



Energy as a Constraint, Not an Objective

Scheduling Mars laser links under decaying RTG power

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The bottleneck is the pipe home



75%

of Mars Relay Network mission data reportedly
dropped at peak load
not for lack of collection, but for lack of downlink

1

Optical wins on capacity

Free-space laser delivers Gbps–Tbps at lower **size, weight, power** and **cost** than RF.

2

Optical costs you a narrow beam

Links require **pointing, acquisition** and **tracking** (PAT) before a single bit moves.

3

So links have to be scheduled carefully

Every link opportunity must be committed to in advance.
That is **Contact Plan Design** (CPD).

Source: R. Gladden, E. Pereira, and B. Sauer, “Lessons learned from the mars relay network: Considerations for future relay networks,” in 2024 IEEE Aerospace Conference, 03 2024, pp. 1–16.

The empty gap



optical interplanetary

LLS

Gerard et al., WiSEE 2024
Max-flow capacity (ΔC),
end-to-end aware, energy-blind

Lifespan-aware CPD

Toledo et al., WiSEE 2026 Lifespan-
aware CPD for Interplanetary FSO
Networks

LEO/terrestrial RF

Other works

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Battery-aware CPD

Fraire et al., 2020
State-of-charge for LEO,
solar recharge, RF

ignores energy

models energy

The empty gap



optical interplanetary

LIS

Gerard et al., WiSEE 2024
Max-flow capacity (ΔC),
end-to-end aware, energy-blind

THIS WORK

RTG decay
+ battery depletion
+ network capacity,
in one scheduler

Lifespan-aware CPD

Toledo et al., WiSEE 2026
Lifespan-aware CPD for Interplanetary FSO
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Battery-aware CPD

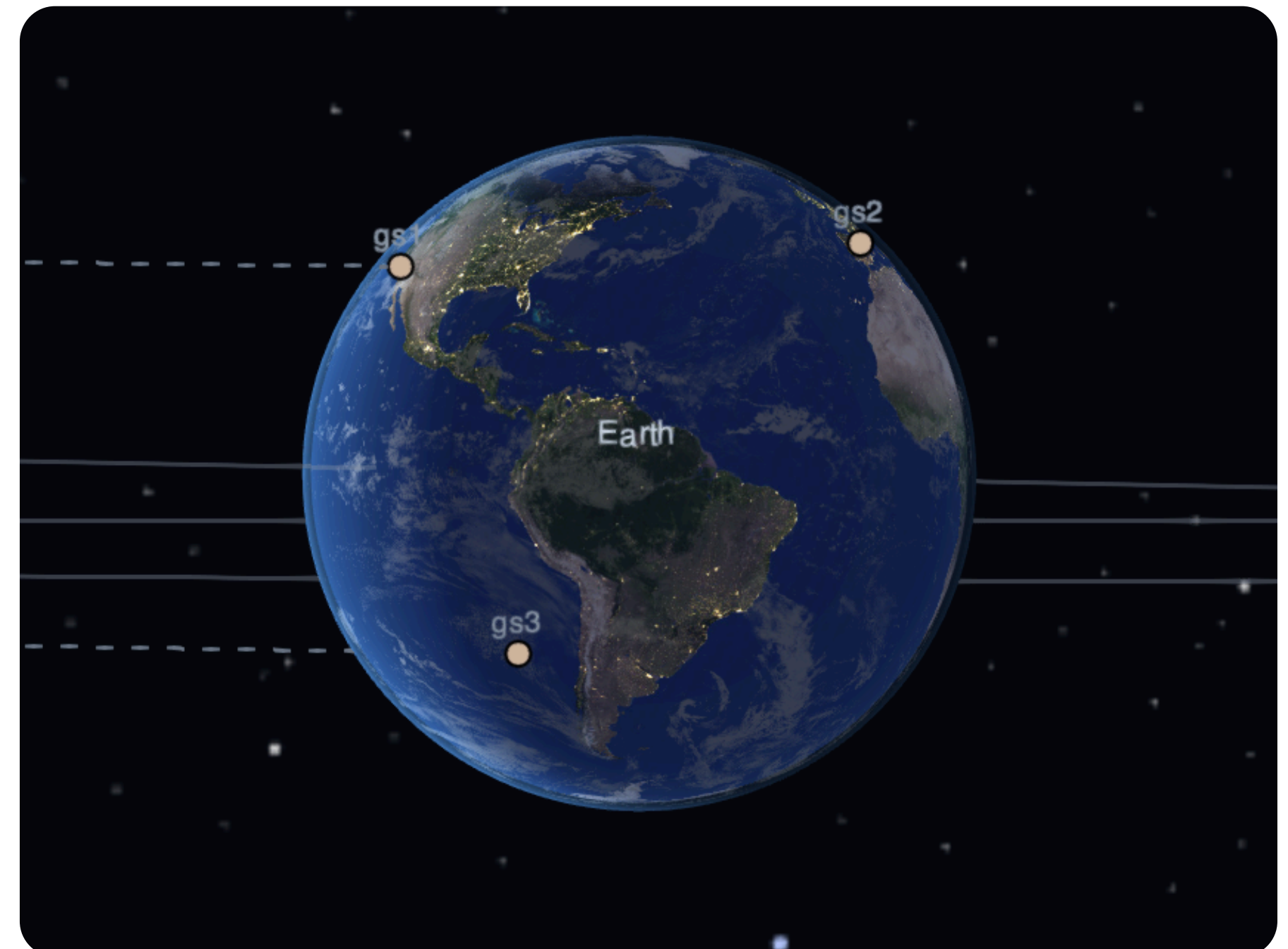
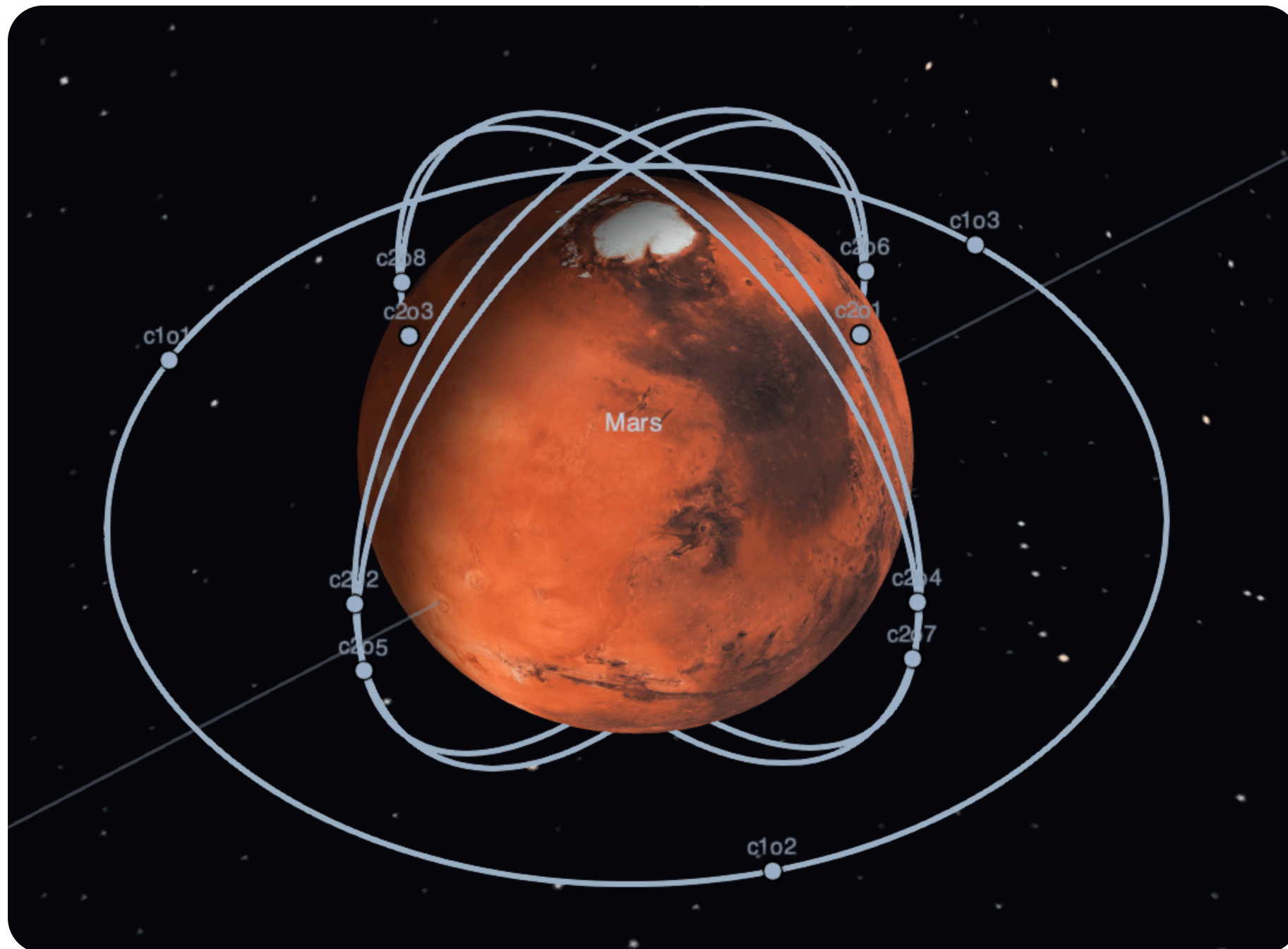
Fraire et al., 2020
State-of-charge for LEO,
solar recharge, RF

ignores energy

models energy

System model

Mars science orbiters → Mars relay → optical ground stations at DSN sites

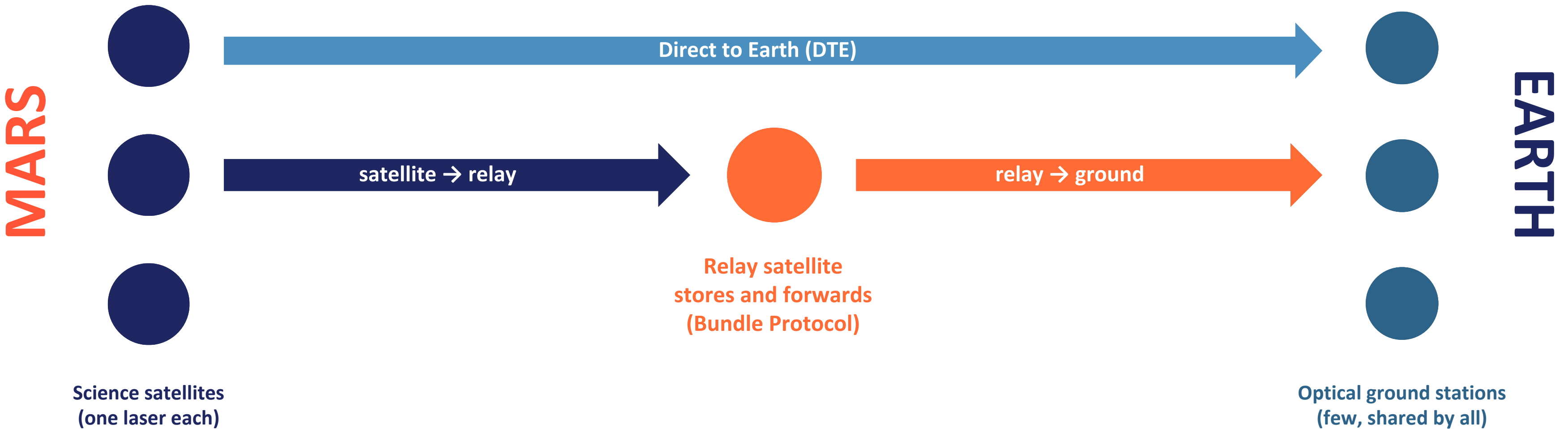


contact-plan-designer.space

Mars-to-Earth laser network

Each satellite has one laser, so a plan decides who talks to whom, and when.

Goal: as much data on Earth as possible.



ONE LASER EACH
one partner at a time: every link in the plan is exclusive

RTG POWER
steady, but weaker every year;
only the spare part pays for the laser

THE CONTACT PLAN
computed on Earth, days ahead, for fleets from a few to dozens

Who can afford to transmit?



ρ

$\rho = \text{spare power} \div \text{laser power}$

the share of the day a satellite can afford to transmit

1

Spare power ($P_{\text{RTG}} - P_{\text{base}}$)

What the generator gives beyond the spacecraft's own needs.
It shrinks every year.

2

Laser power (P_{tx})

What the laser terminal draws while it transmits.

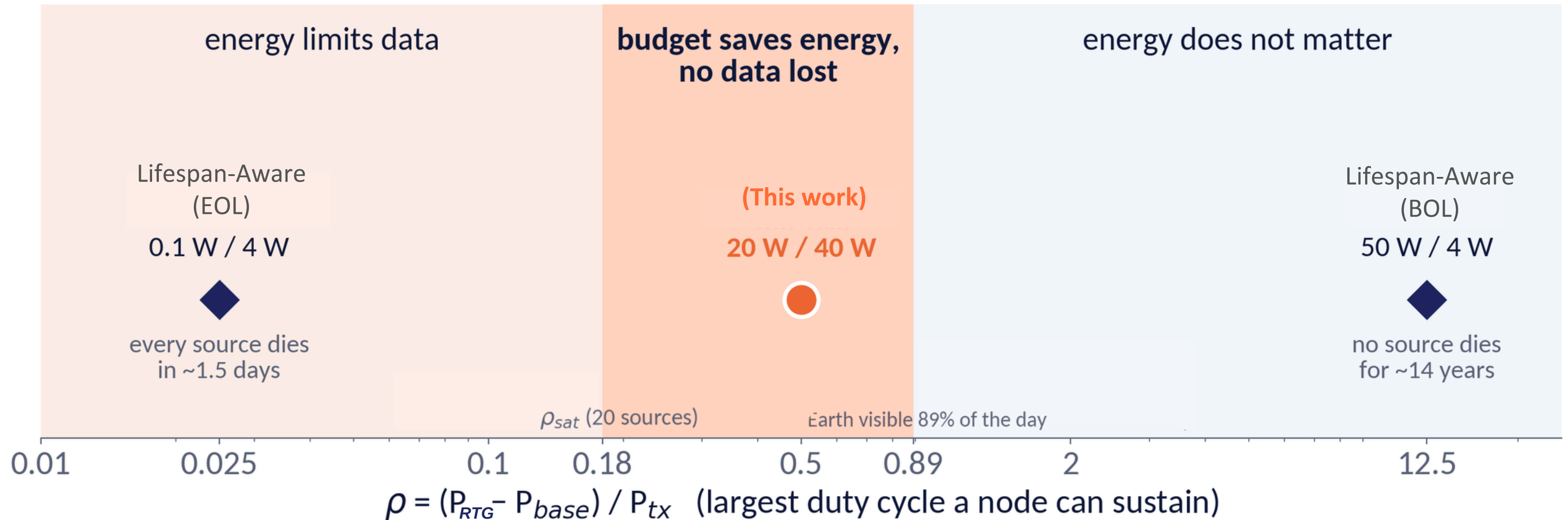
3

Transmit more than ρ : the battery drains

The battery covers the gap until it is empty.
Then the satellite is lost.

Data-only planners (e.g. LLS) keep their busiest satellites transmitting whenever they see Earth: far above ρ .

Where can a schedule matter?



A plan can only make a difference in the middle zone, and only if it caps how long each satellite transmits. That is where we work.

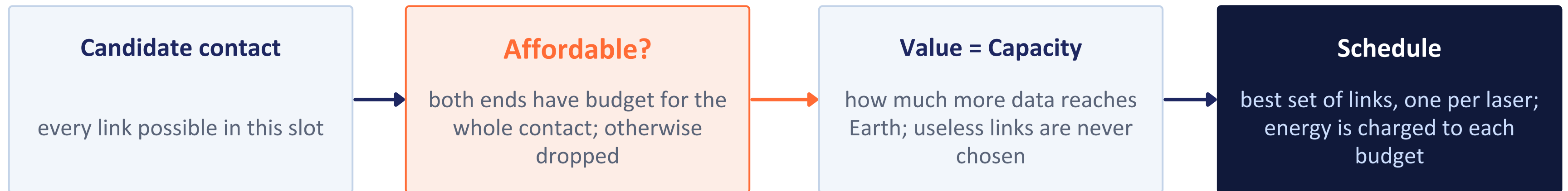
LLS-Budget



**Keep maximising data,
give every satellite a daily energy budget.**

Budget = what the generator can spare + what the battery can safely give

Every time slot: drop the links a satellite cannot afford, then pick the best



Result: over a day, no satellite transmits more than ρ

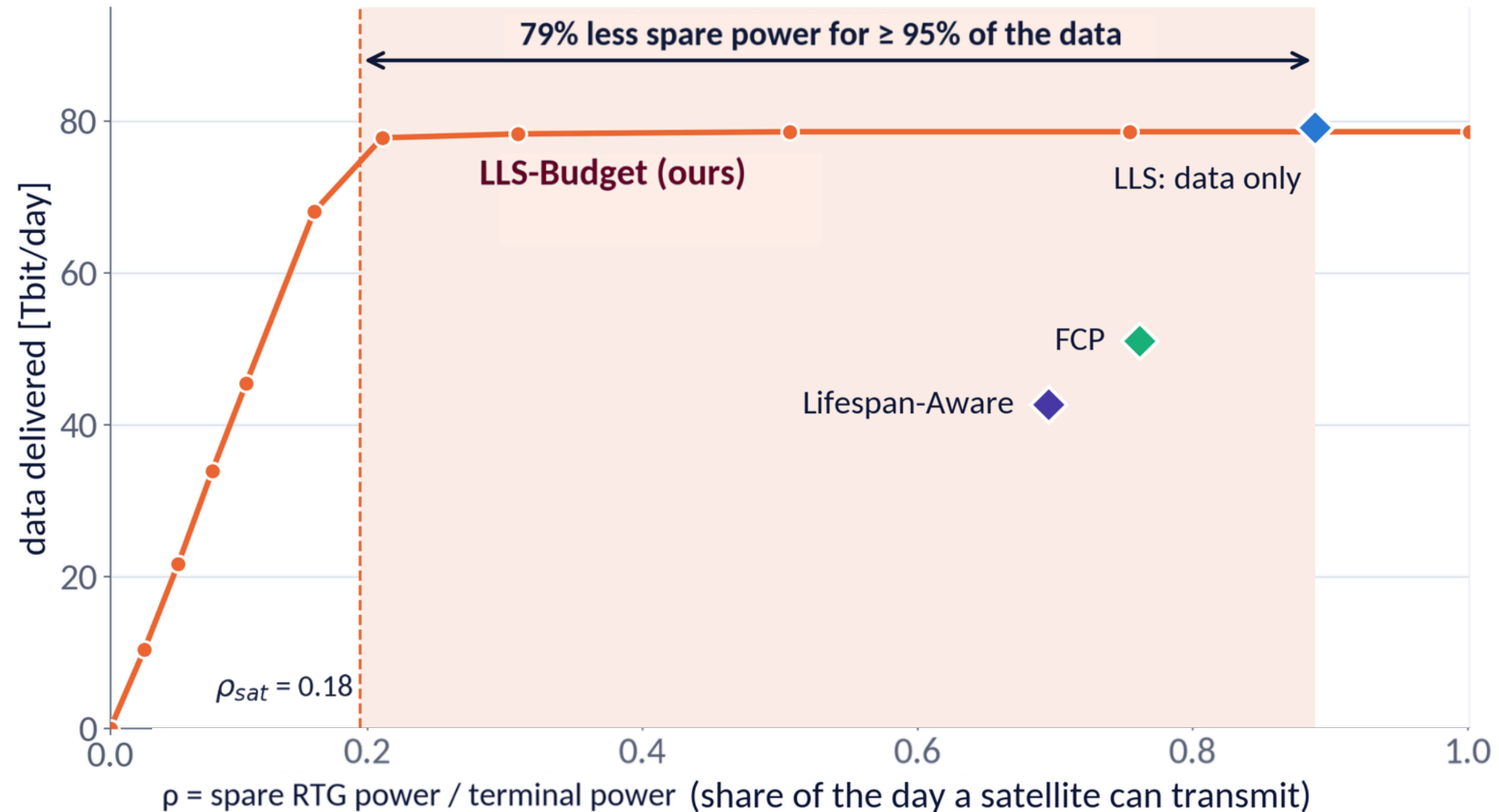
WHY A BUDGET, NOT A PENALTY

Penalties in the link weights (fairness in FCP, lifetime in Lifespan-Aware) reshape the plan, but nothing stops a satellite from overspending. A budget does.

Same data, ~80% less spare power

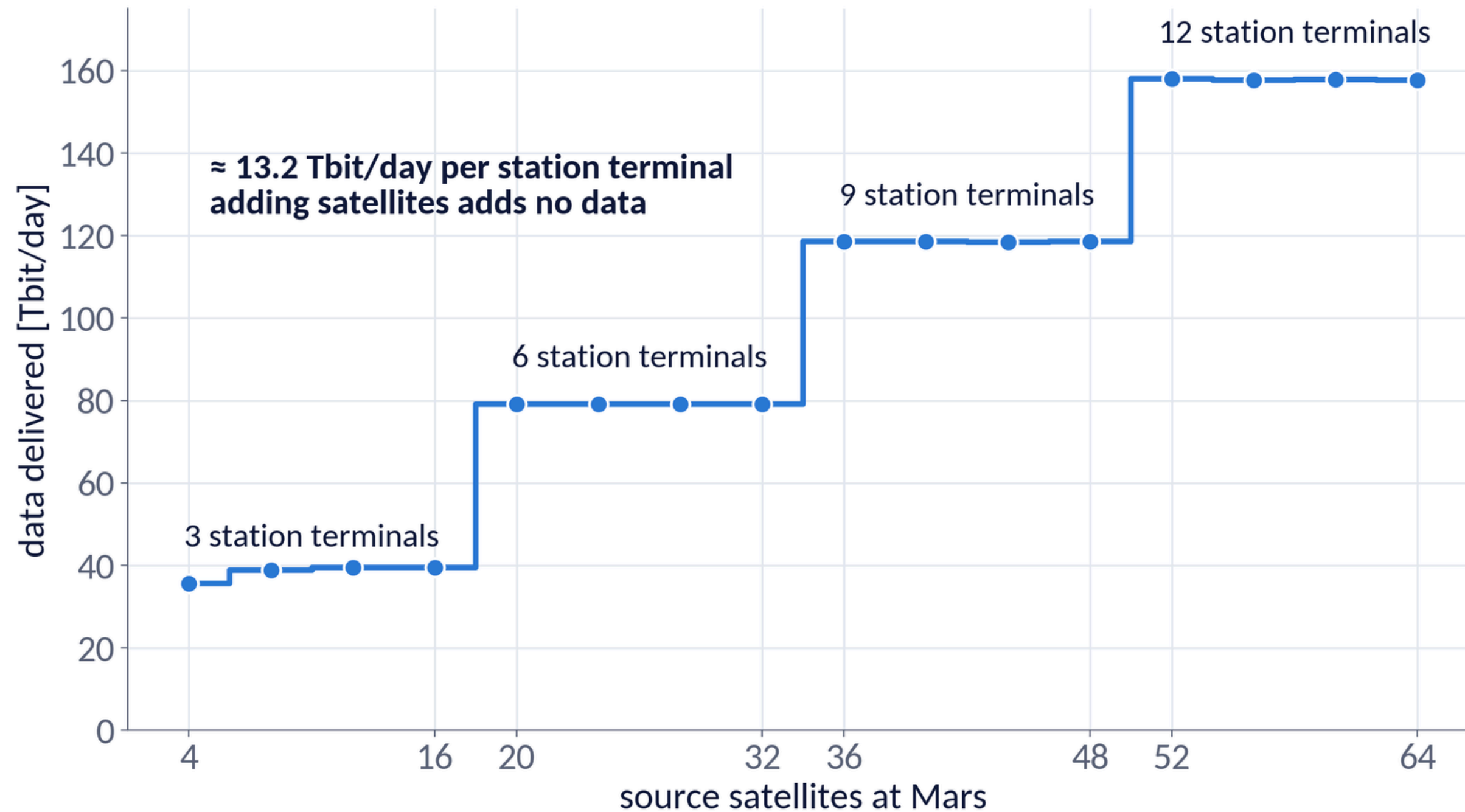


The same picture holds for every network size we tested.



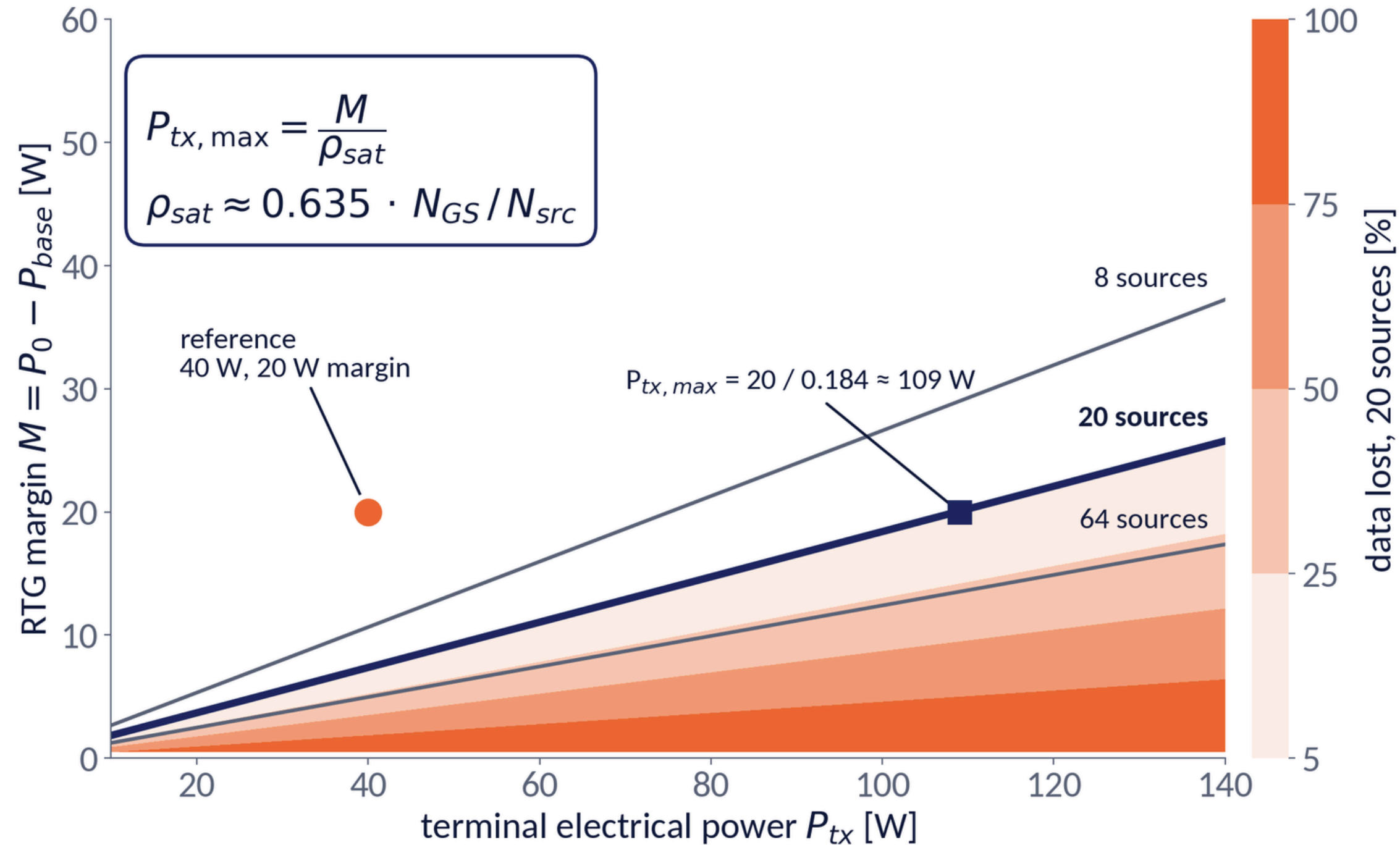
Stations are the bottleneck

Data grows with ground stations, not satellites. Transmitting more than the stations can receive wastes energy.



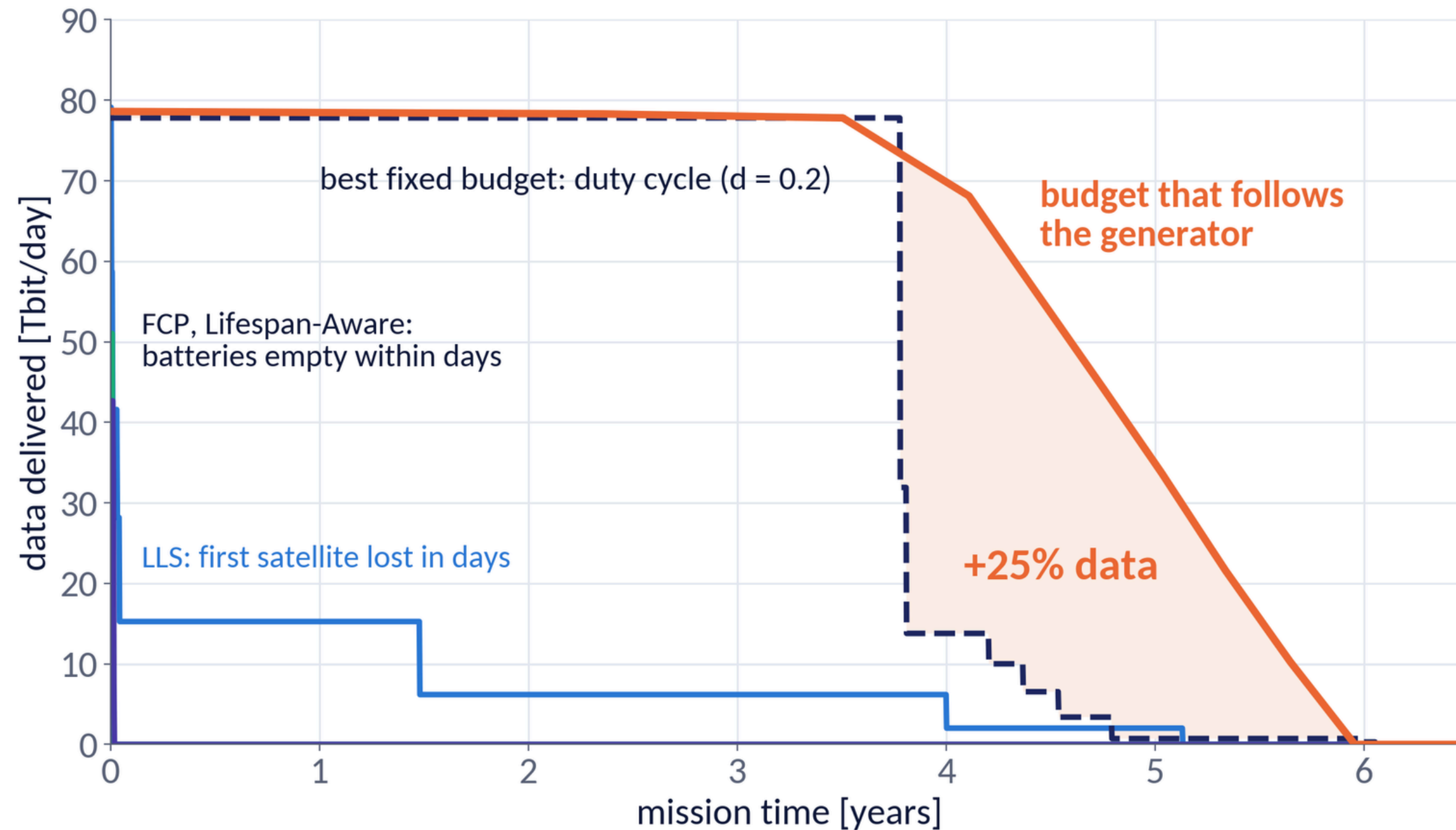
A sizing rule for the laser

Largest affordable laser = spare power ÷ share of time the stations can serve each satellite.



Follow the generator: ~25% more data

The generator weakens every year. A budget that follows it beats any fixed budget, in every case we tested.



Take-aways



p

One ratio, spare power over laser power, tells how much a plan can save and how big the laser may be.

1

Budget, not penalty

Same data with ~80% less spare power than a data-only plan.

2

A sizing rule for the laser

Largest affordable laser = spare power ÷ share of time the stations can serve each satellite.

3

Follow the generator

~25% more data over the mission than the best fixed budget.

FUTURE WORK

Optimal planner, model solar energy (depletion and battery recharge).



Thanks! 😊

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