STINT 2026 · SPACE-TERRESTRIAL INTERNETWORKING WORKSHOP · KU LEUVEN · 14 SEPTEMBER 2026

Light-Time-Corrected Contact Plans: Re-Introducing Contact Plan Designer

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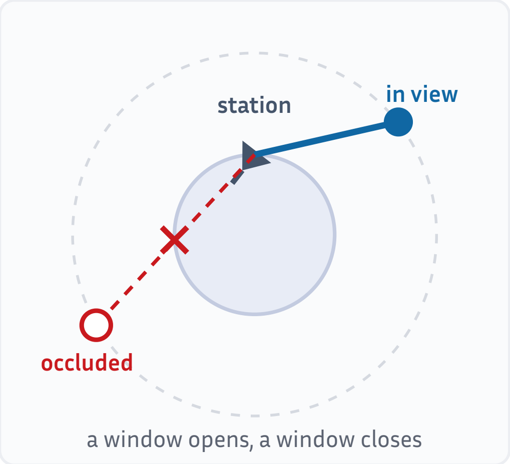
Inria, Lyon · CONICET / Universidad Nacional de Córdoba

Joint work with **Pablo G. Madoery** · tool, scenarios and paper material at **contact-plan-designer.space**

The contact plan

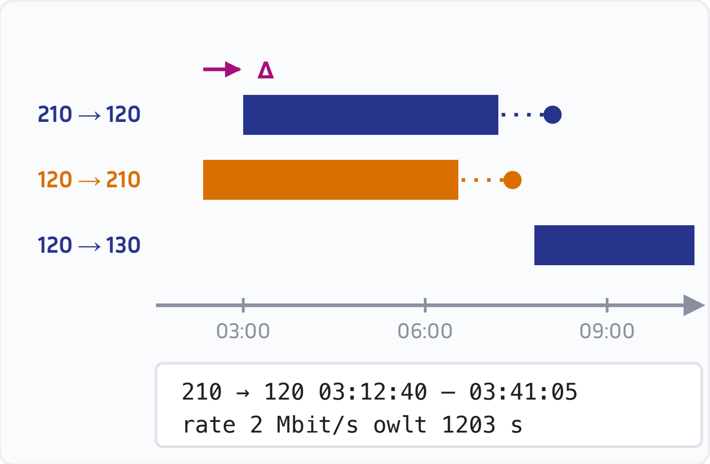
- A contact plan is a **list of directed, time-bounded transmit opportunities**, each with its own **rate** and its own **delay**.
  - Astrodynamics proposes them; the **platform** and the **operator** decide which ones are real.

GEOMETRY



ephemerides · elevation · range · occlusion

THE CONTACT PLAN



one record per direction · start, end, rate, delay

WHAT CONSUMES IT

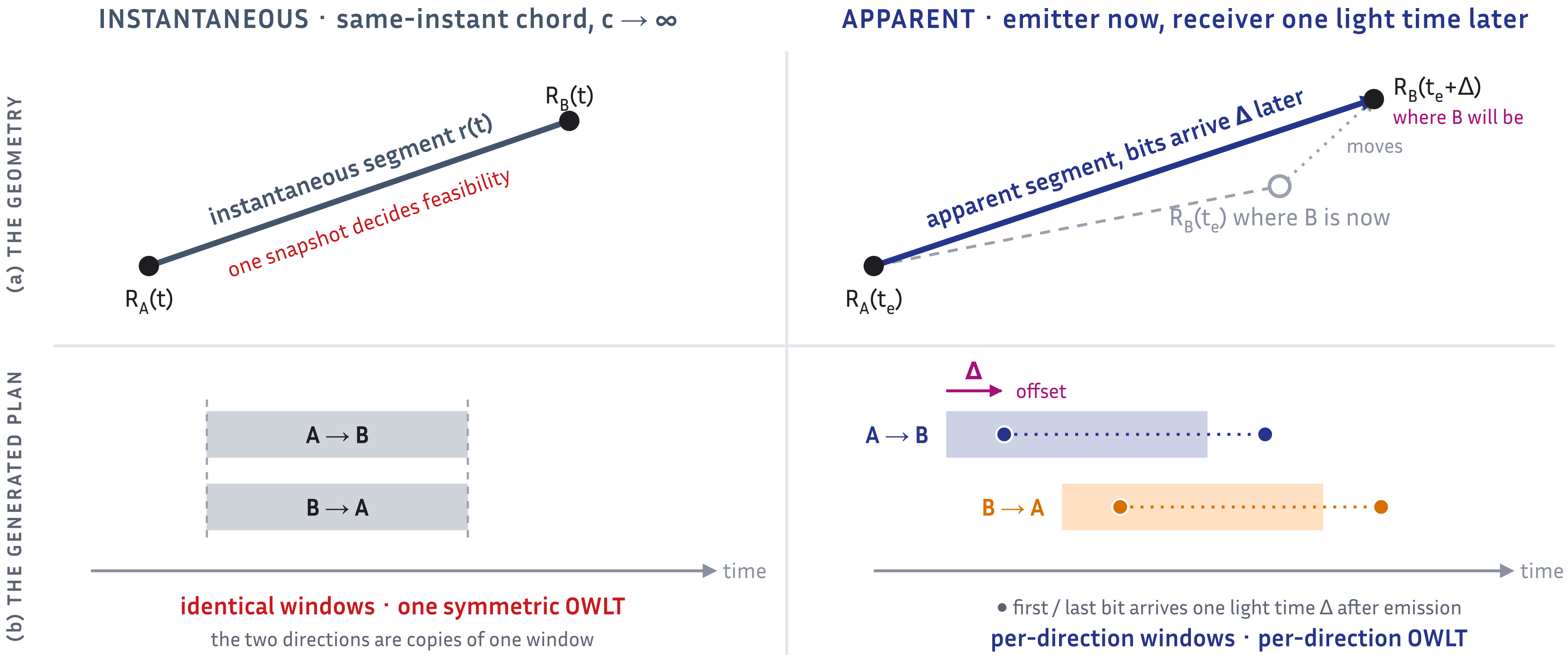
- Routing · CGR, SABR
- Forwarding and storage
- Simulation and testbeds
- Operations and scheduling
- Visualization · IPN-V

every layer above inherits its errors

The contact plan is where astrodynamics becomes networking. Get it wrong once, and everything downstream is wrong with it.

- Two questions follow, and the rest of this talk is those two: **is it correct**, and **is it affordable**.

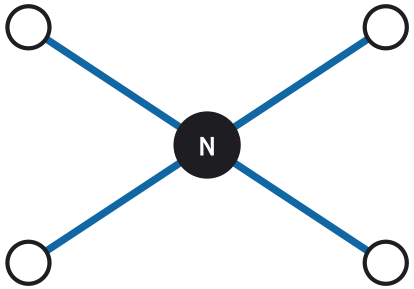
Is the contact plan correct? → Apparent Position



Fix. Solve the light time as a fixed point, $|\vec{R}_B(t_e{+}\Delta) - \vec{R}_A(t_e)| = c\,\Delta$

Is it affordable?

GEOMETRY OFFERS



4 feasible at the same instant

THE PLATFORM AFFORDS

TX

transceivers · energy budget · pointing / PAT

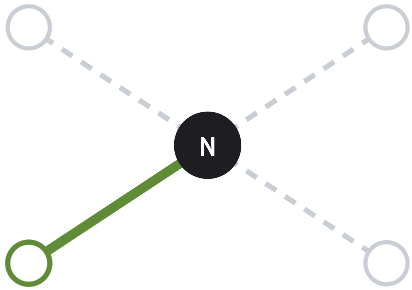
N links at a time, whatever the geometry offers

THE OPERATOR ALLOWS

mission priority · booked time · quiet windows

and only when the mission grants it

DESIGN CHOOSES

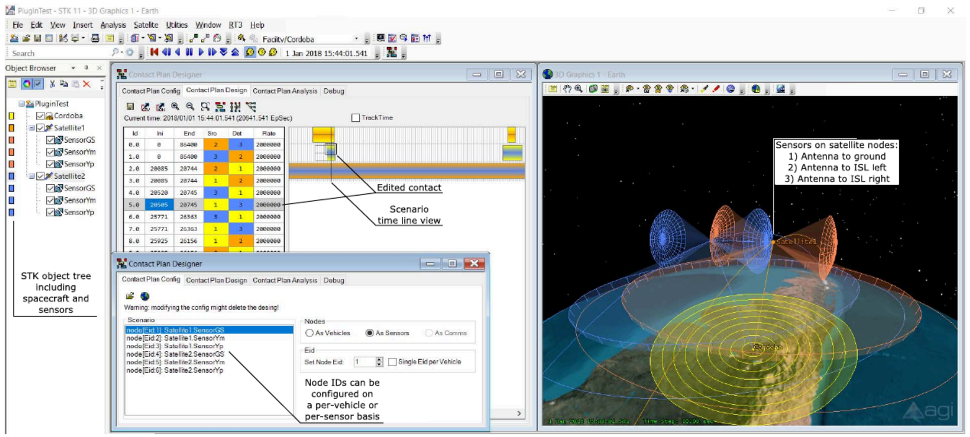


the **affordable, allowed** subset

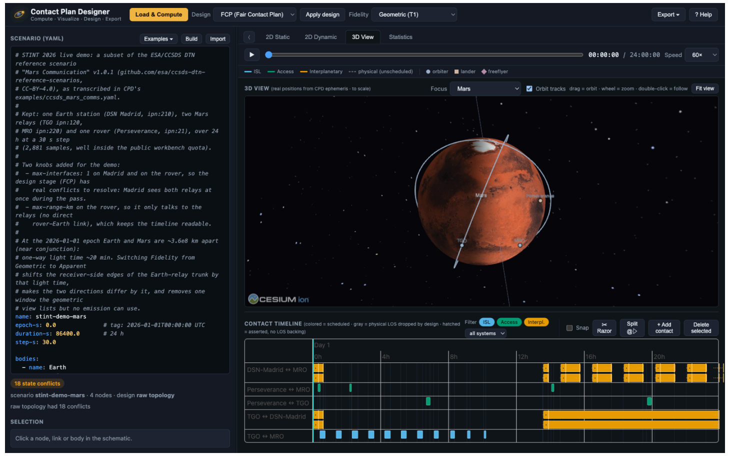
Topology first, plan second. Geometry lists every feasible contact; the **platform** and the **operator** decide which survive.

PART 2 · THE TOOL

Contact Plan Designer



2017 · a plug-in inside STK (SMC-IT 2017)



2026 · an open core, MIT: CLI, web workbench and library

scenario.yaml
constellation-code keys
+ bodies, landers, epochs
+ light-time options

→

ephemeris
multi-body Kepler
or DE440 through SPICE
one Sun-centred frame

→

contacts
geometric (T1), default
apparent (T2), directed
occlusion, range, horizon

→

design
FCP, time-expanded graph
matching per state
interfaces, fairness

→

export
ION · HDTN · TVR · IPN-V
STK access, AER
directed windows kept

one pure-Python core, MIT · three faces that cannot diverge: **CLI** · **web workbench** · **library**

Live at `contact-plan-designer.space` · source at `gitlab.inria.fr/jfraire/contact-plan-designer`

Research software under active development: results may contain errors and come with no warranty of any kind. Validate before operational use.

Open and follow along

contact-plan-designer.space

gitlab.inria.fr/jfraire/contact-plan-designer
juan.fraire@inria.fr

Under active development, MIT licence, no warranty: results may contain errors.

A simple scenario by hand

```yaml
name: stint-demo-earth
epoch: 2026-09-14T00:00:00Z    # t = 0, UTC
duration-s: 86400              # 24 h
step-s: 60

nodes:
  - id: 1
    name: Leuven
    type: lander
    central-body: Earth
    latitude-deg: 50.88
    longitude-deg: 4.70
    constraints: { min-elevation-deg: 10 }

  - id: 2
    name: LEO-sat
    type: orbiter
    central-body: Earth
    elements: { altitude-km: 550, inclination-deg: 97.6 }
```

Other default keys

`data-rate-bps: 1000`, `max-interfaces: 1`, orbit angles 0, geometric fidelity. `epoch` only sets the clock (omitted, t = 0 is 1970-01-01 UTC). `id` is the node number in the exported plan.

A constellation

Replace node 2 with the I-D's Walker code

```yaml
constellations:
  - code: "D:550:97.6:12/3/1"
    base-id: 2
    constraints: { max-range-km: 3000 }
```

IETF draft

This is how the **draft-piraux-space-constellation-code-02** specifies scenarios

Load & Compute → four passes over Leuven in 24 h, exported as `a contact +633 +960 1 2 1000` for ION, or as HDTN, TVR, IPN-V.

Inria

A deep space scenario

```yaml
name: stint-demo-mars
epoch: 2026-01-01T00:00:00Z   # ESA/CCSDS reference epoch
duration-s: 86400.0
step-s: 30.0
bodies:
  - name: Mars
    parent: Sun
    radius-km: 3389.5
    rotation-period-h: 24.623
    elements: { sma-km: 227944541, ... }
nodes:
  - id: 210
    name: DSN-Madrid
    type: lander
    central-body: Earth
    latitude-deg: 40.234
    longitude-deg: -4.253
    max-interfaces: 1
    constraints: { min-elevation-deg: 5 }
  - id: 120
    name: TGO
    type: orbiter
    central-body: Mars
    elements: { sma-km: 3796.19, ... }
```

- Same keys as **draft-piraux-space-constellation-code-02**
  - kebab-case CDDL names. Shells and ground stations import unchanged
- Added for the **interplanetary case**:
  - bodies with their own orbit and spin, landers on any body, and others.
- **Reference scenarios bundled**:
  - the three ESA/CCSDS DTN reference scenarios

CCSDS scenario	Nodes	Web horizon
LEO Earth observation	3	2 days
Lunar communication	8	6 days
Mars communication	7	6 days

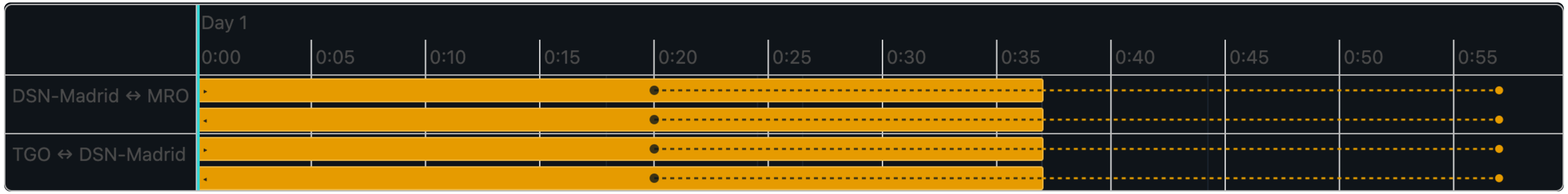
The full 7- and 30-day ESA horizons run locally without limits.

PART 2 · LIVE DEMO

A deep space scenario: The Eart-Mars trunk

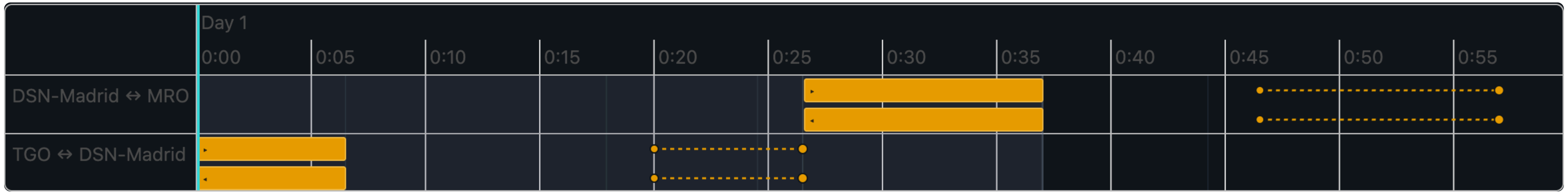
1 · Geometric, raw

18 conflicts, 14 once reception counts · both directions copy one window



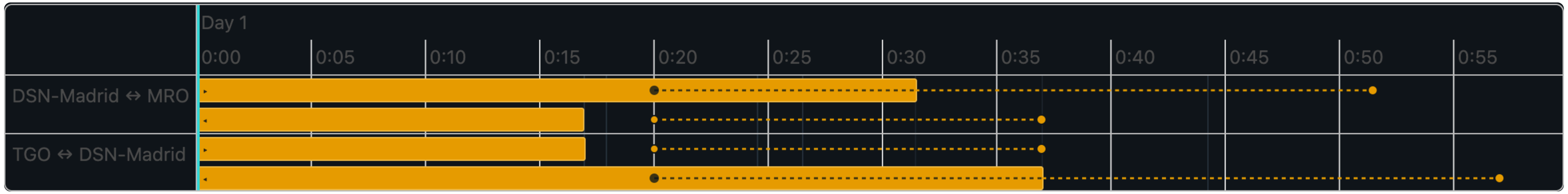
2 · Geometric + FCP

conflict-free, light-time clean · Madrid serves TGO, waits for its last bit to land, then turns to MRO



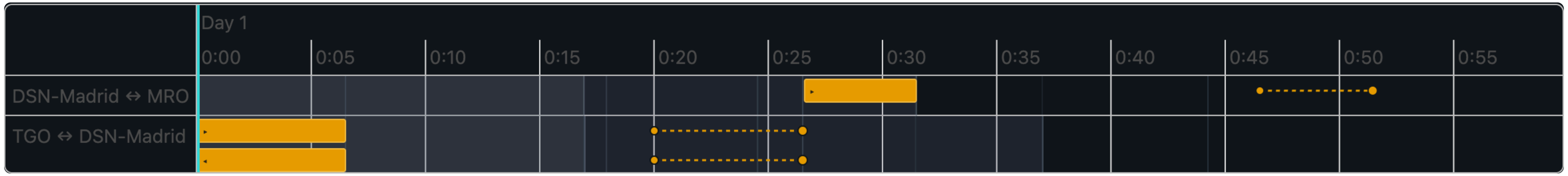
3 · Apparent, raw

45 conflicts, 12 with reception · Mars→Earth closes 20 min early: later bits would arrive after Madrid sets



4 · Apparent + FCP

conflict-free, light-time clean · the MRO→Madrid slot is gone with its window; every scheduled minute carries bits



Bar: transmit window on the sender's clock · dotted rail: where those bits land, one light time (20 min) later · grey: physical windows the design dropped. FCP books the receiver for that light time, re-decides every 10 min, commits a link for 5 min. DSN Madrid, TGO, MRO, Perseverance on 2026-01-01; `stint_demo_mars.yaml`.

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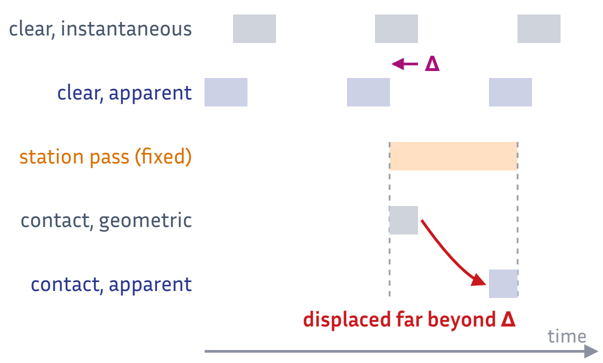
Is the contact plan correct? → Apparent Position

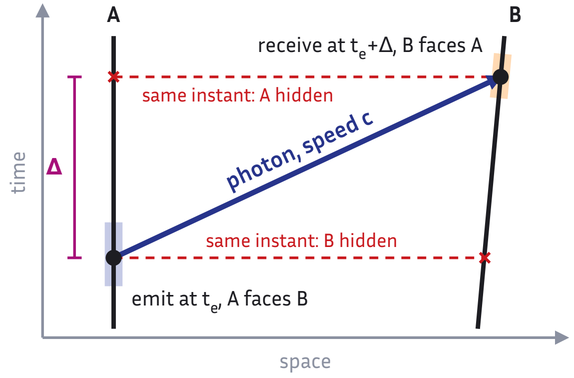
- Three consequences of ignoring apparent position:

Boundaries move



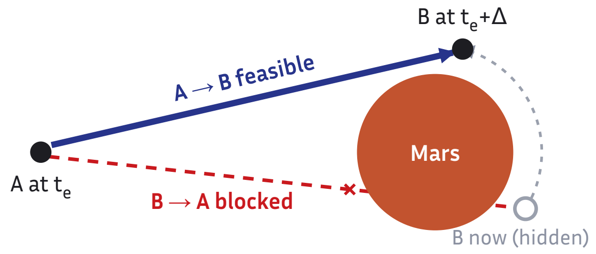
Each edge shifts by up to one light time, and fragments can be displaced

Transit-only contacts



The nodes might never in mutual view, yet the bits leave and arrive.

Directions become asymmetric



An occluder can block the return crossing and leave the forward one clear.

Negligible near Earth · **quantitatively wrong at Mars** · **qualitatively wrong in deep space**.

BACKUP · LIVE DEMO

The same hour in numbers: directed contact minutes

Link (a ⇄ b: a → b / b → a)	geometric, raw	geometric + FCP	apparent, raw	apparent + FCP
DSN-Madrid ⇄ MRO	37	10	32 / 17	5 / 0
DSN-Madrid ⇄ TGO	37	7	37 / 17	7
MRO ⇄ Perseverance	9	9	9	9
MRO ⇄ TGO	20	0	20	0
Total scheduled	**205**	**51**	**159**	**35**
of which physically usable	159	35	159	35

46 min

of the geometric hour are phantoms: transmit time in which no emission can succeed, because the receiver has set before the bits arrive.

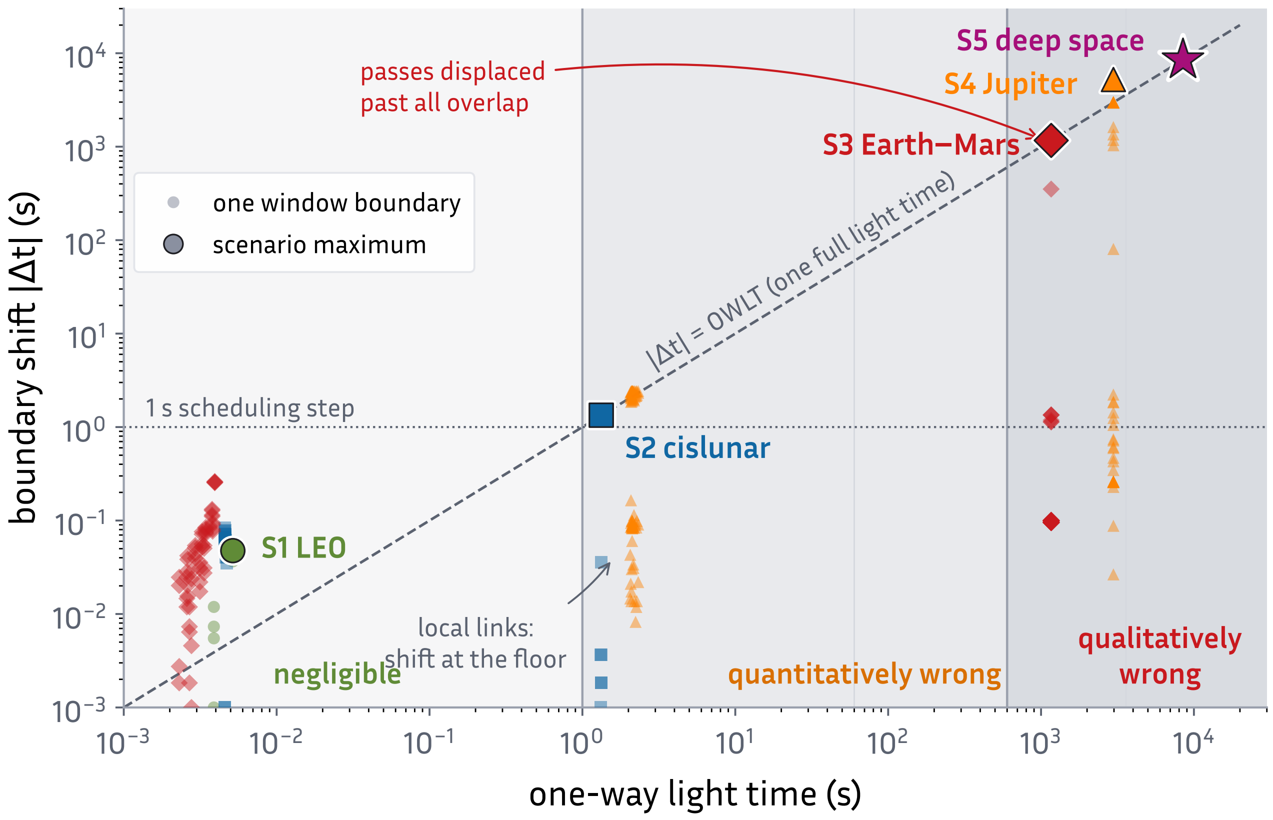
154 · 124 min

dropped by FCP on the geometric and on the apparent plan: one antenna at Madrid, and a receiver booked for one light time after every hand-over. Design decides what is affordable.

16 vs 0 min

of false promises inside the two FCP schedules: both carry the same 35 usable minutes, but the geometric one promises 51. The corrected plan keeps every promise it makes.

What the convention costs: one figure, three zones



0 → 20

S5 deep-space relay: geometric contacts against apparent ones. 22.5 h delivered while the stations are never in mutual view.

79 %

of the epochs across one real Earth–Mars synodic cycle (DE440) carry a mistimed or missing pass.

up to 5×

the light time: re-fragmentation displaces whole passes past all overlap (9.5× on DE440). Every number validated against SPICE.

Decision rule. Keep the convention near Earth and in cislunar space. Correct it from Mars outward. In deep space the geometric plan is empty.

Light-time-aware contact plan design (LT-CPD)

The gap

- Every time-expanded-graph method, FCP included, books **both terminals over the transmit window**. With light time Δ the receiver is idle for the first Δ and **still busy for the Δ after the window**.

Variants

- **V1 reservation** (in the tool: **Book reception**): occupancy [s, e + Δ], FCP, shrink. One Δ idle per hand-over; a **min run** commitment keeps foreign state boundaries from chopping reservations below Δ.