Low-latency Downlink for LEO Satellites

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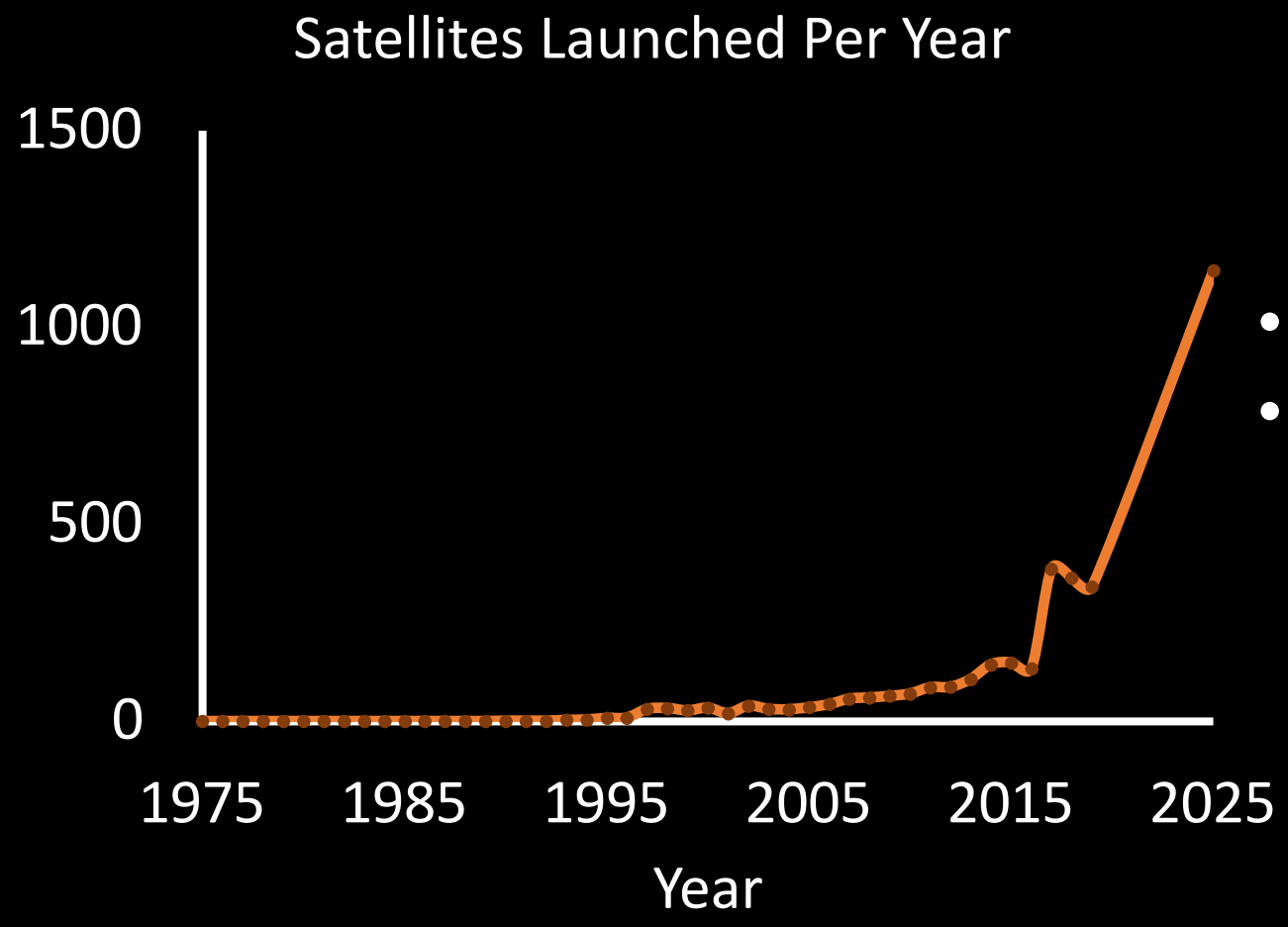
Microsoft



- Low-cost Cubesats
- Rideshare agreements for launch

Source: UCS Satellite Database

Communication

Earth Observation

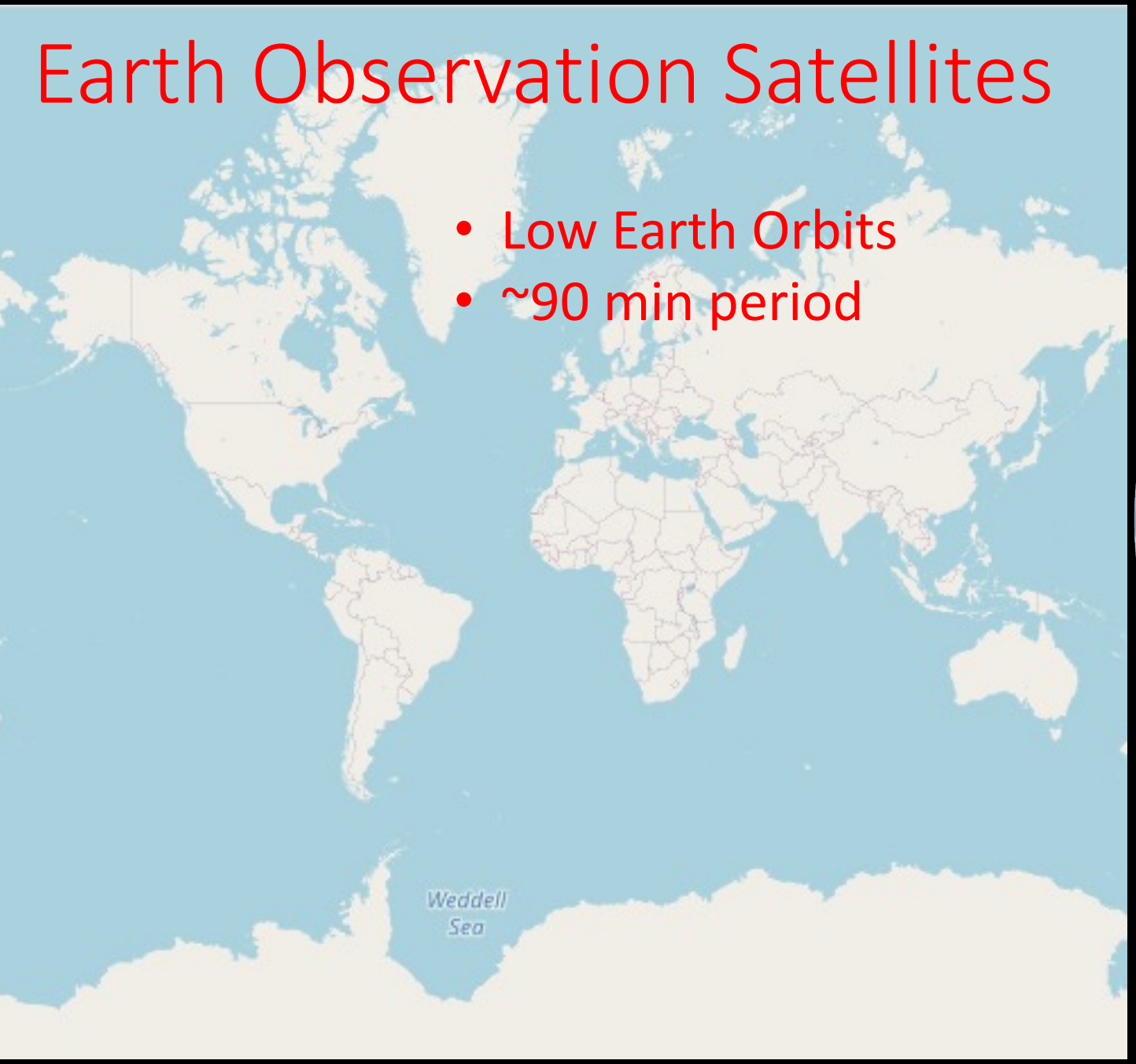
Global Internet Connectivity

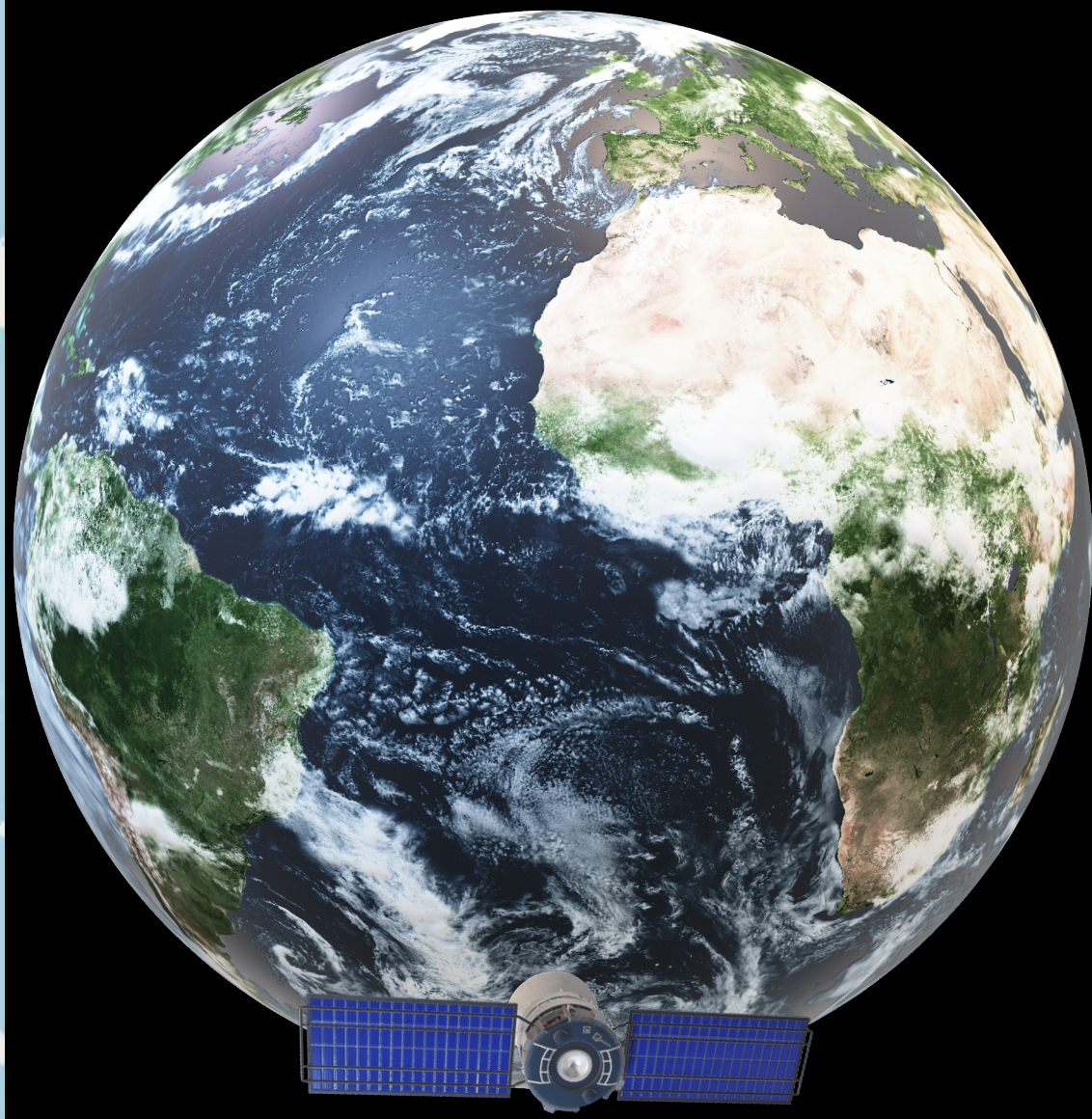
Sensing from Space

Today, 45% of LEO satellites are Earth Observation

Earth Observation Satellites

- Low Earth Orbits
- ~90 min period





Earth Observation Satellites

Low orbits

High Resolution

Large constellation

Frequent revisits

Better Hardware

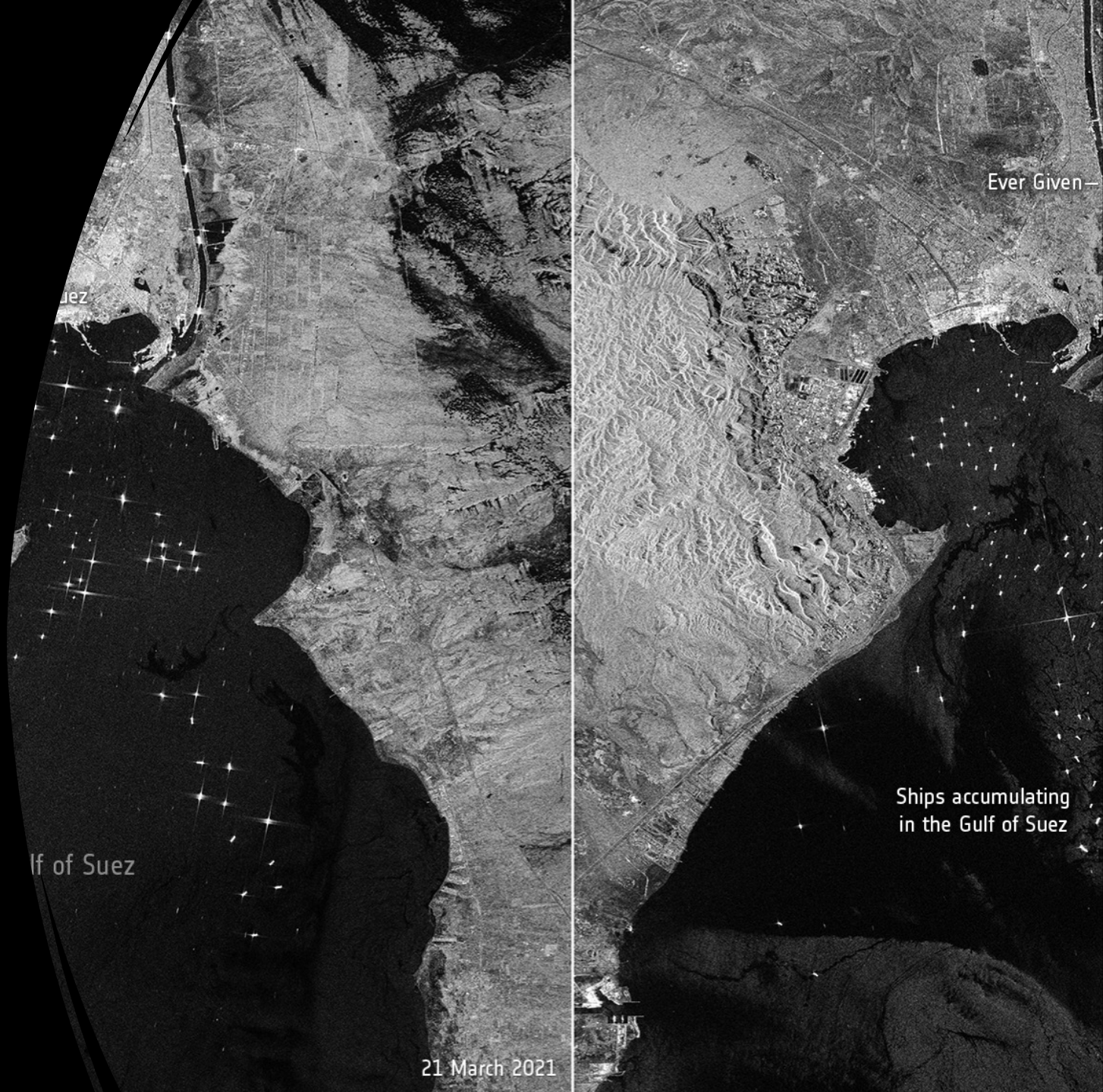
Multi-spectral

Earth Observation Applications: Agriculture

- Precision Agriculture
- Monitoring events like floods

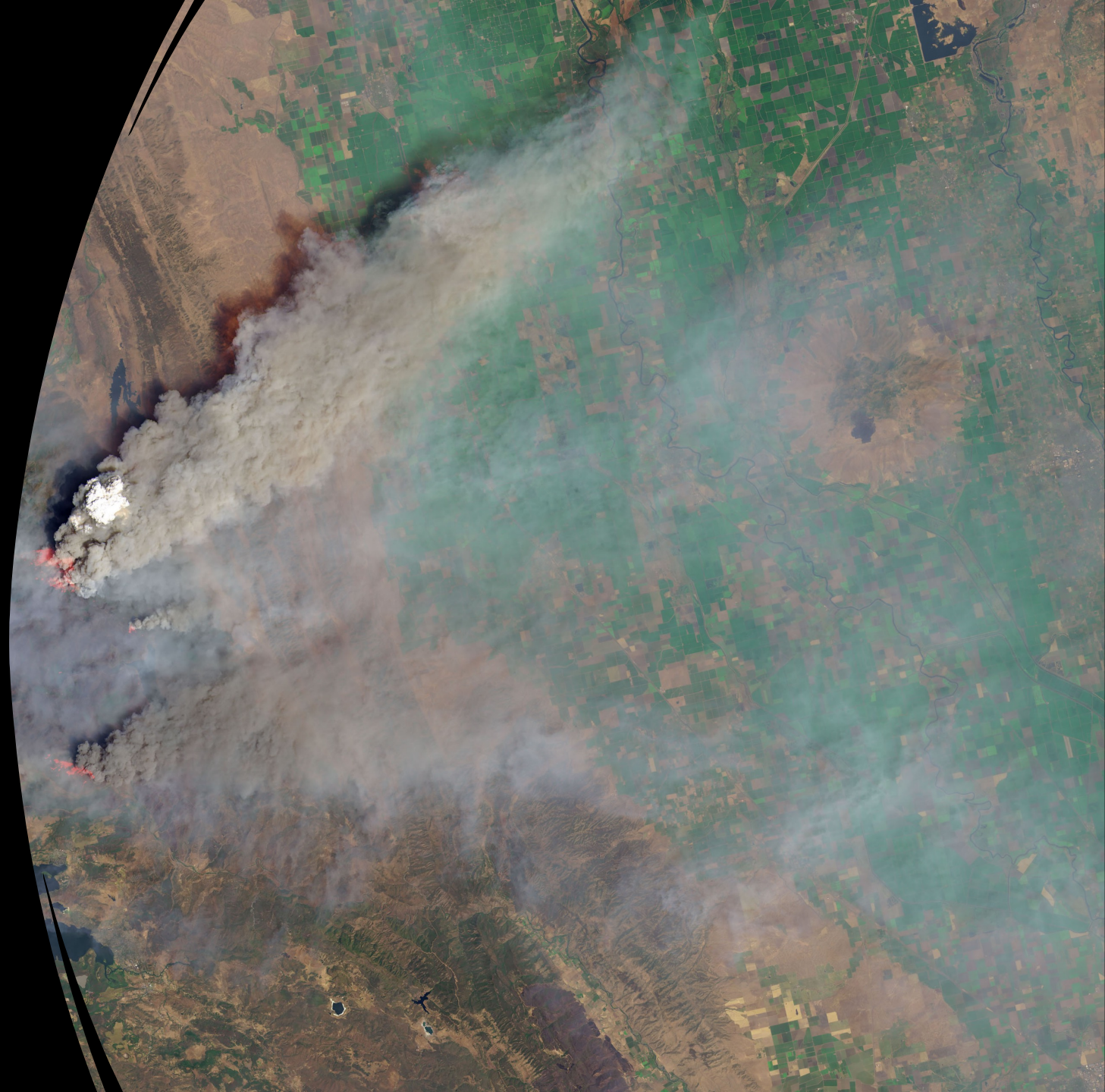
Earth Observation Applications: Maritime Tracking

- Track illegal smuggling
- Monitor ship traffic



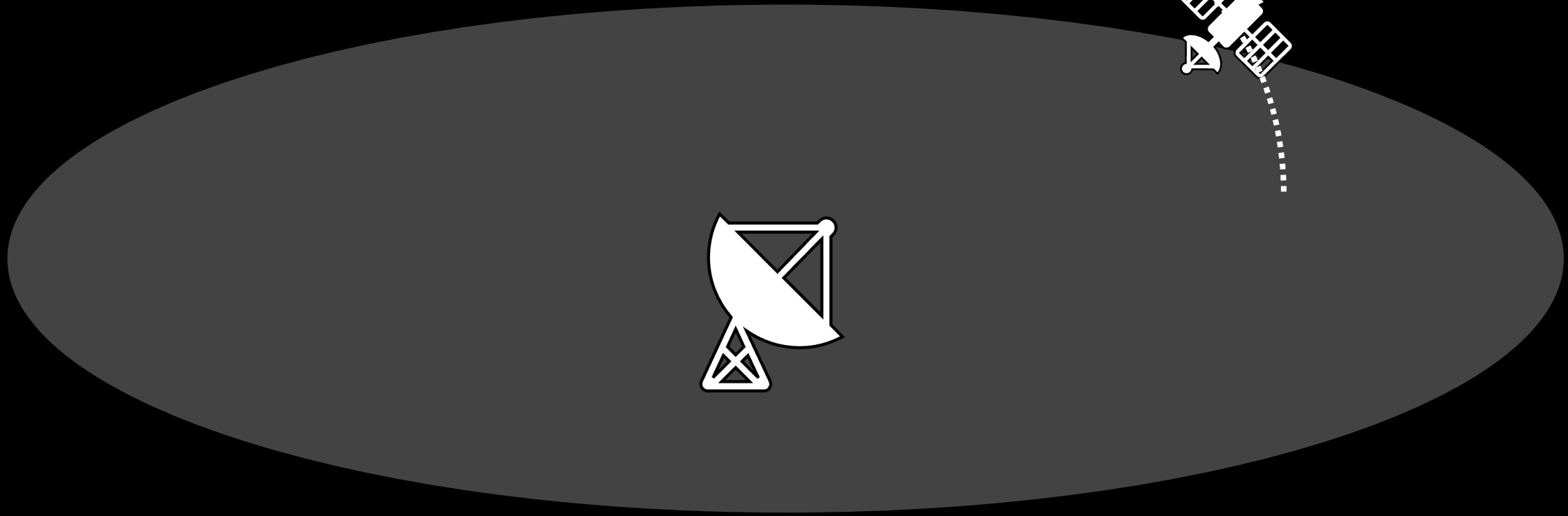
Earth Observation Applications: Disaster Monitoring

- Early detection
- Tracking propagation



Challenge: Data Downlink

- 100s GB of Data per pass
- Each contact lasts nearly 10 minutes



Challenge: Data Downlink

- Collects 100s of GigaBytes of data per pass
- Only 10 minutes to download the data

Need high-capacity downlink across 500 Km

Today: Large Complex Ground Stations

- Multi-million dollar investments
- 4 to 5 massive ground stations located close to the poles

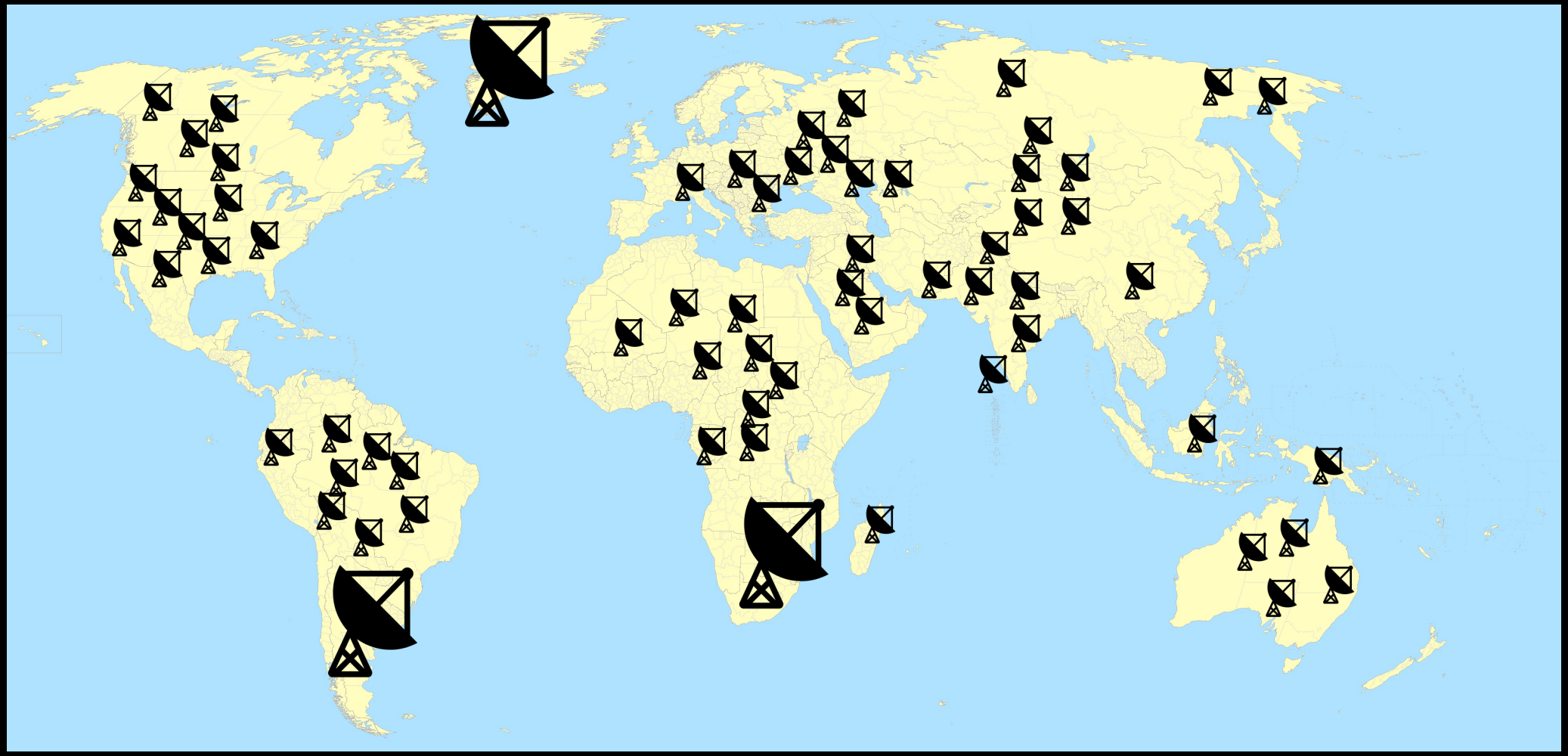
Shortcomings

- Large latency (hours)
- Scaling is capital-intensive
- Failures (e.g. weather) are disruptive

Proposal: Distributed Hybrid Ground Station

Can a network of tiny ground stations outperform the capital-heavy huge ground stations?

Proposal: Distributed Hybrid Ground Station



Proposal: Distributed Hybrid Ground Station

- Fault-tolerant
- Low Latency
- Hybrid: not everyone needs to transmit

05 Jun 2019 | 16:55 GMT

Is Amazon's Satellite Ground Station Service Ready for Primetime?

Amazon Web Services has promised immediate service but FCC filings suggest the company has yet to obtain the long-term licenses necessary to operate

Challenges

- Rate adaptation without feedback
- Scheduling satellite-ground station links
- Lack of acknowledgements

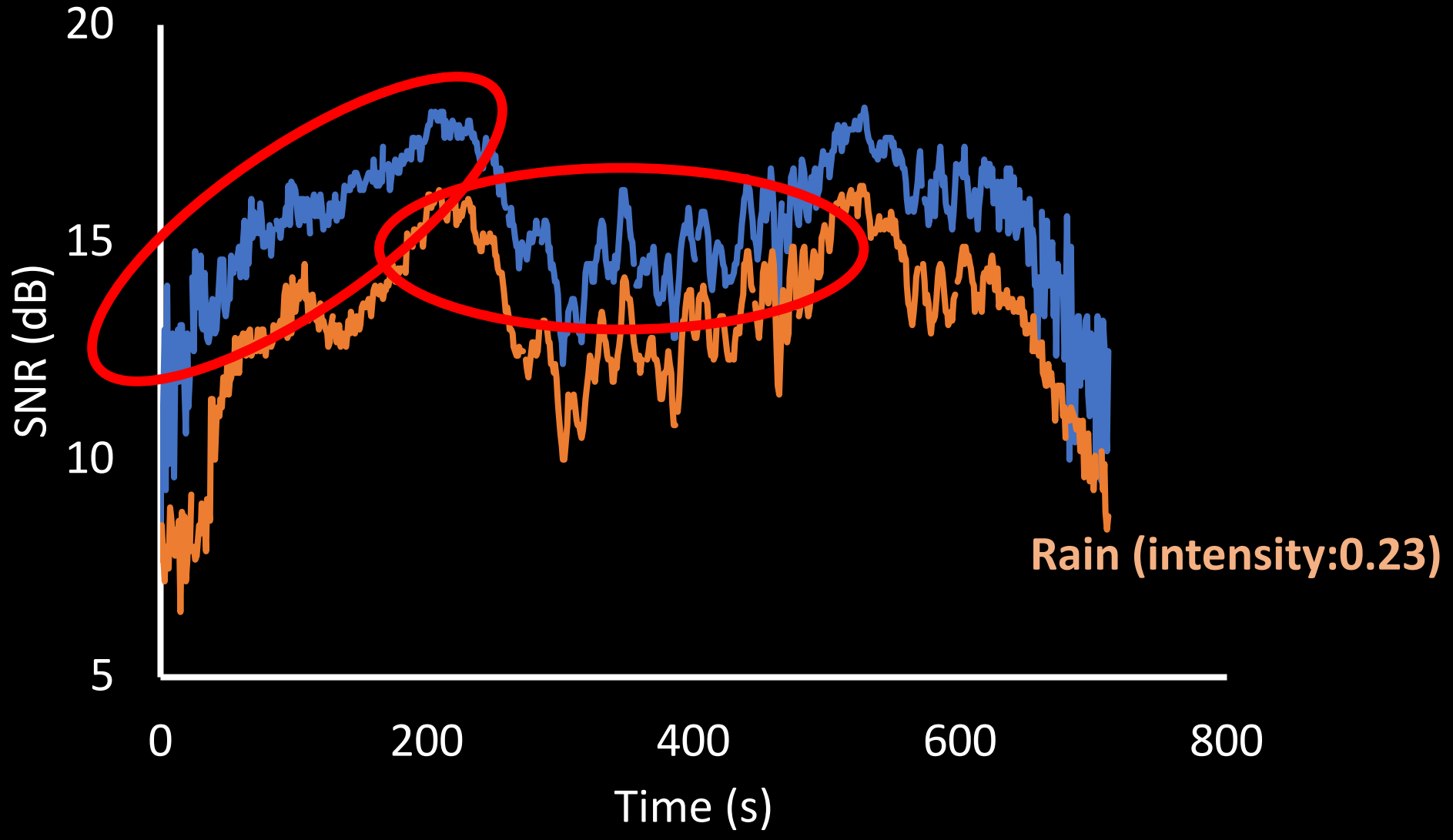
Challenge 1: Rate Adaptation

- Link quality varies by 10 to 20 dB
  - Depends on elevation
  - Weather (8-10 dB for X, Ku, Ka bands)
  - Equipment

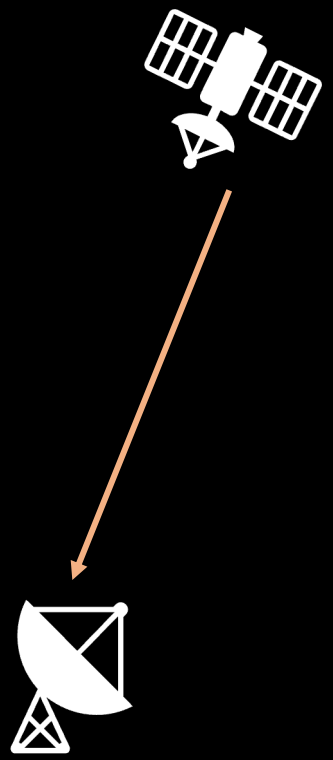
- No feedback → No rate adaptation
  - Low rate → Wasted opportunity

Need rate adaptation without feedback

Link Quality: X-band



Solution: Link Quality Estimation

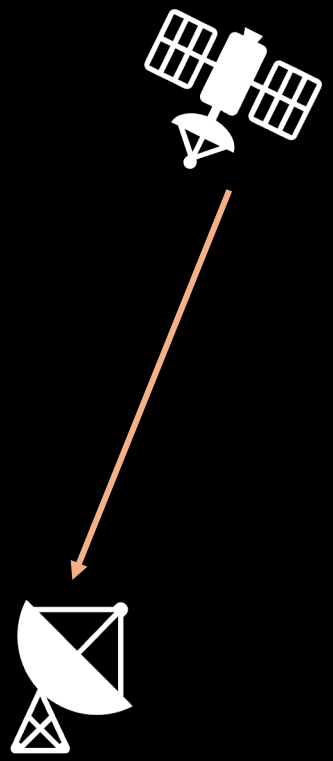


Propagation loss due to distance

Weather related loss

Device/location specific losses (multipath, etc.)

Intuition: Link Quality Estimation



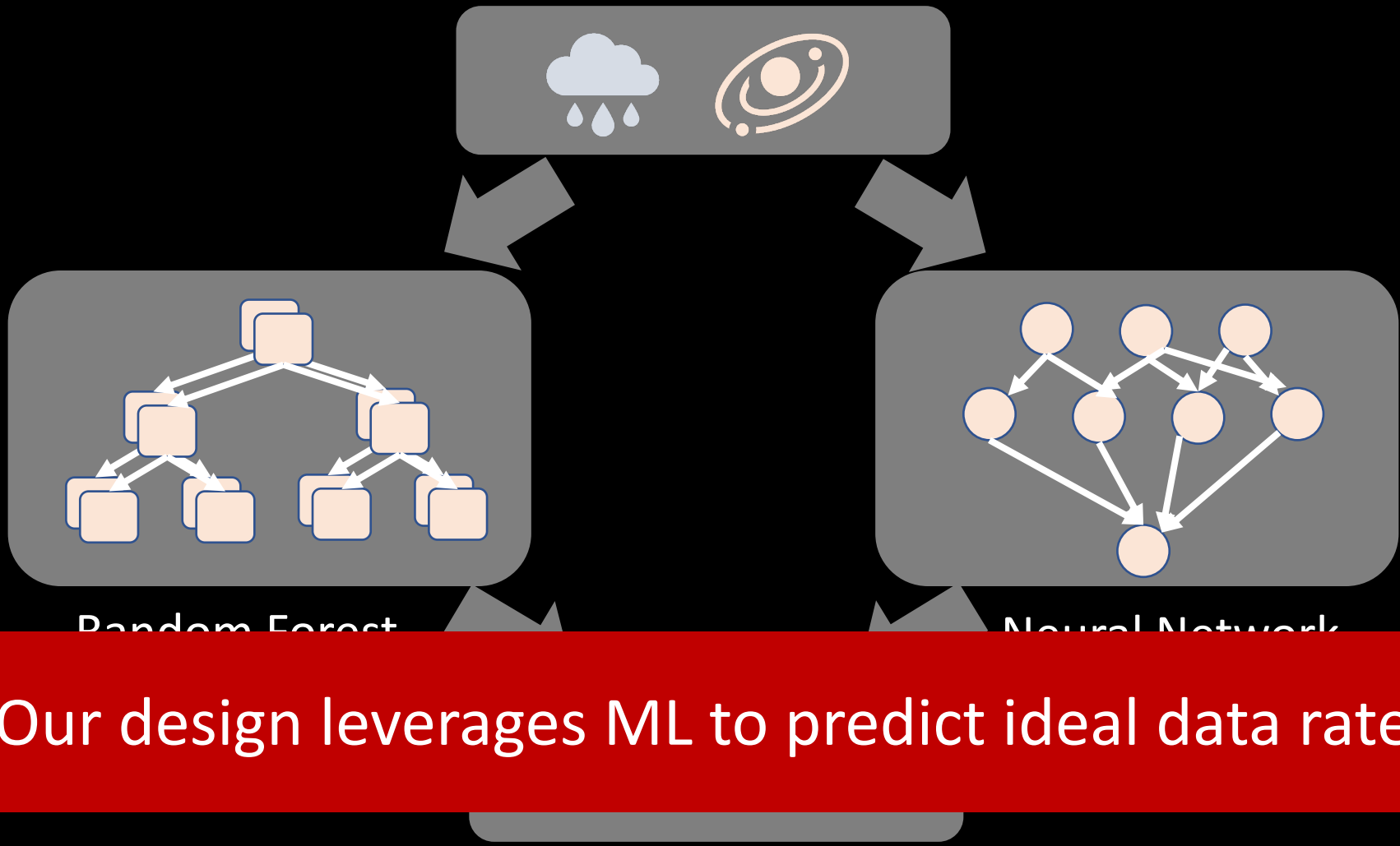
Predict distance using orbit parameters

Use weather forecasts for weather loss

Train for multipath and hardware losses

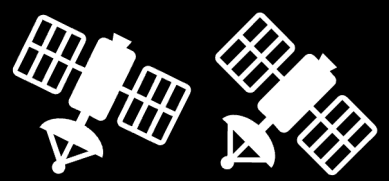
Datarate

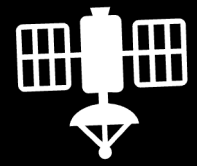
ML Model to Predict Link Quality



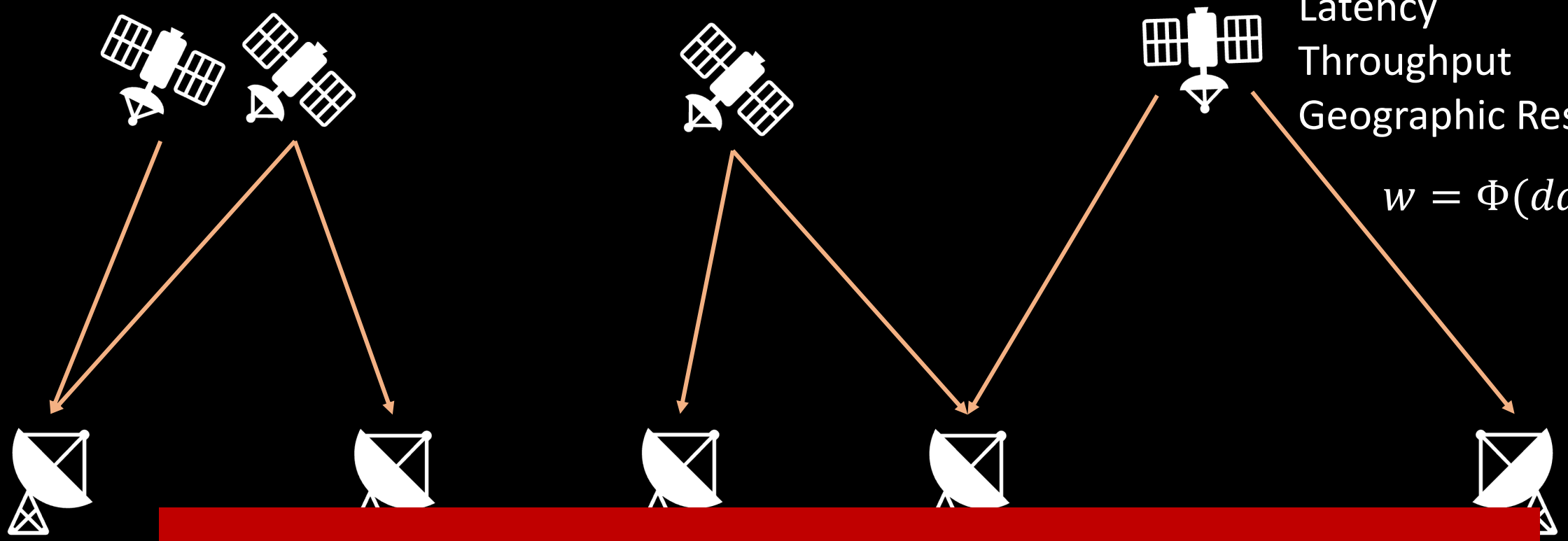
Our design leverages ML to predict ideal data rate

Challenge 2: Scheduling Satellite-GS Links





Challenge 2: Scheduling Satellite-GS Links

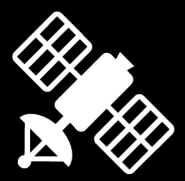


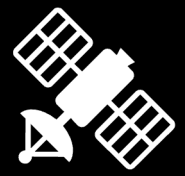
Latency
Throughput
Geographic Restriction

$$w = \Phi(data)$$

Bipartite Graph Matching Problem

Challenge 2: Scheduling Satellite-GS Links

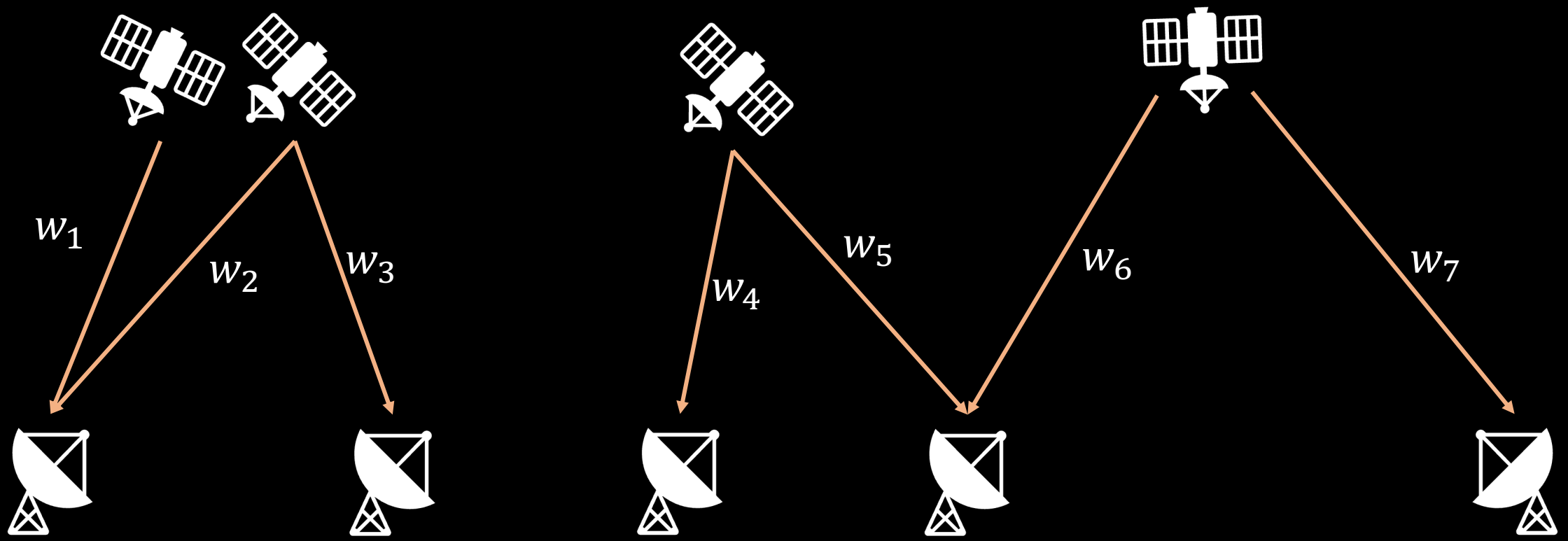




Switching links takes time
→ Matchings are not time-independent

NP Hard!

Solution: Greedy Algorithm with Penalty



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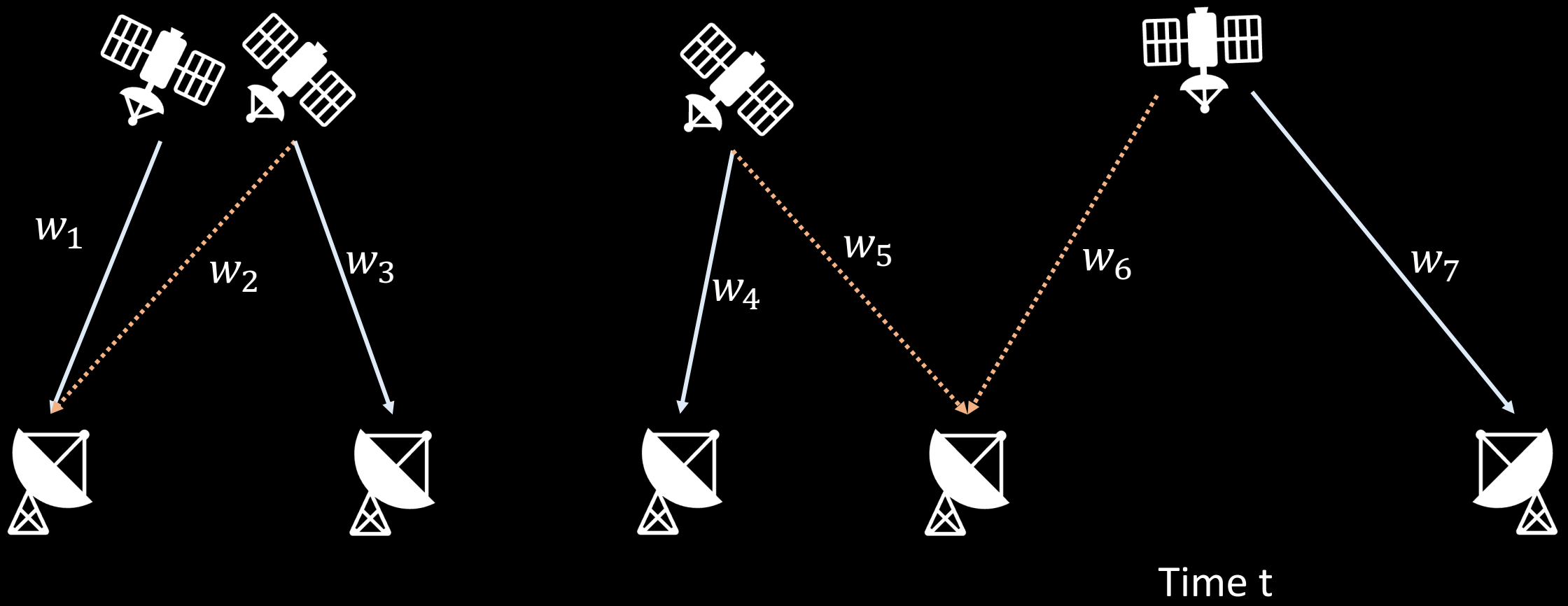

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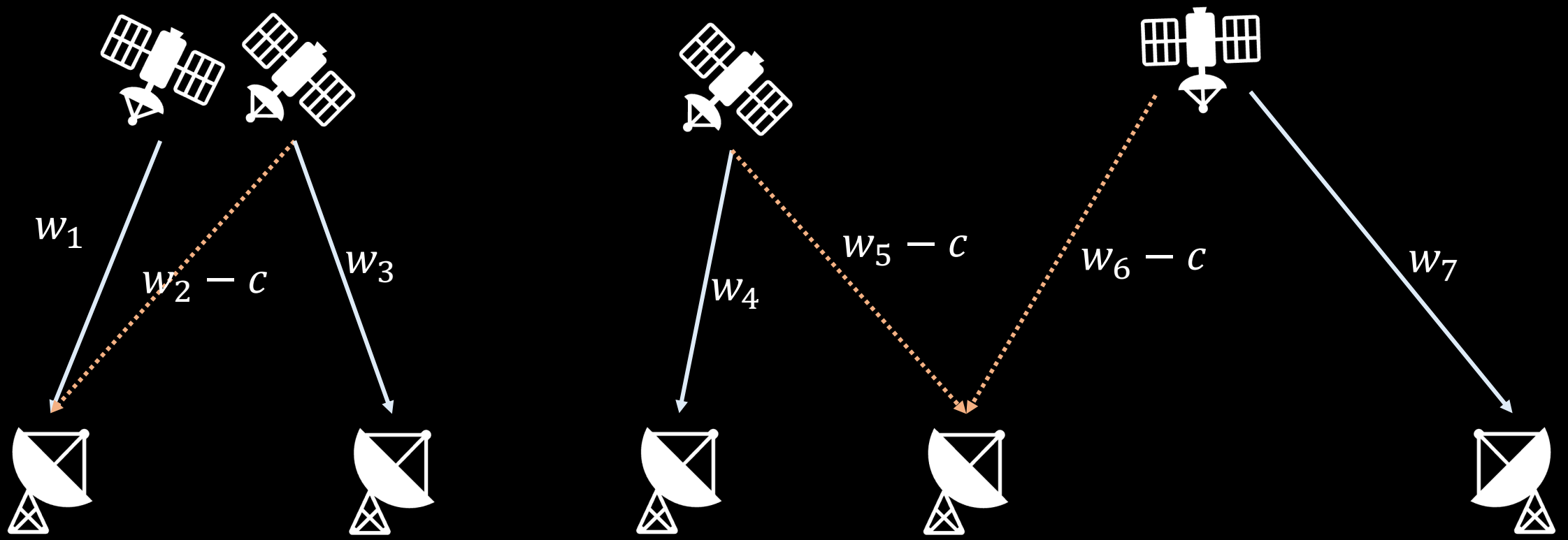
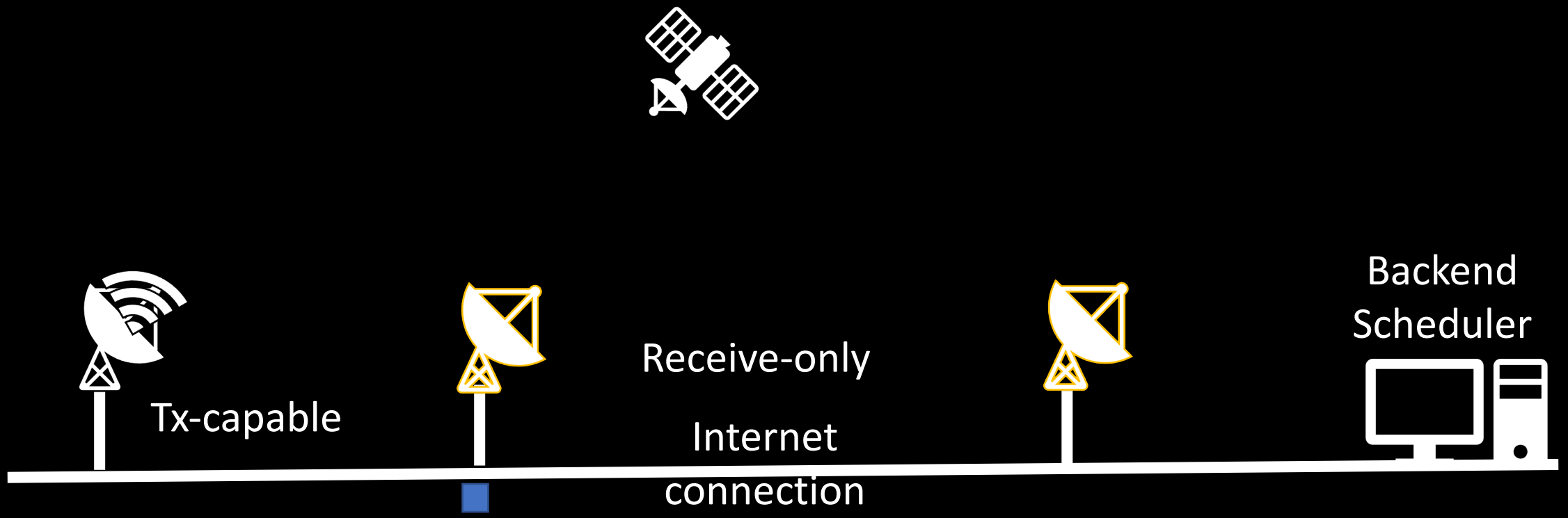


Solution: Greedy Algorithm with Penalty

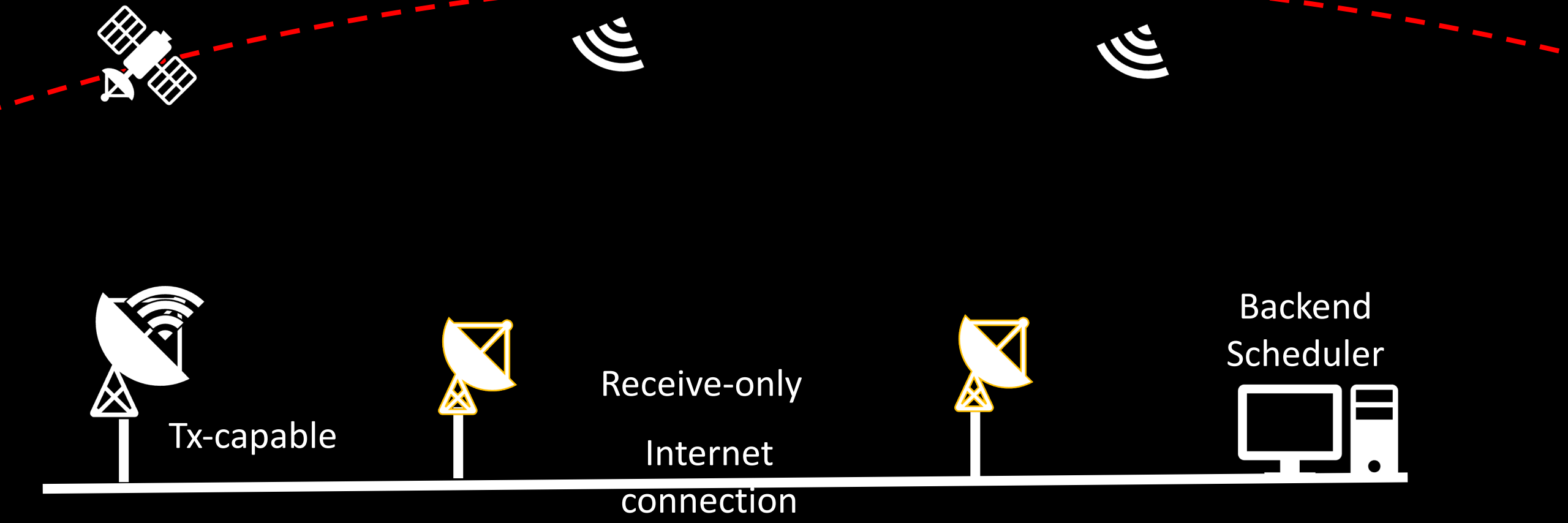
- Use Hungarian algorithm to find maximal matching
- Converges in O(K^3) where K=max(#satellite, #ground stations)
- Next step: find approximation guarantees

Challenge 3: No acks



Relay Acks Through Tx-Capable (With delay)

DGS: Distributed Ground Station



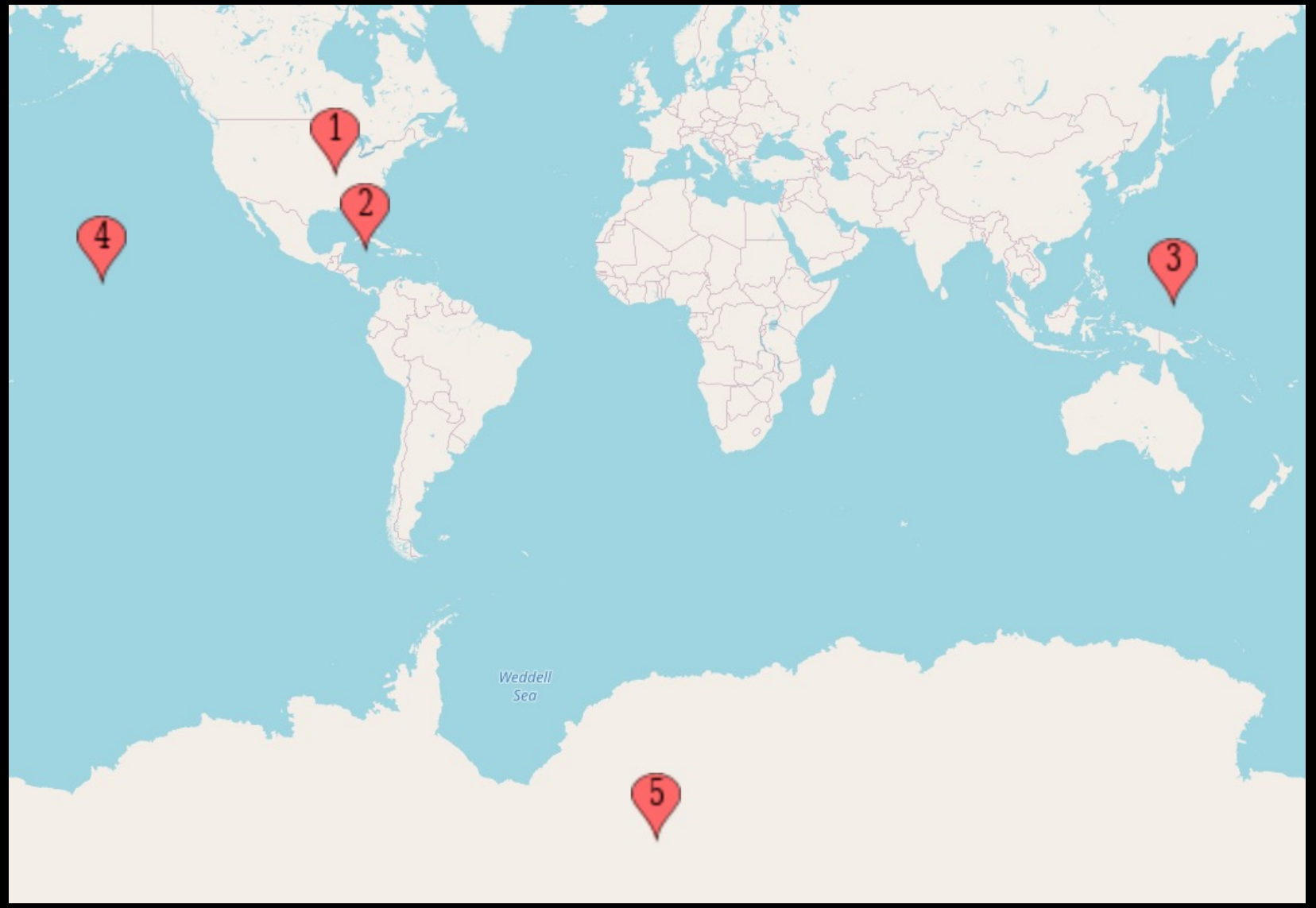
Experiments: Real-world Measurements

- 5 Ground Stations: Wisconsin, Florida, Guam, Hawaii, Antarctica

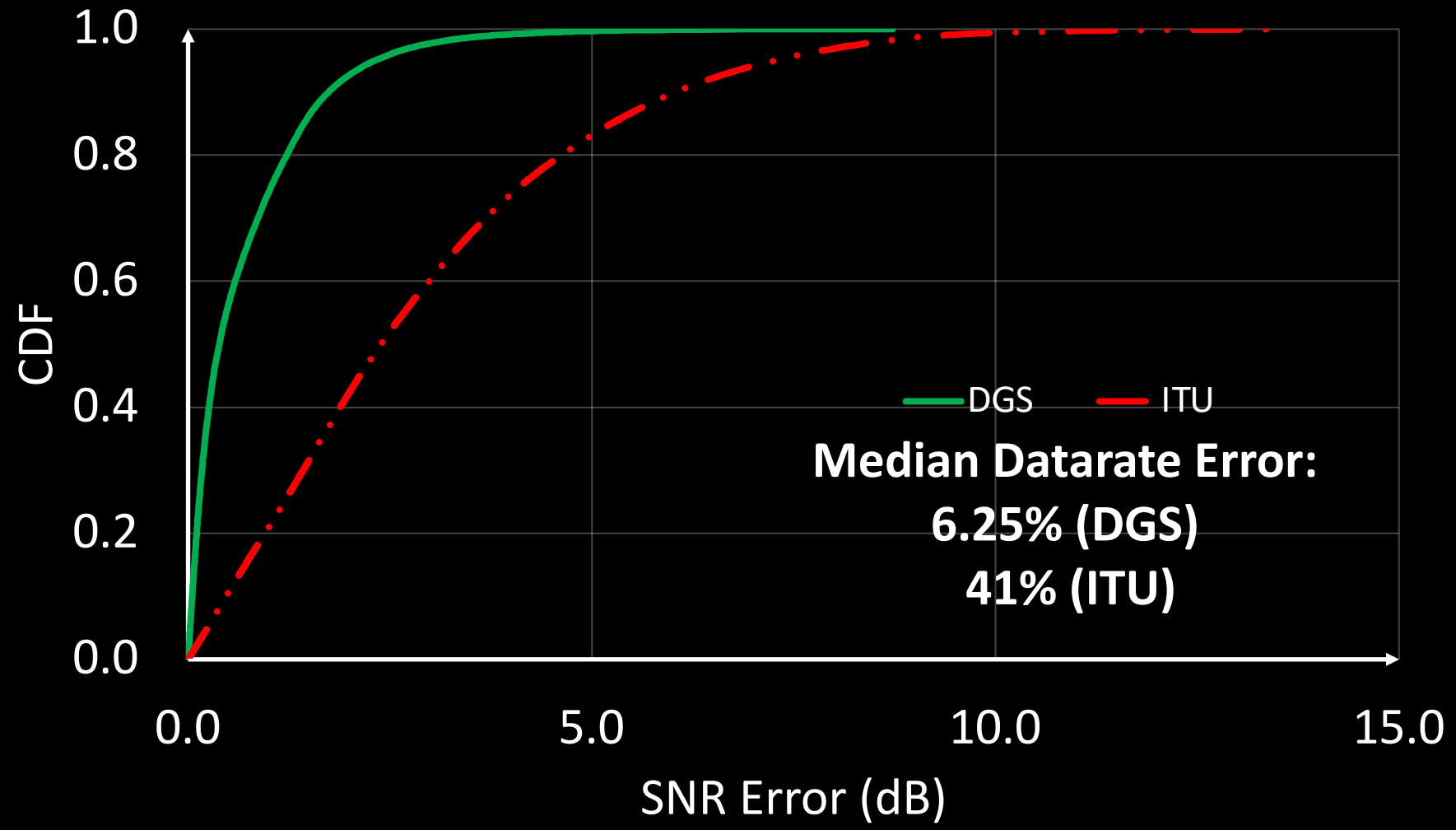
- 4 Satellites: JPSS, SNPP, Aqua, Terra
  - X-band Downlink: JPSS, SNPP, Aqua, Terra
  - Ka-band Downlink: JPSS

- Measurements across one month in 2020

Ground Station Locations



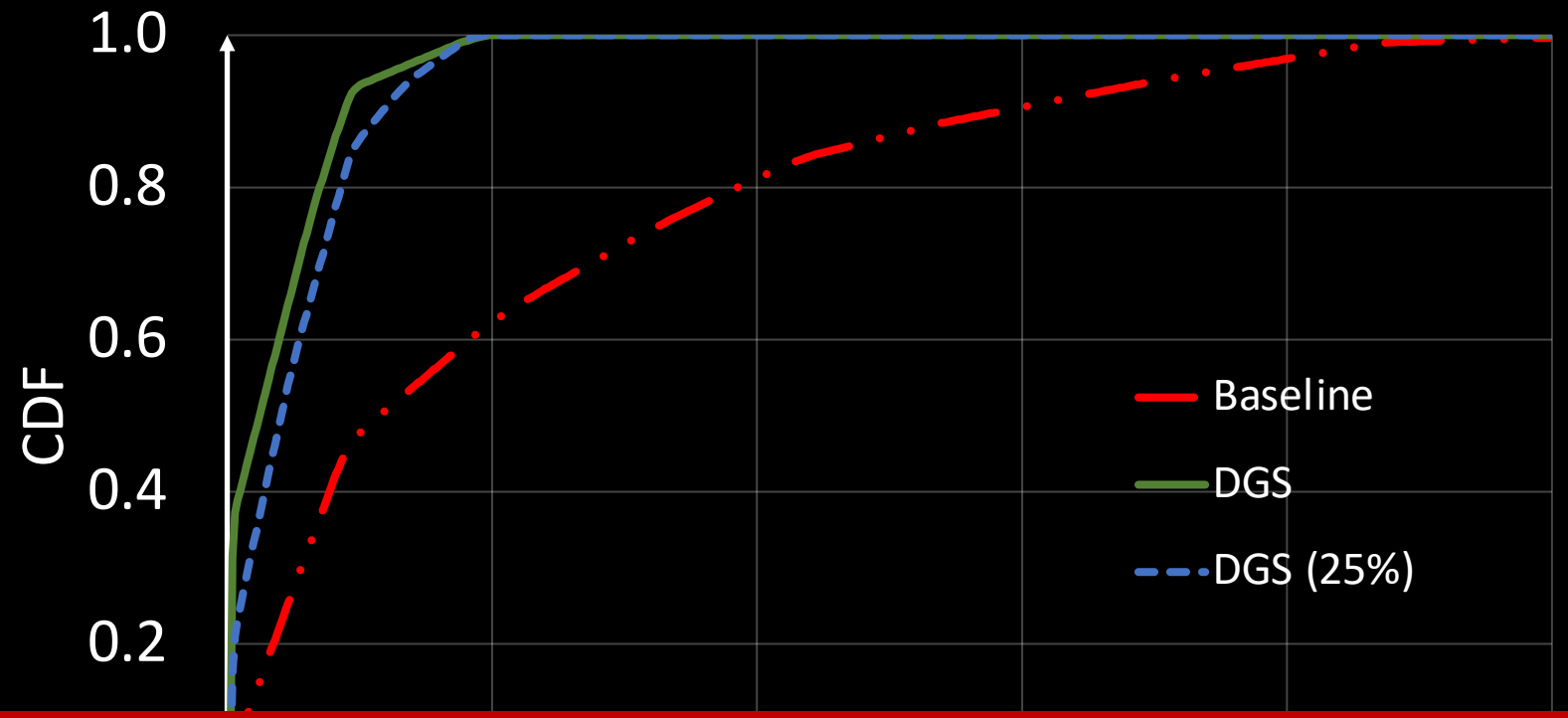
DGS ➔ Accurate Link Prediction



Large Scale Emulation

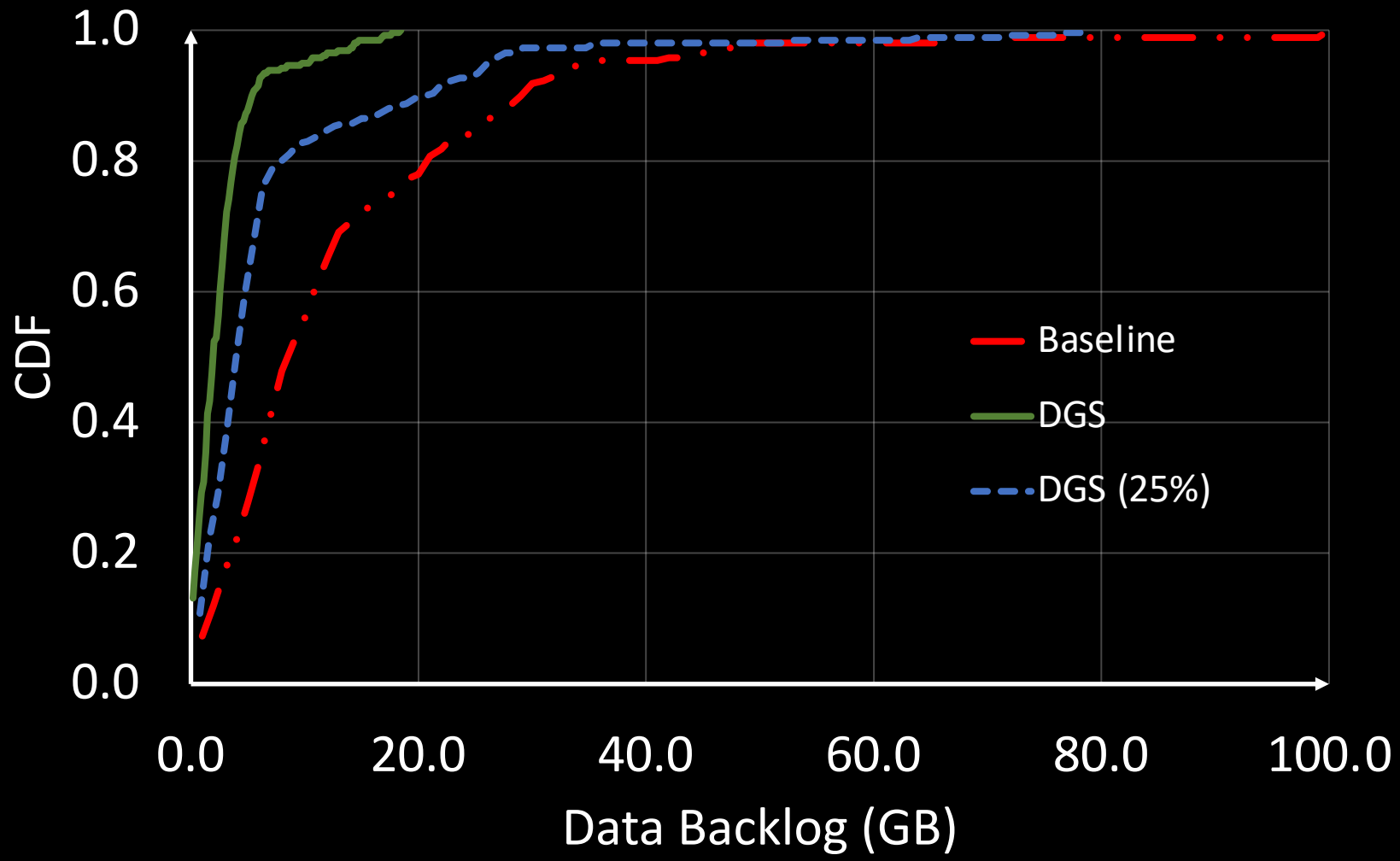
- SatNOGS: Open Source Ground Station Network
  - 259 satellites
  - 173 Ground Stations
- 100 GB data per day per satellite (26 TB total)
- Baseline: 5 Ground Stations
  - At least 10X higher median throughput

DGS ➔ Lower Latency

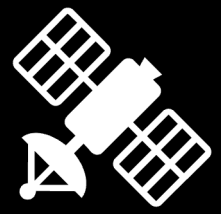


Distributed Ground Station reduces latency from hour to minutes

DGS ➔ Smaller Backlog



Open Questions



Satellite Power

Economic Model

Edge Compute

Beamforming

Checkout our paper in ACM SIGCOMM 2021