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

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: \(\text{bandwidth}_i(X_{ij}, q_{ij}) \leq W^* \quad \forall \text{sate } i\)
- Latency: \(\text{tdnn}_i \leq t^* \quad \forall \text{sate } i\)
- Accuracy: \(y_j = \begin{cases} 1 & \text{Accuracy}_{ij}(X_{ij}, q_{ij}) \geq A^* \\ 0 & \text{Accuracy}_{ij}(X_{ij}, q_{ij}) < A^* \end{cases}\)

Optimization goal: \(\max(\sum_{j} y_j)\)

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]

#2 Ensure the inference accuracy
- approximate accuracy with bandwidth

#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

Real-time handle ability: up to 61.5% scalability