Towards Optimization for Large-scale Earth Observation Missions from a Global Perspective

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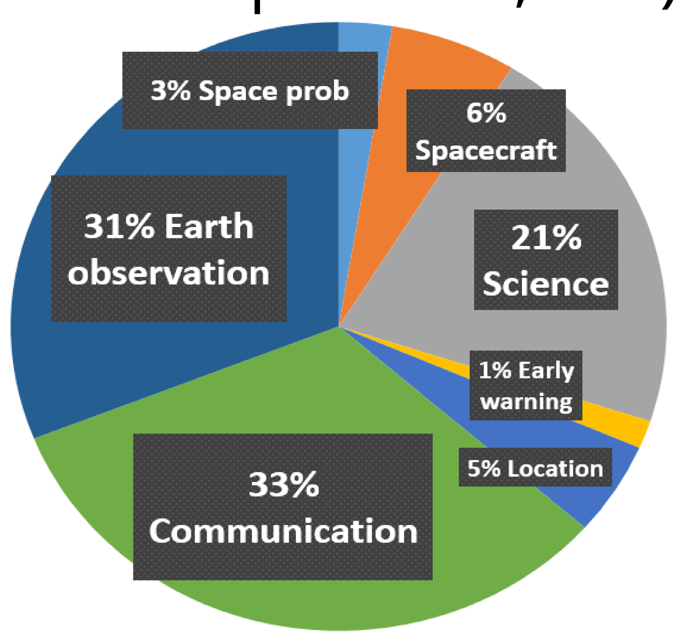
Background

Earth Observation is crucial for many real-world applications (military, environmental protection, rescue operation, etc.)



More than ***30%*** of all launched satellites have been used for Earth observation by 2020.

Low-Earth orbit (LEO) nanosatellite systems:

- Low production and manufacturing costs
- ***Thousands*** satellites to form mega-constellation
- Boosting the Earth observation missions

✓Low orbit height → high-resolution
✓Large constellation scale → high revisit rate

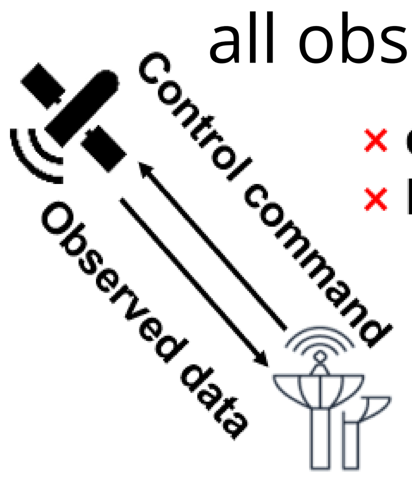
Numerous missions VS Limited bandwidth resources →Optimization of Earth observation

In order to maximize mission completion rate, how should we **allocate Earth observation task to the satellites** based on their distributions?

Motivation

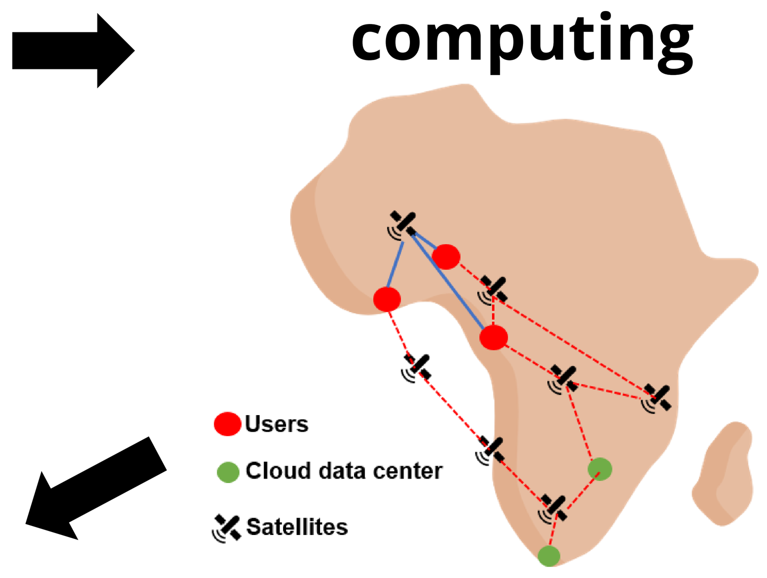
Design goal: Maximize mission completion rate

Bent-pipe : deliver all observed data



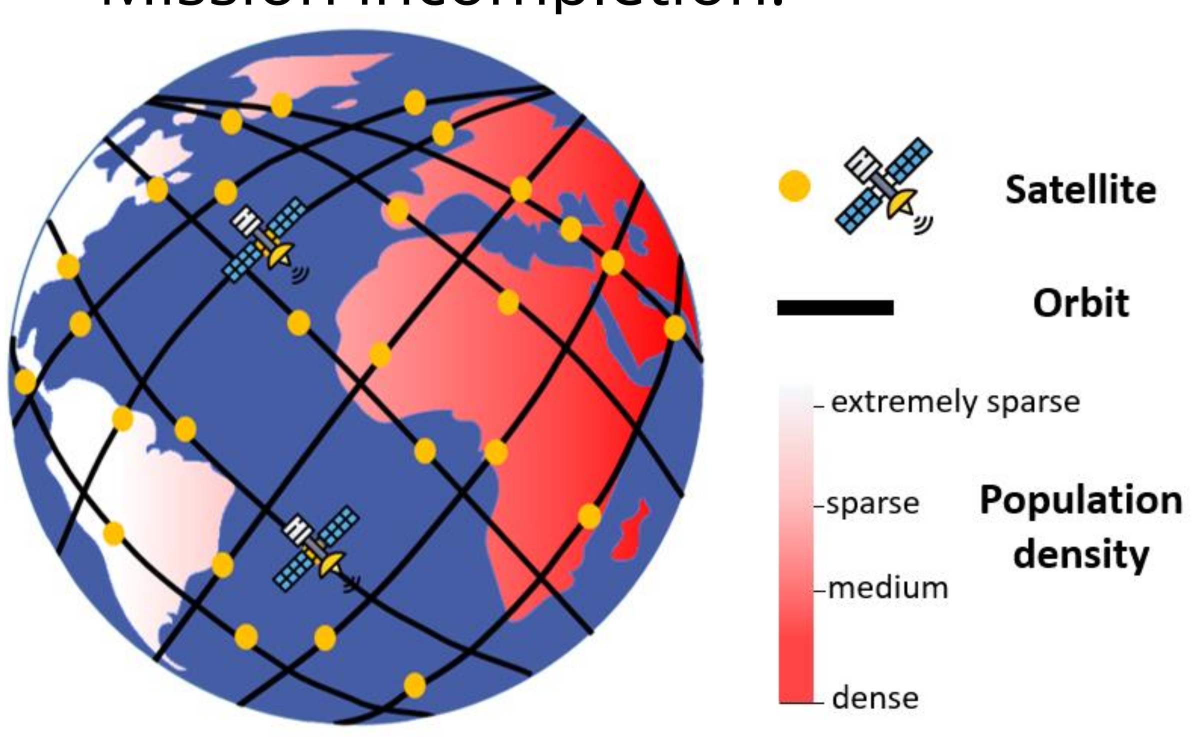
× downlink load
× loss packet rate

In-orbit edge computing



Limitation of local optimization:

- Sub-optimal resource utilization
- Mission incompletion.



Underlying reason: imbalance of geographical matching relationships

Main Idea

Our observation: we need to optimize Earth observation from ***a global perspective***.

➢In global optimization, resources are allocated to the most needed missions.
➢Global optimization also enables the collaboration among multiple satellites complete more missions.

LP Formulation

Modelling into a linear programming (LP)

Decision variables:

X_ij: whether satellite i transmits the image spot j
q_ij: Image quality

Constraints:

Bandwidth: $bandwidth_i(X_{ij}, q_{ij}) \leq W^* \ \forall sate\ i$

Latency: $Tddn_i \leq t^* \ \forall sate\ i$

Accuracy: $y_j = \begin{cases} 1 & Accracy_j(X_{ij}, q_{ij}) \geq A^* \\ 0 & Accracy_j(X_{ij}, q_{ij}) < A^* \end{cases}$

Optimization goal: $max(\sum_j^N y_j)$

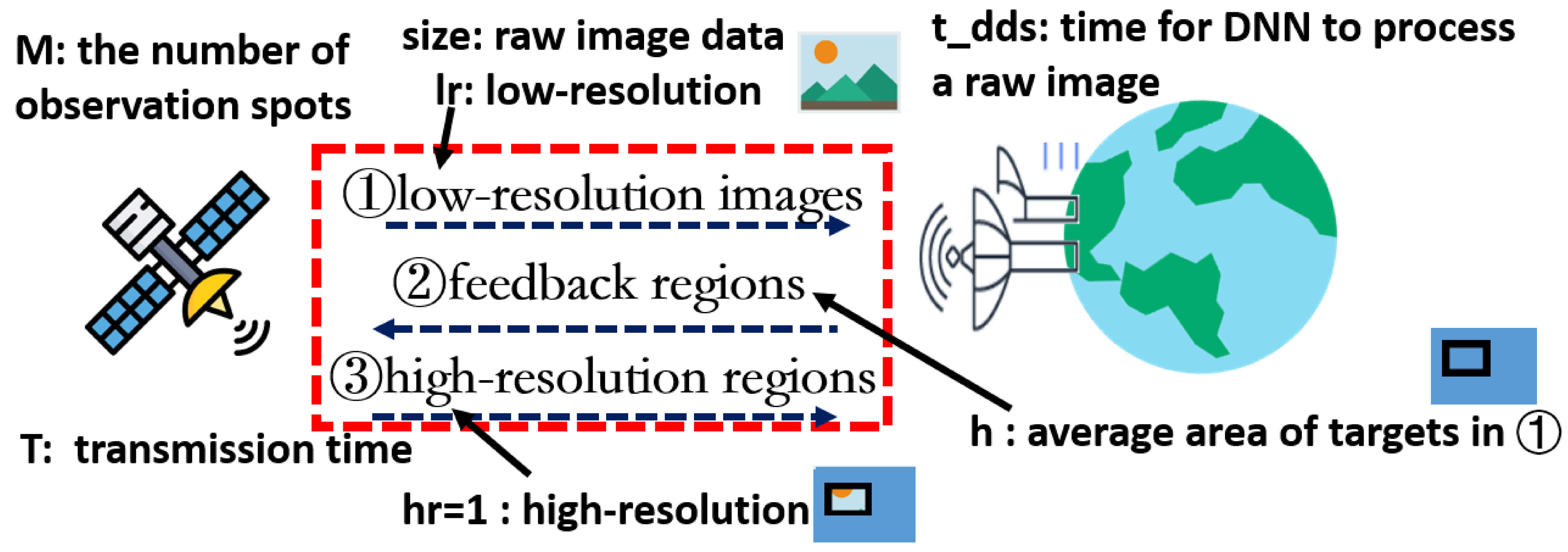
Design Challenges

#1 Coordinate the optimization with the existing mechanisms of visual tasks

- model with different types of image quality based on DDS [SIGCOMM'20]

$$bandwidth: \sum_j^M X_{ij}(lr_{ij} size + hr \times h \times size) \leq W^* \ \forall sate\ i$$

$$latency: \sum_j^M X_{ij} t_{dds}(lr_{ij} + hr \times h) \leq t \ \forall sate\ i$$



#2 Ensure the inference accuracy

- approximate accuracy with bandwidth

$$accuracy: y_j = \begin{cases} 1 & bandwidth_j \geq A^* \\ 0 & bandwidth_j < A^* \end{cases}$$

#3 Reduce the complexity of the model

- prune unnecessary variables

Real-time setup : resources will be updated after each round of optimization and all parameters are continuously updated to adjust the model.

Evaluation