RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

SWIFT-SAT:

Software Defined Radio based Emulation of SAT-Terrestrial Network Coexistence in FR3 Bands

Project #: 2332637

Investigators: Narayan Mandayam, Ivan Seskar, and Chung-Tse Michael Wu

Students: Rifat Bin Rashid, Vidhitkumar Malaviya, Sreeram Mandava, and Donglin Gao

Summary

The radio frequency band spanning from 7.125 GHz to 24 GHz, referred to as Frequency Range 3 (FR3), holds significant promise for the evolution of next-generation cellular systems. This project aims to extend the current COSMOS testbed at WINLAB to facilitate experimental studies of coexistence between terrestrial and satellite systems using software-defined radios (SDR) to emulate dense 5G cellular networks and satellite equipment. Specifically, the project focuses on spectrum sharing between terrestrial 5G and active commercial satellites in the 12.2-12.7 GHz band, and adjacent band coexistence between terrestrial 5G, operating at 10-10.5 GHz, and passive scientific satellites in the 10.6-10.7 GHz band. Metamaterial software-defined beamforming is used to emulate coexistence with satellites like non-geostationary orbit fixed satellite service (NGSO-FSS), and hot-cold calibration and comparison to datasets from on-orbit AMSR-E and AMSR2 sensors is used to enhance the reliability and realism of radiometer interference experiments.

The project unfolds in three key thrusts:

(1) Designing, validating, and deploying FR3 SDR-based heterodyne devices, emulating 5G New Radio (NR) and SAT waveforms, and developing coexistence emulation methods.

(2) Employing emulation experiments to craft centralized Machine Learning algorithms for integrated radio resource management in sharing between terrestrial 5G and active commercial satellites.

(3) Leveraging emulation experiments to evaluate radiometer sensitivity to terrestrial 5G interference and develop Machine Learning algorithms for interference identification and mitigation by passive scientific satellites.

One outcome from thrusts 2 and 3 is the measurement of the fraction of spectrum allocated to terrestrial 5G cellular systems that is lost due to the strategies used to mitigate interference to satellites.

Research Progress

SDR-based Heterodyne Transceiver for FR3 spectrum using COSMOS Sandbox

- We built and tested a working FR3 capable SDR heterodyne transceiver up to 24 GHz (Figure 4)
- Experimental validation of frequency conversion up to 24 GHz completed
- Optimized filtering/amplifier chain enables clean up-conversion and realistic FR3 coexistence emulation (5G NR at 10–10.5 & 12.2–12.7 GHz, DBS/NGSO FSS at 12.2–12.7 GHz) in COSMOS Sandbox
- Next Steps:
  - Architecture finalized for FR3-band PCB design. Fabrication planned for 2025 with integrated up/down conversion up to 24 GHz

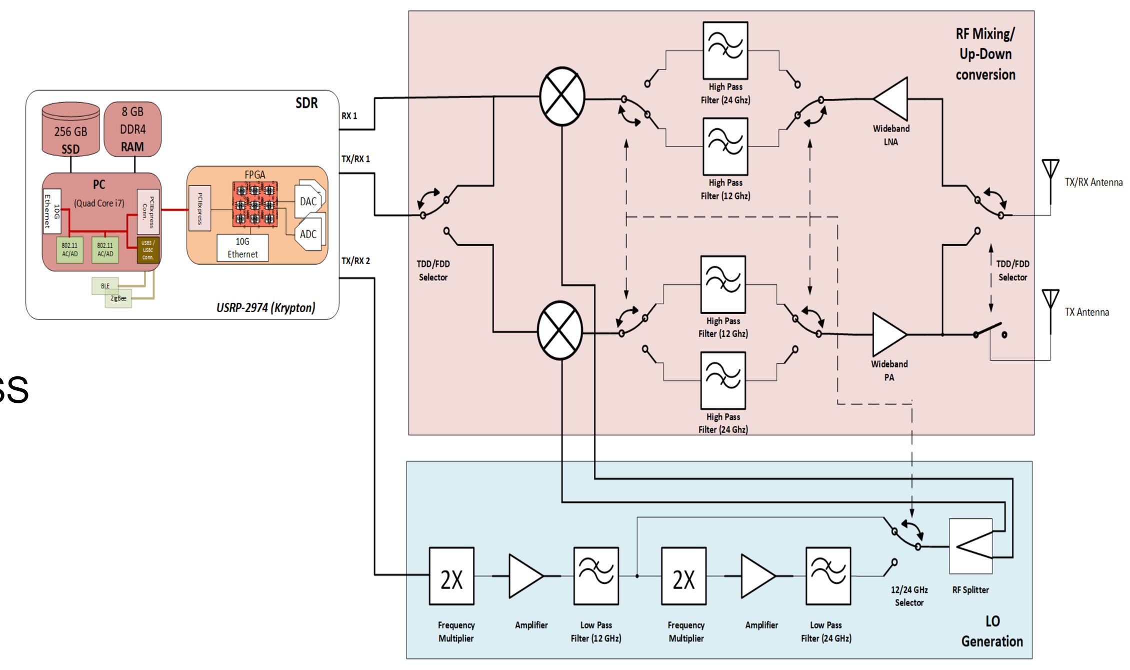


Figure 1: Proposed SDR-Based Heterodyne Transceiver for FR3 Testbed for full-band operation up to 24 GHz

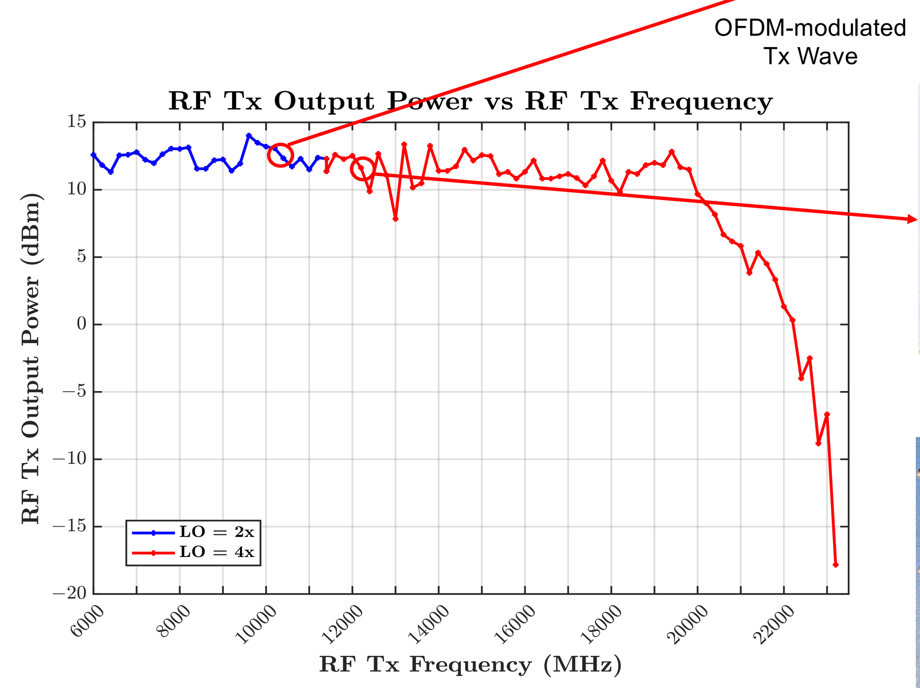


Figure 2: FR3 power levels (6–23 GHz). Roll-off > 20 GHz due to PA bandwidth; key bands: 10–10.5 & 12.2–12.7 GHz

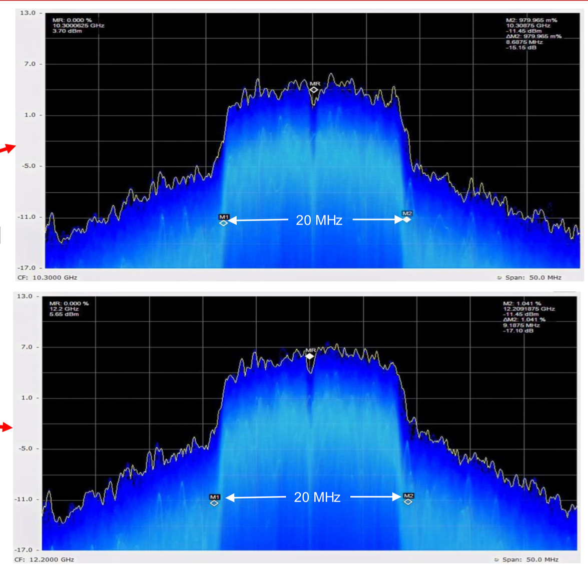


Figure 3: Upconverted OFDM Spectrum at (a) 10.3 (top) & (b) 12.2 GHz (bottom)

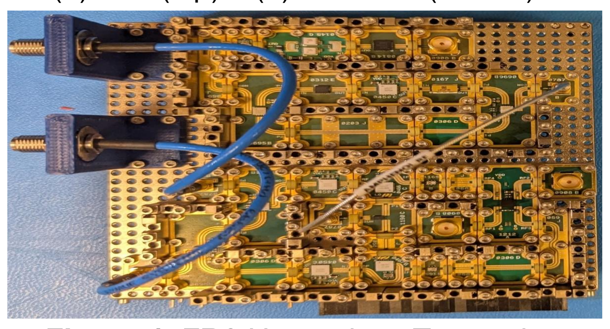


Figure 4: FR3 Heterodyne Transceiver (Quantic X-Microwave Prototyping Board)

Emulation of 5G NR Protocol Stack and DBS SAT Downlink Signals in 12 GHz

- Spectrum Management - Digital Broadcasting Satellite Emulation
  - Digital Video Broadcasting Satellite Generation 2 (DVB-S2) Transmitter/Receiver through GNU Radio w/ SDR B210 & X310
  - Simulate 64-bin & 256 QAM 5G OFDM through Amarisoft
  - Baseband Spectrum Management through Linear Quadratic Regulator Approach; preserved DVB-S2 link 82-99%
- Next Steps:
  - Integrate 12 GHz FR3 upconverter with current SDR & GNU Radio setup
  - Develop Reinforcement Learning (RL) control model for DVB-S2 & 5G systems coexistence in 12.2-12.7 GHz

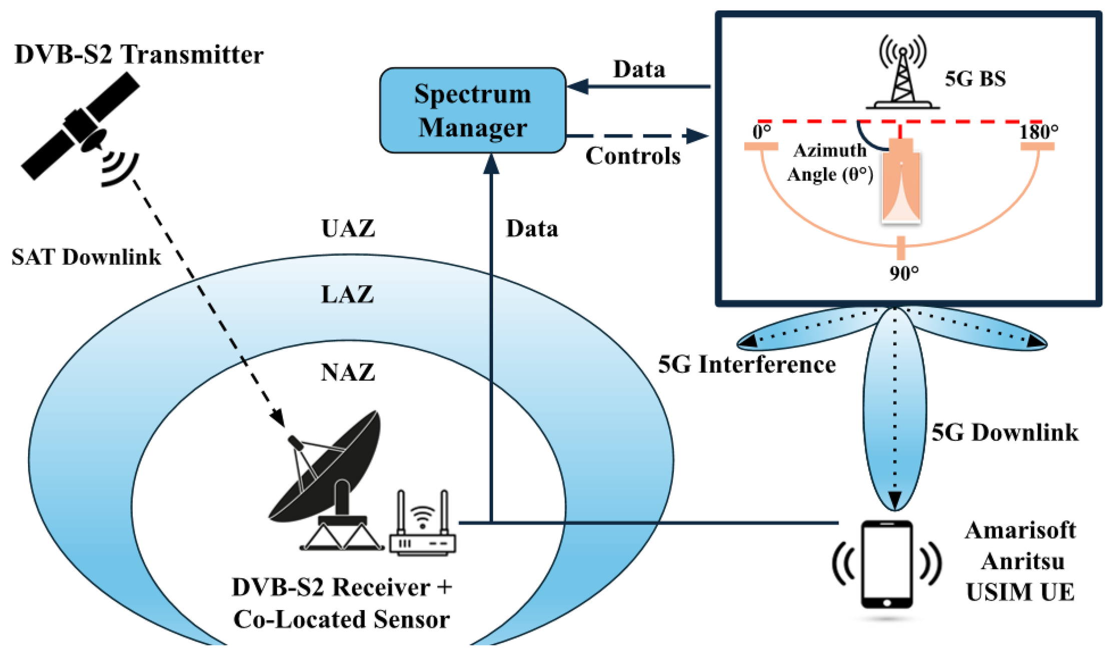


Figure 5: Spectrum Management Framework : with 5G BS beam sweeping 0°–180° azimuth and satellite interference control

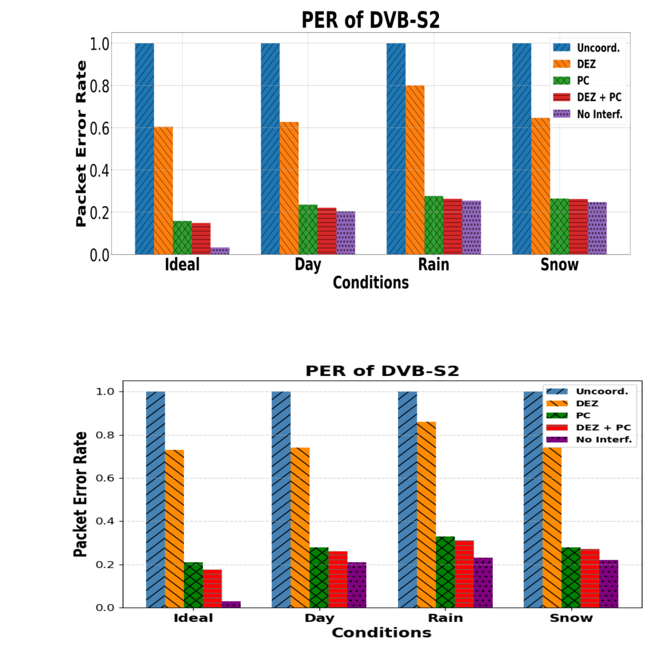


Figure 6: PER of DVB-S2 with (a) Single (top) and (b) Multiple omnidirectional 5G BS (bottom)

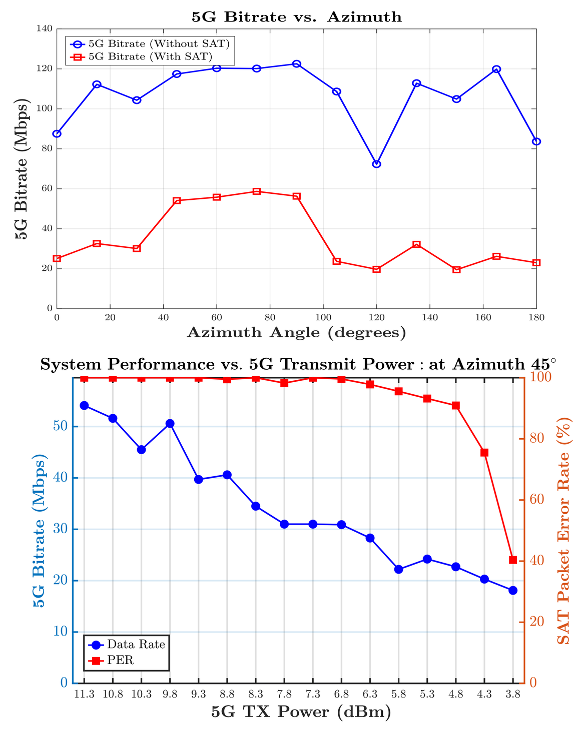
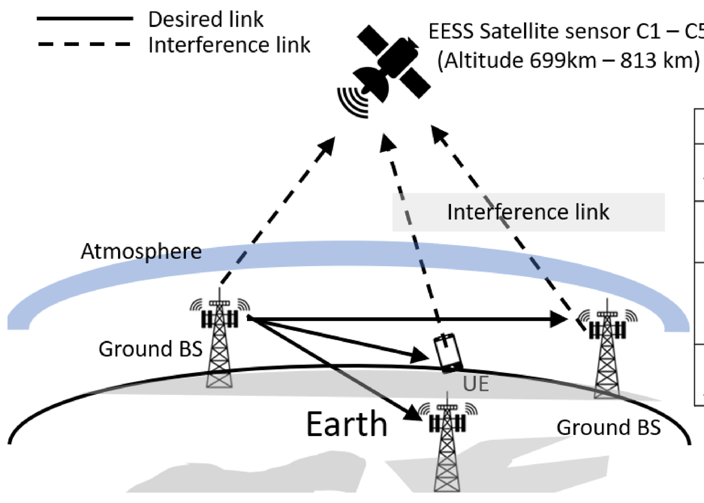


Figure 7: (a) 5G Bitrate vs. Azimuth Angle during SAT Scenarios w/ Constant Power (top) (b) 5G Bitrate and SAT PER vs. TX Power w/ Constant Azimuth (bottom)

Modeling 5G–Satellite Coexistence at 10–10.7 GHz

- Future 5G deployment at 10–10.5 GHz is estimated by mapping Gompertz-based population forecasts to network demand and base station density
- Radio Frequency Interference (RFI) to Earth exploration satellites in the adjacent 10.6–10.7 GHz band is evaluated using array-aware propagation modeling with beam tilt and angular loss
- Our case study of New York City reveals how spectral efficiency, elevation angle, and sidelobes jointly shape coexistence margins and deployment scale
- Next Steps:
  - Integrate real-world base station angle and user equipment into base station planning and beamforming scenarios
  - Validate array–sensor interference with over-the-air SDR experiments and fabricated antenna prototype



Parameter	C1	C2	C3	C4	C5
Altitude (km)	817	705	833	835	699.6
Max Beam Gain (dBi)	36.0	42.3	45.0	36.0	44.1
Instantaneous FOV (km²)	56 × 30	51 × 29	48 × 28	76 × 177	41 × 21
Incidence Angle (°)	52	55	58.1	65	55

Figure 8: 5G–Satellite Coexistence Framework and the parameters of the EESS sensors

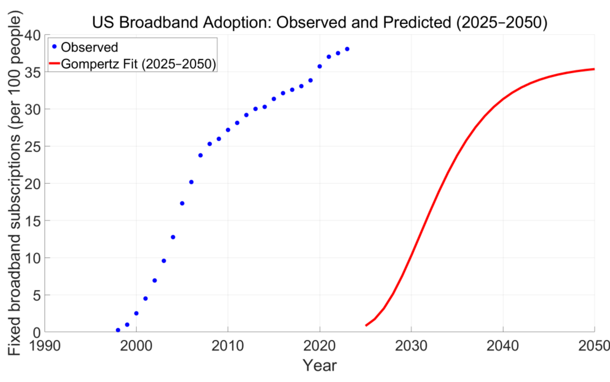


Figure 9: 5G FR3 adoption growth rate predicted using Gompertz model

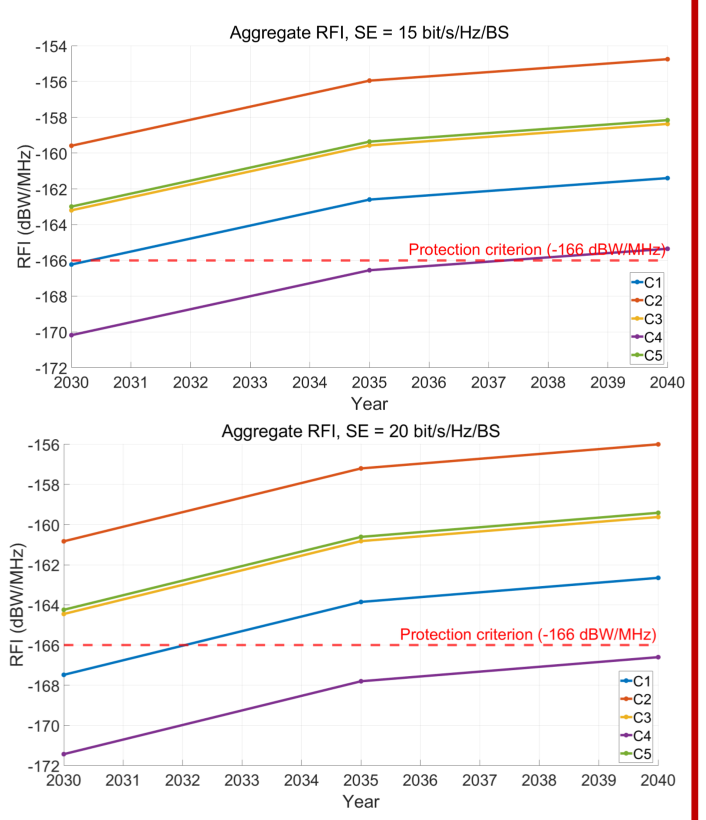
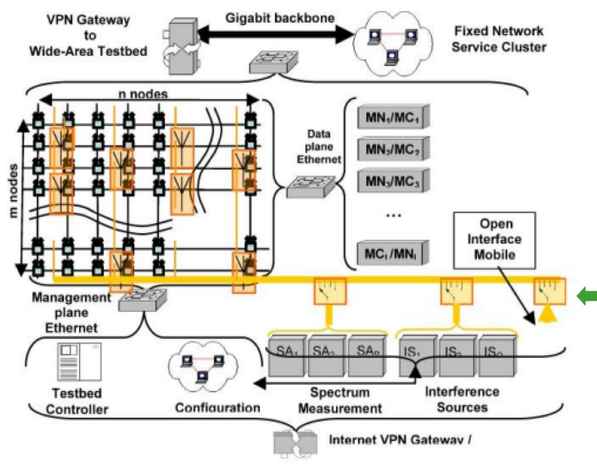


Figure 10: Simulated result of aggregate Radio Frequency Interference (RFI) when Spectral Efficiency = 15 (top) and 20 (bottom) bits/s/Hz/BS

Spectrum Coexistence of 5G Terrestrial Networks with NGSO-FSS and Passive Weather Sensors

- COSMOS Sandbox Emulation of Spectrum Coexistence between 5G Terrestrial Networks and Passive Sensors on Earth Observation Satellites in 10.6-10.7 GHz
  - Data-Driven Approach to Modeling Sensor Sensitivity and Identifying RFI Sources
  - Dynamic Spectrum Access for Proactive RFI Mitigation
- Spectrum Coexistence between 5G Terrestrial Networks and 12.2-12.7 GHz NGSO-FSS
  - Emulation of Starlink-like NGSO-FSS Signals Incorporating Full Frame Structure
  - Radio Resource Management Based on Interference-to-Noise Ratio (INR) Feedback

COSMOS Radio Grid



Radio Grid Architecture

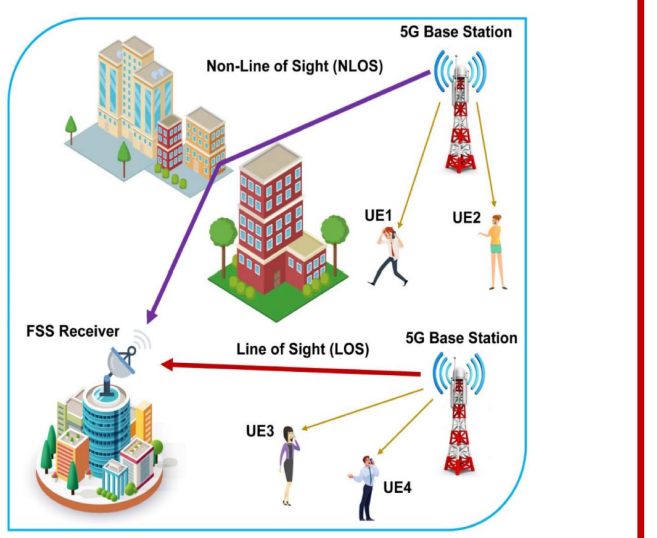


Figure 11: COSMOS GRID@WINLAB with Control Plane, Measurement Infrastructure and Radio Mapping

References

[1]. FCC Technical Advisory Council, “A Preliminary View of Spectrum Bands in the 7.125 - 24 GHz Range; and a Summary of Spectrum Sharing Frameworks ,” August 2023. [Online].

[2]. J. Chen, D. Zhou, L. Zhong, and D. Li, “Coexistence study of 5G in 10–10.5 GHz and passive Earth exploration-satellite service in 10.6–10.7 GHz,” Proc. Int. Wireless Communications and Mobile Computing Conf. (IWCMC), Marrakesh, Morocco, 2023, pp. 711–716, doi: 10.1109/IWCMC58020.2023.10182698.

[3]. S. Mandava, R. B. Rashid, S. Vosoughitabar, C.-T. M. Wu, I. Seskar, and N. B. Mandayam, “Software defined radio based emulation of sat–terrestrial network coexistence,” in Proc. IEEE Global Communications Conference (GLOBECOM), 2025, accepted for publication.

[4]. S. Mandava, R. B. Rashid, D. Gao, V. Malaviya, P. Maddala, C.-T. M. Wu, I. Seskar, and N. B. Mandayam, “SAT–terrestrial coexistence with adaptive beam and power control: An SDR-based emulation,” submitted to IEEE Future Networks World Forum (FNWF), 2025.

[5]. D. Gao, R. B. Rashid, V. Malaviya, C.-T. M. Wu, I. Seskar, and N. B. Mandayam, “Emulation-Based Coexistence Analysis of Future 5G FR3 Networks and Passive Earth Exploration-Satellite Sensors in the 10–10.7 GHz Band,” in preparation.