STINT 2026 · SPACE-TERRESTRIAL INTERNETWORKING WORKSHOP

A Tool Suite Towards a Solar System Internet Digital Twin

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1 From scenario files to a navigable interplanetary network

Scenario definition
- network nodes
- celestial bodies
- time window and time step
- per-node or per-contact rules

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IPN-g
- GODOTPY orbit propagation
- light-time propagation
- geometric events
- visibility → contact plan

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Scenario folder
- one config file
- positions and rotations, per object
- contact plan in IPN-v format
- contact plan in ION format

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IPN-v
- 3D scene
- space and time navigation
- physical and logical contact plans
- contact filtering, latency coloring

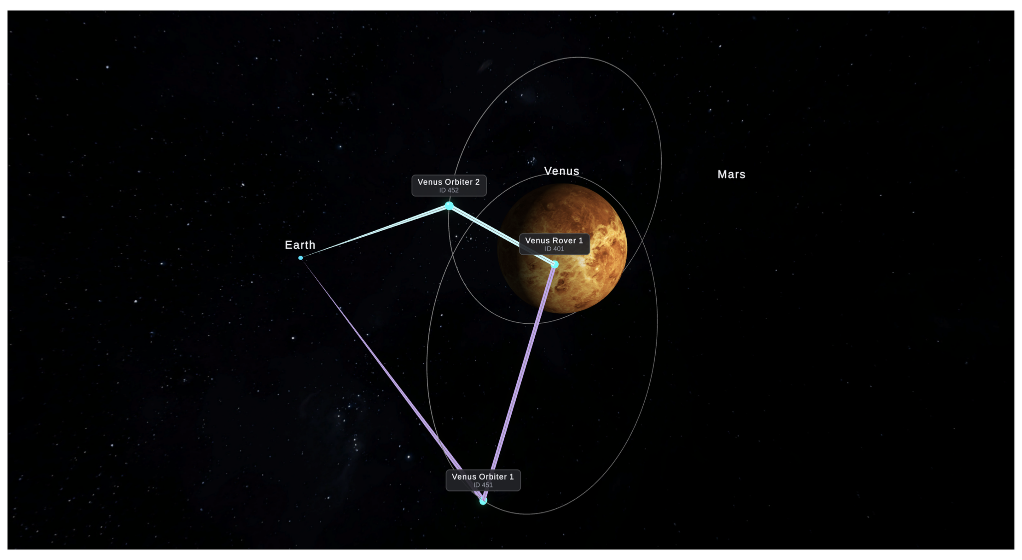
IPN-g for high-fidelity scenario generation

- **Built on an ESA library.** IPN-g drives GODOT, ESA's own astro-dynamics library, used for mission operations and analysis.
- **Configure celestial bodies.** Choose from the built-in planets and moons, or add a celestial body with its own ephemeris and rotation parameters.
- **Define the network.** Declare orbiters, ground stations and landers in the scenario folder, and constrain any node to communicate only within its own planet.
- **Adjust contacts.** Run contact search over all node pairs, one-way or two-way, or over an explicit source-destination set; declare static links between landers or ground stations on the same body.

Try it yourself: IPN-g is available on Space CODEV, open to ESA member-state citizens.
gitlab.space-codev.org

IPN-v for interactive contact plan 3D visualization

- **Physical visibilities against logical contact plans.** Load the geometric visibility windows alongside one or more logical contact plans to showcase different network behaviors.
- **Link coloring.** Automatically color links by an adaptive latency or data rate range.
- **Custom contact filters.** Hide, show or highlight subsets of contacts.
- **Bundles in flight.** Define a bundle plan and follow data as it traverses the network.
- **Navigation.** Fly free or focus any body or node, play the simulation in real time or sped up, jump to a specific timestamp.



Venus network with two filtered contact sets connecting to Earth.

Try it yourself: IPN-v [1] is fully open source and available on Inria's GitLab.
gitlab.inria.fr

Impact: IPN-g and IPN-v were used to review ESOC's DTN reference scenarios [2] prior to publication. IPN-v screenshots are also now a regular part of Solar System Internet outreach.

2 Towards a full Solar System Internet Digital Twin

MOTIVATION

Building a unified, high-fidelity, scalable and accessible framework to model and predict the behavior of the Solar System Internet, capable of mirroring the current state of the future real network or running in autonomous sandbox mode.

Evaluate and optimize before deployment
Cross-layer evaluation and interoperability testing of DTN stacks, routing strategies and protocols under realistic interplanetary conditions.

Advanced operational support capabilities
Monitoring and management of the Solar System Internet as it grows, assessment of the network-wide impact of mission-specific operational decisions.

Train operators
Training and decision-support environments that enable operators to explore "what-if" scenarios and understand the behavior of complex interplanetary networks.

ARCHITECTURE

Solar System Internet Digital Twin

Asset-specific digital twins
spacecraft, rovers...

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Data
- asset telemetry
- space weather
- Tx/Rx schedules
- network metrics
- management decisions...

Models
- link models
- spacecraft models
- environmental models
- DTN protocol stacks
- orbit propagation and contacts... IPN-g

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Logic
- data-driven network management decisions
- predictive models
- visualization for operators IPN-v
- mission operations software...

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Solar System Internet

Elements after the IRTF Network Digital Twin reference architecture [3].

MAIN CHALLENGES

Challenged networks. Link disruptions, high latencies and bandwidth constraints: unavoidable data staleness causing delayed synchronization between the real and twin networks.
→ Evaluate and minimize the average Age of Information metric of the twin [4], perform machine learning on historical data, compress telemetry information and prioritize critical telemetry [5].

No deployed system yet. No real network to interface the twin with, no large traffic dataset to build models on, the precise Solar System Internet architecture is still being defined and will keep evolving.
→ Data generation and augmentation, a modular twin architecture allowing for design changes [5].

Accuracy versus compute. High modeling accuracy, sufficient protocol-stack granularity and orbit propagation precision required to reliably predict the network state when fresh data is not available, raising the cost of using the twin.
→ When possible, interface with existing asset digital twins to avoid redundancies [5].

REFERENCES

[1] A. Le Bihan et al., "IPN-V: The Interplanetary Network Visualizer", IEEE SMC-IT 2024.
[2] C. Malnati, F. Flentge, "Reference Scenarios for Evaluation of Disruption Tolerant Network Technologies", SpaceOps 2025.
[3] C. Zhou et al., "Network Digital Twin (NDT): Concepts and Reference Architecture", IRTF Internet-Draft, 2026.
[4] F. D. Quazi et al., "Building Delay-Tolerant Digital Twins for Cislunar Operations using Age of Synchronization", IEEE ICC Workshops 2024.
[5] H. Al-Hraishawi et al., "Digital Twin for Non-Terrestrial Networks: Vision, Challenges, and Enabling Technologies", 2023.