Emulation for LEO Interference Analysis in FR3 Spectrum

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Motivation

Emerging LEO mega-constellations are crowding the 10.7–12.7 GHz downlink band, where overlapping allocations and rapid satellite motion create a congested, highly dynamic interference environment.

This project emulates LEO–LEO interference on USRP software-defined radios, reproducing realistic orbital effects to measure INR, signal degradation, and outages. Extensive MATLAB simulation of the full constellations precedes the emulation, establishing the interference baseline and the scheduler designs that the FR3 testbed then validates.

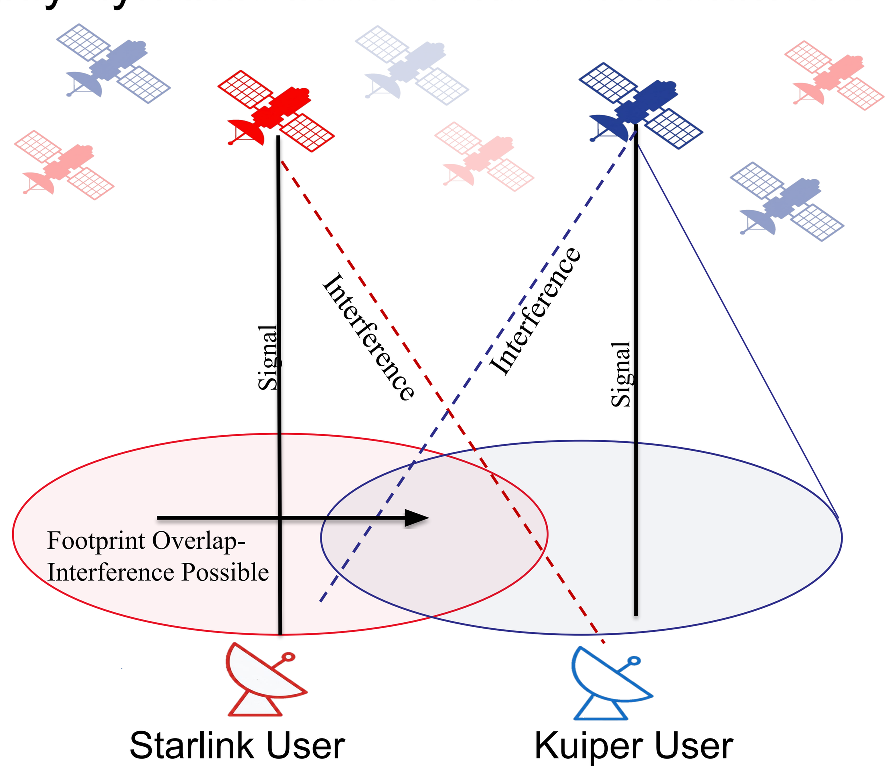

Fig. 1. Downlink Interference Diagram

Approach

- **GOAL:** Quantify interference in multi-beam, multi-SAT mega-constellations.
- Measure Signal-to-Interference-plus-Noise Ratio (SINR) and Interference-to-Noise Ratio (INR) at both receivers.
- Develop a protective scheduler for Kuiper that minimizes LEO–LEO interference.

ORBIT Emulation

- Emulate the Starlink and Kuiper constellations from real TLE data.
- Transmit and receive over USRP X310 software-defined radios (SDRs).
- Schedulers select serving satellites and apply orbital attenuation.
- Emulate the LEO channel: path loss, Doppler shift & weather effects.

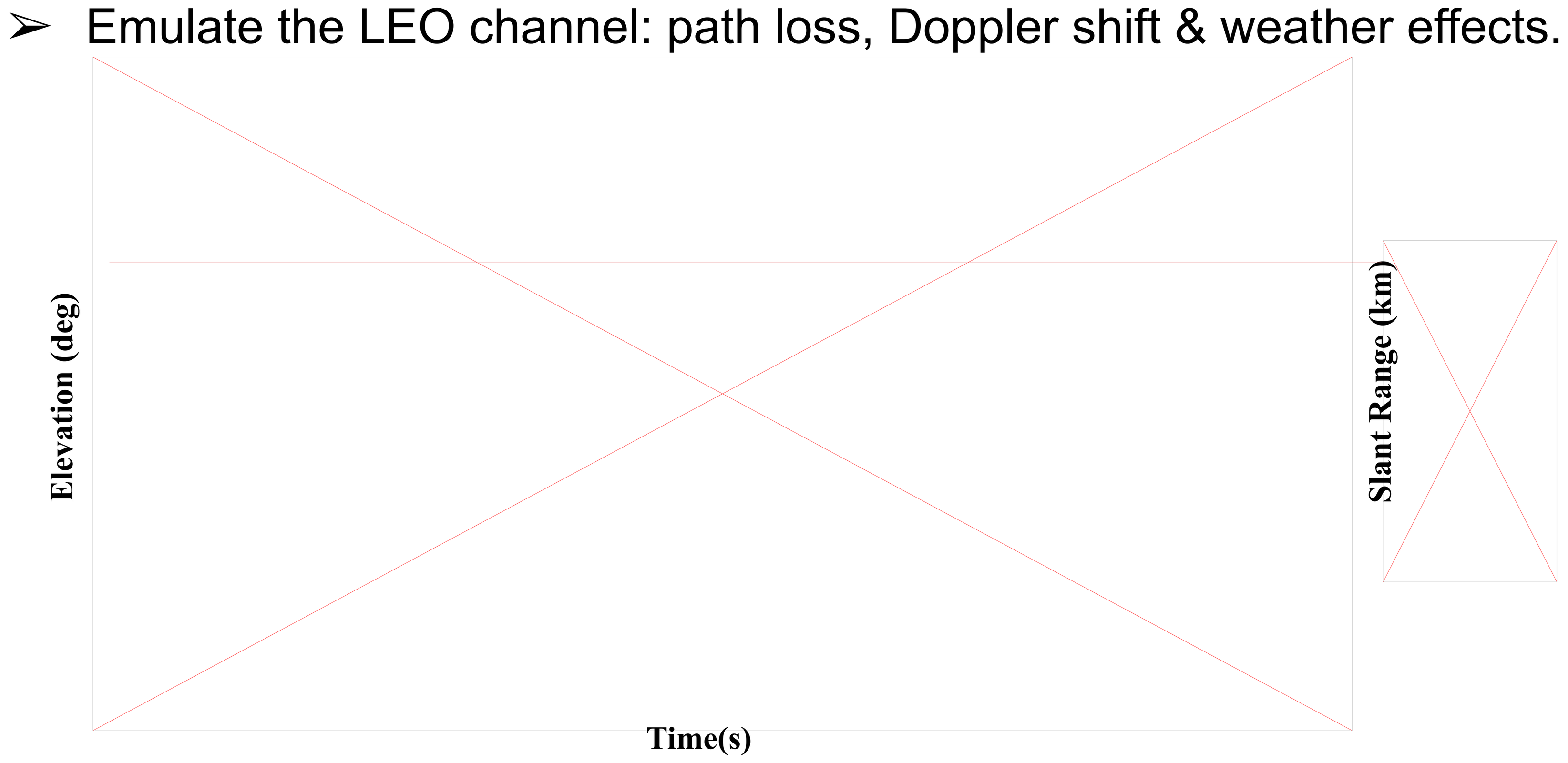

Fig. 2. Starlink Transmitter Elevation & Slant Range

Fig. 3. Errored Packets at the Starlink Receiver

MATLAB Simulation

MATLAB simulation modeling in-band coexistence between Starlink and a full Kuiper Gen 1 deployment.

- Propagate real TLE data from CelesTrak for the Starlink constellation and the current Kuiper deployment.
- Generate synthetic TLEs for a full Kuiper Gen 1 deployment, based on the constellation structure in the 2024 FCC filings of 3,232 Kuiper satellites.
- Design **protective schedulers** for the later entrant (Kuiper) to hold INR below the **ITU threshold** (−12.2 dB).
  - Angle Separation: maximize the angle from the primary serving satellite.
  - Power Control: reduce Kuiper TX power to cap INR.
  - Angle Separation & SNR Awareness: relax separation only when the secondary SAT SINR falls below a set threshold.

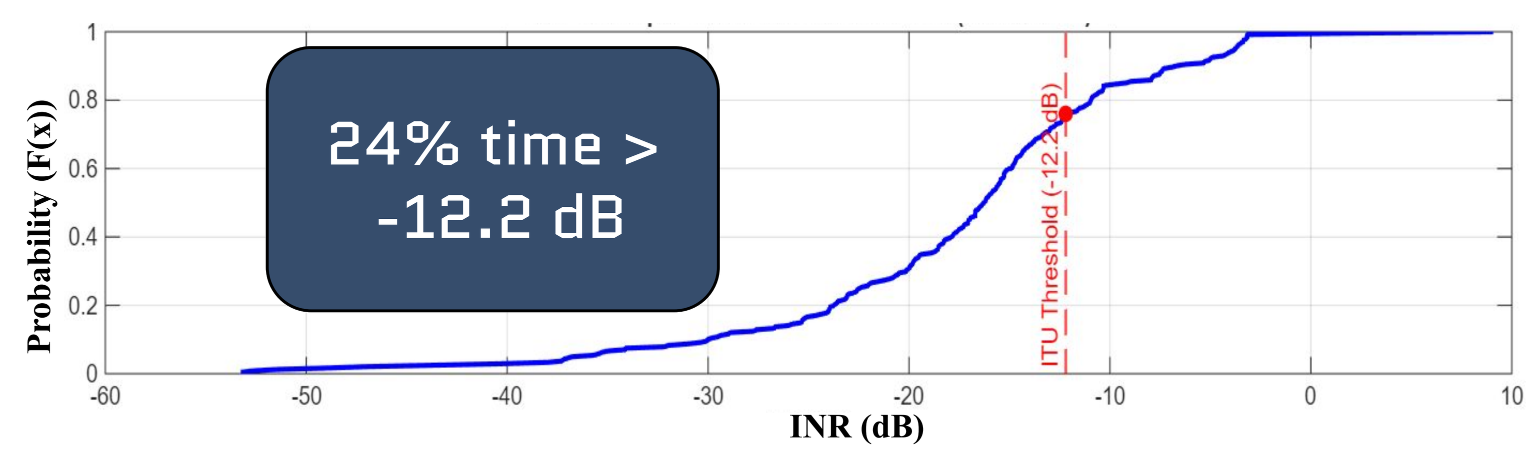

Fig. 4. Kuiper Interference on Starlink under Baseline Scheduler

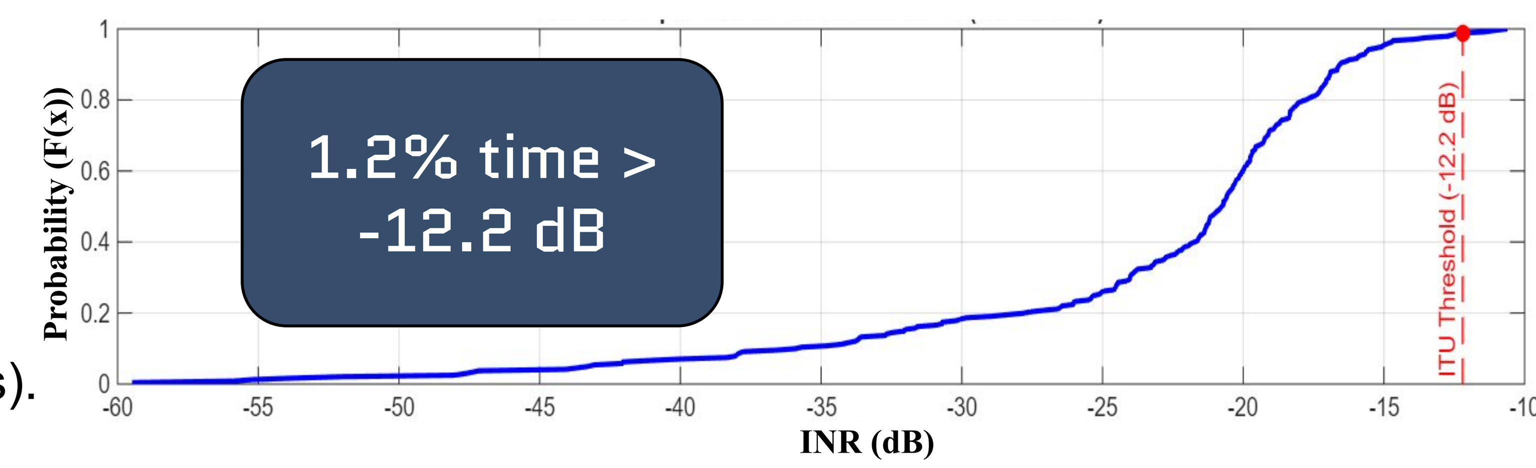

Fig. 5. Kuiper Interference on Starlink using Protective Scheduler

Protective Scheduler Evaluation

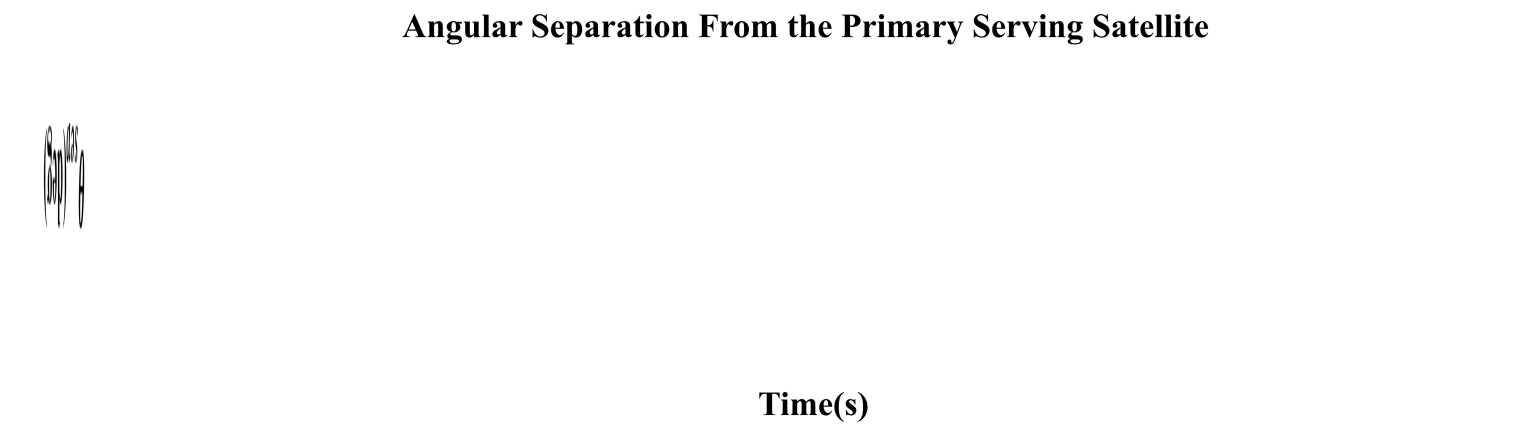

Fig. 6. Angular separation from the primary serving satellite

- The protective scheduler widens angular separation between the serving Starlink and Kuiper satellites from 0.6° to 10.4°.

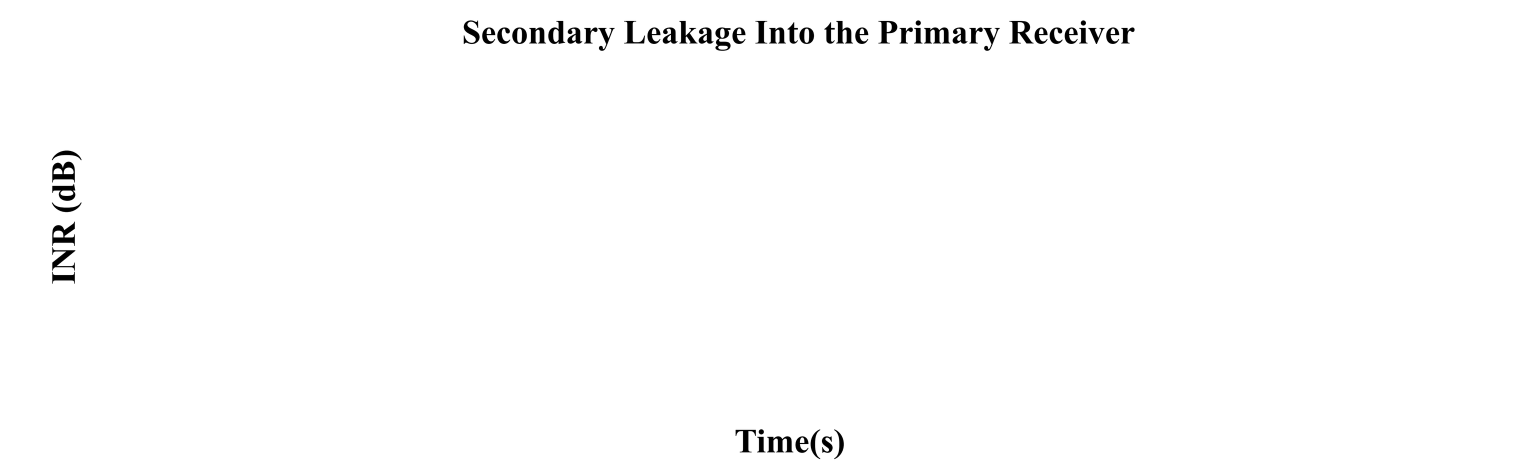

Fig. 7. INR at the primary receiver

- The wider separation lowers INR: time above the ITU threshold drops from 24% to 1.2% over a 10-minute run.

Conclusion

- Full Kuiper Gen 1 deployment exceeds the ITU threshold too frequently for unmanaged coexistence; mitigation is required.
- Power control and angle separation each suppress Kuiper's co-frequency interference into Starlink, but at a cost to link quality.
- The combined Angle Separation & SNR Awareness scheduler gives the best trade-off: less interference onto Starlink while preserving Kuiper's own link.

Future Work

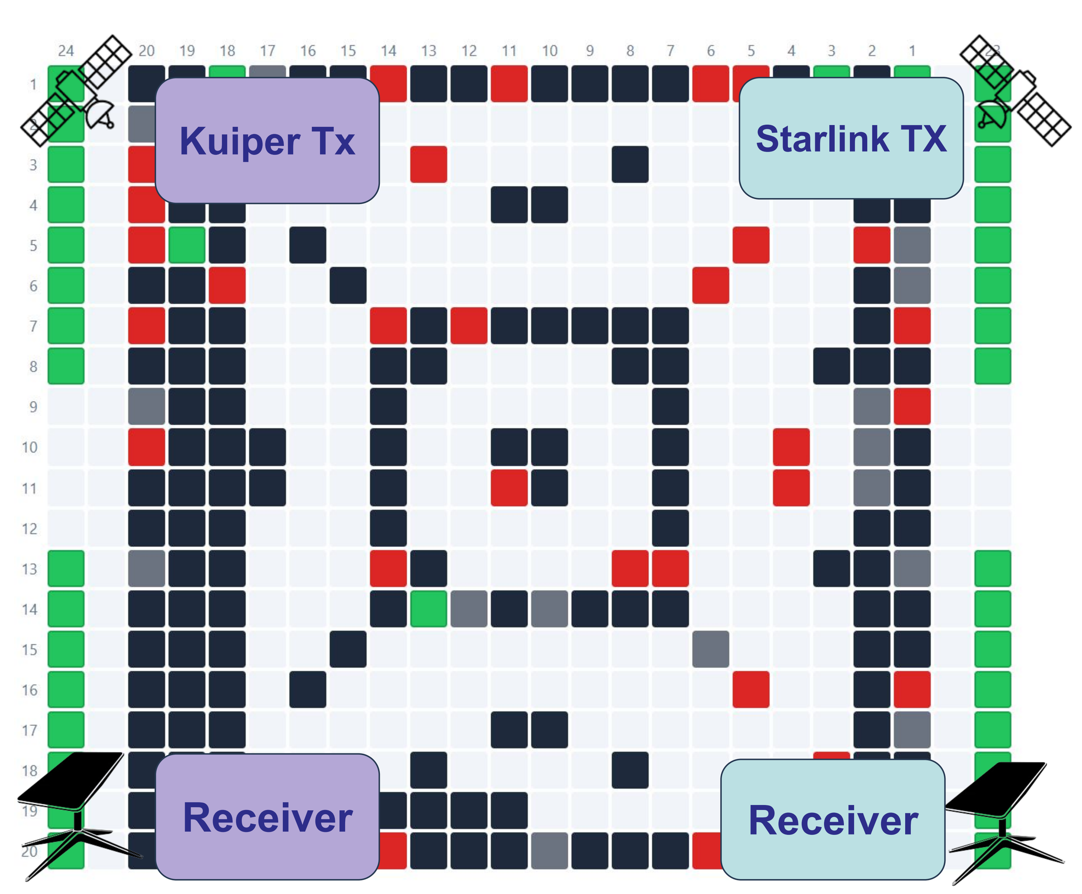

Fig. 8. Emulation Layout on the Grid

- Validate the MATLAB simulation findings in hardware.
- Transmit in FR3 using Pi-Radios.
- Collect metrics at the Starlink receiver with Kuiper on the baseline scheduler, then the protective scheduler, for direct comparison.

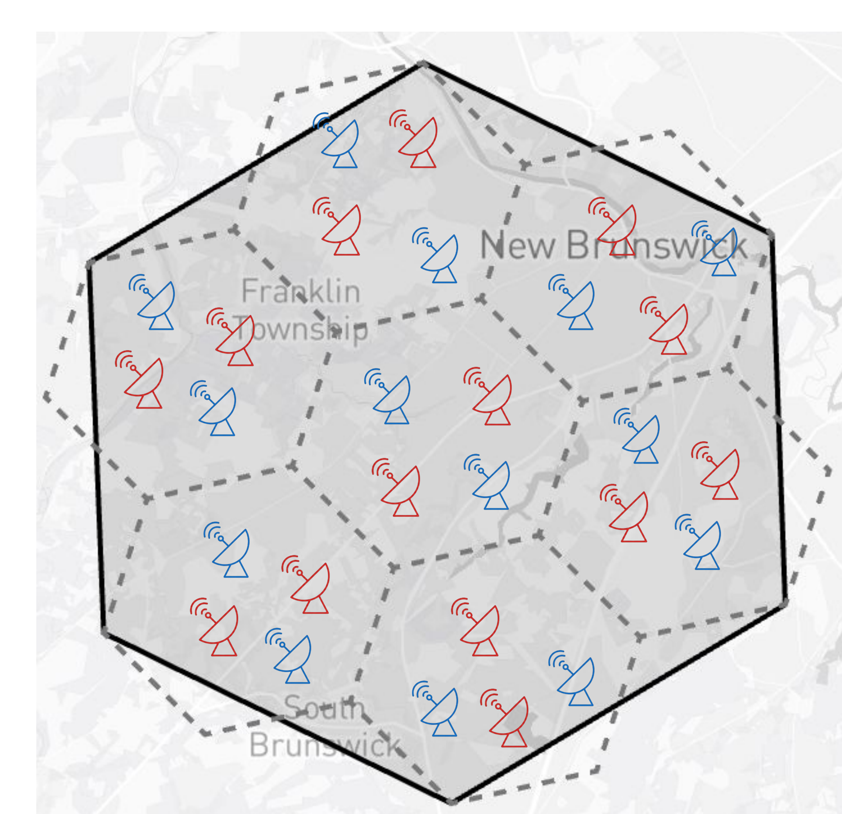

Fig. 9. Multiple SAT Users in an H3 Cell

- Extend from a single-user to a multi-user system.
- Scale to futuristic SAT deployments (~100k LEO SATs).
- Model multi-beam satellites.
- Evaluate a fairness score across scheduler policies.
- Use MU-MIMO in the emulation.

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