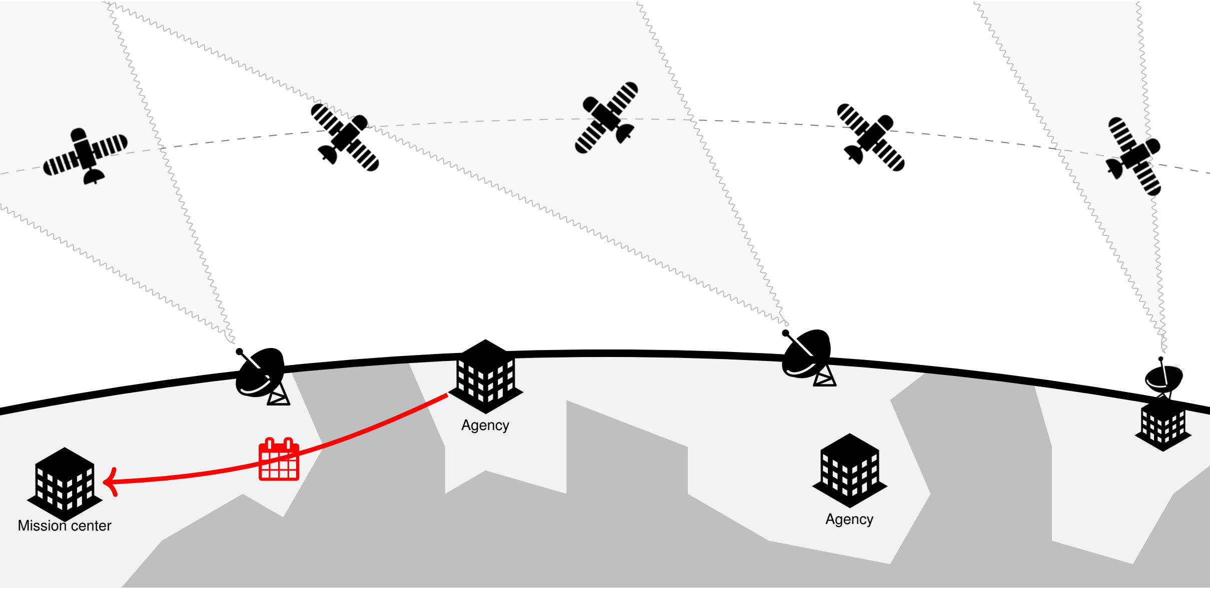

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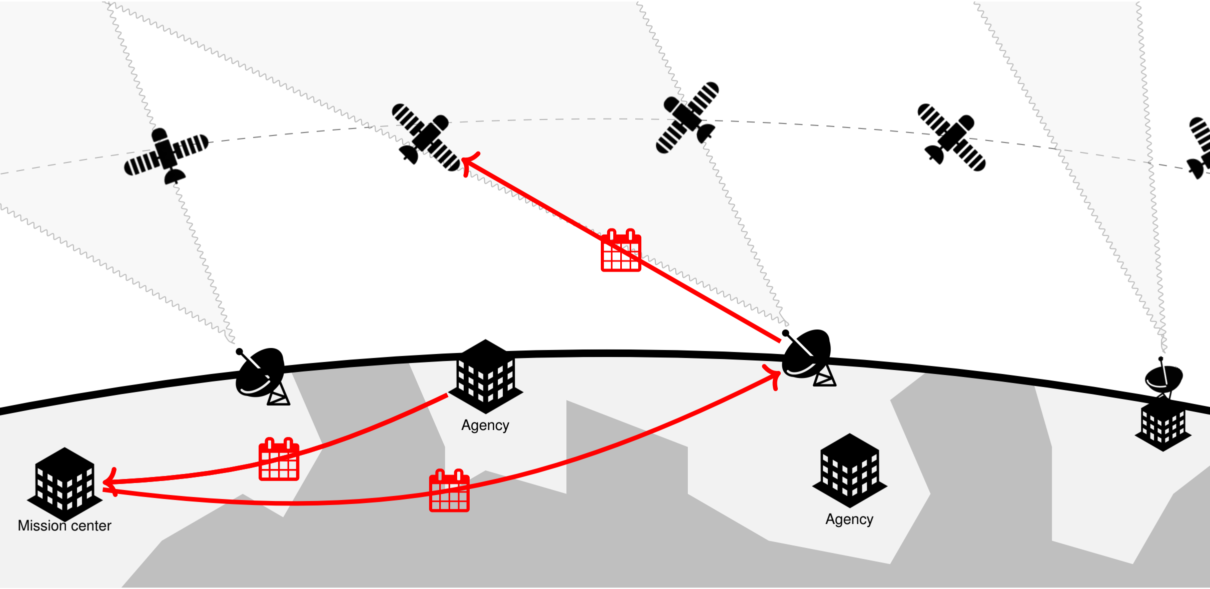

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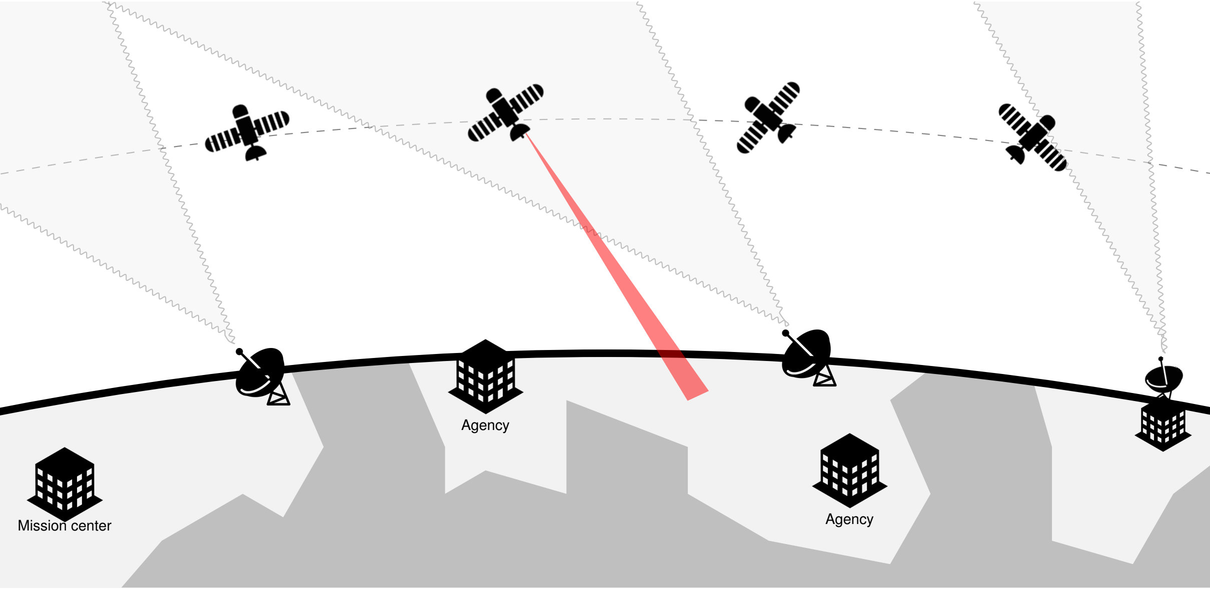

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- *On-board decision-making* and inter-agent cooperation
  - *Dynamic Distributed Constraint Optimization* (DynDCOP) [HOANG et al., 2016; RUST et al., 2020]
  - *Multiagent plan repair* techniques [KOMENDA et al., 2014]
  - *Dynamic consensus* techniques [FRANCESCHELLI and FRASCA, 2018; LI et al., 2014]
  - ⚠ Limited scalability and resilience to communication loss and asynchronicity [DIBAJI and ISHII, 2015; JOHNSTON, 2020; RUST et al., 2020]
  - ⚠ Strong requirements for on-board operations

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Interaction and Protocols

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- *Network of communication links*
  - inter-satellite link
  - direct communication between mission centers
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- Coordination, Organisations, Institutions, and Norms
- Engineering Multiagent Systems
- Knowledge Representation, Reasoning, and Planning
- Learning and Adaptation
- Markets, Auctions, and Non-Cooperative Game Theory
- Modelling and Simulation of Societies
- Robotics
- Social Choice and Cooperative Game Theory

Acknowledgements

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