Coexistence of EESS Passive Radiometer Measurements and 5G/6G Networks at 7.3 and 6.925 GHz

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This material is based in part upon work supported by the National Science Foundation under Grant No. 2232368

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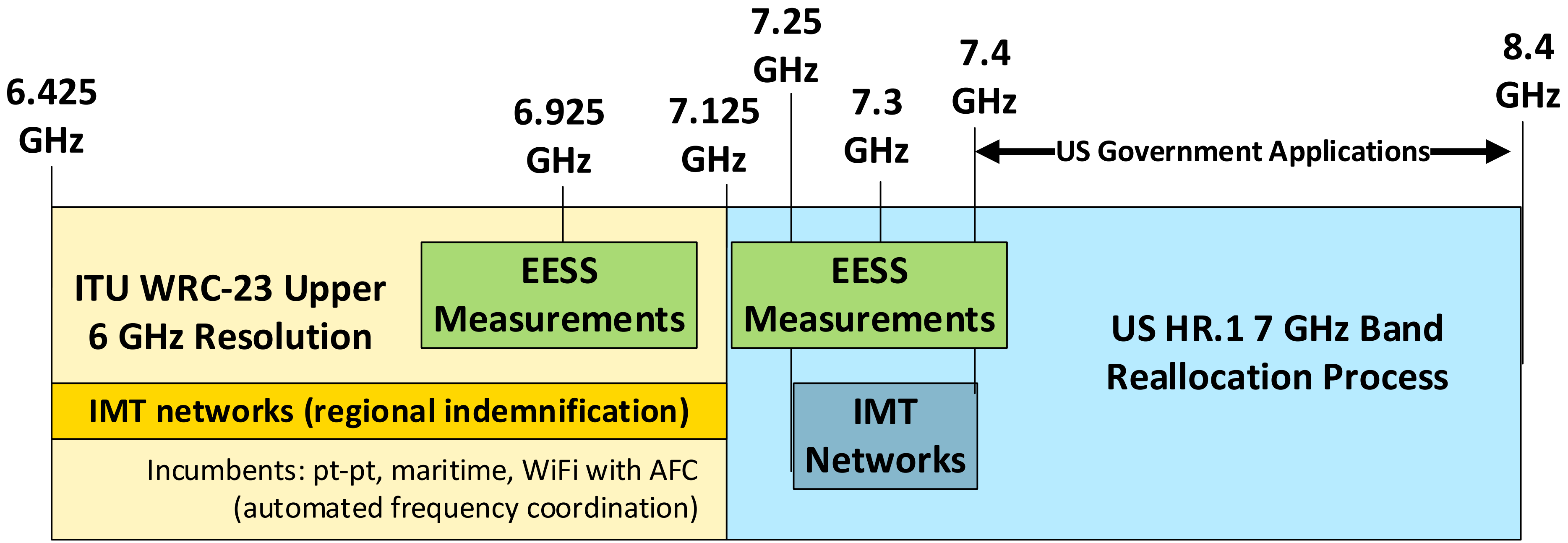
Why are passive EESS measurements at 6.925 & 7. 3 GHz important? → Disasters, Economy, National Security

- Sea Surface Temperatures:
  - Hurricane/Cyclone track and landfall predictions
  - Accurate weather forecasting
  - Climate models (heat exchange between the atmosphere and oceans)
  - Fisheries, supply chains (shipping), naval operations
- Other parameters: sea ice (where & how thick), soil moisture, ocean wind speed (in heavy seas)

Why are the 6.925 & 7. 3 GHz bands special ?

- Sea Surface Temperatures can be derived from optical IR imaging and from higher microwave frequencies
  - IR images 3.6-4.1 μm and 10.1-12.2 μm can provide SST data, but can be blocked by cloud cover
  - Passive microwave brightness measurements < 10 GHz provide good temperature sensitivity < 10° C

Where is the conflict with wireless networks?



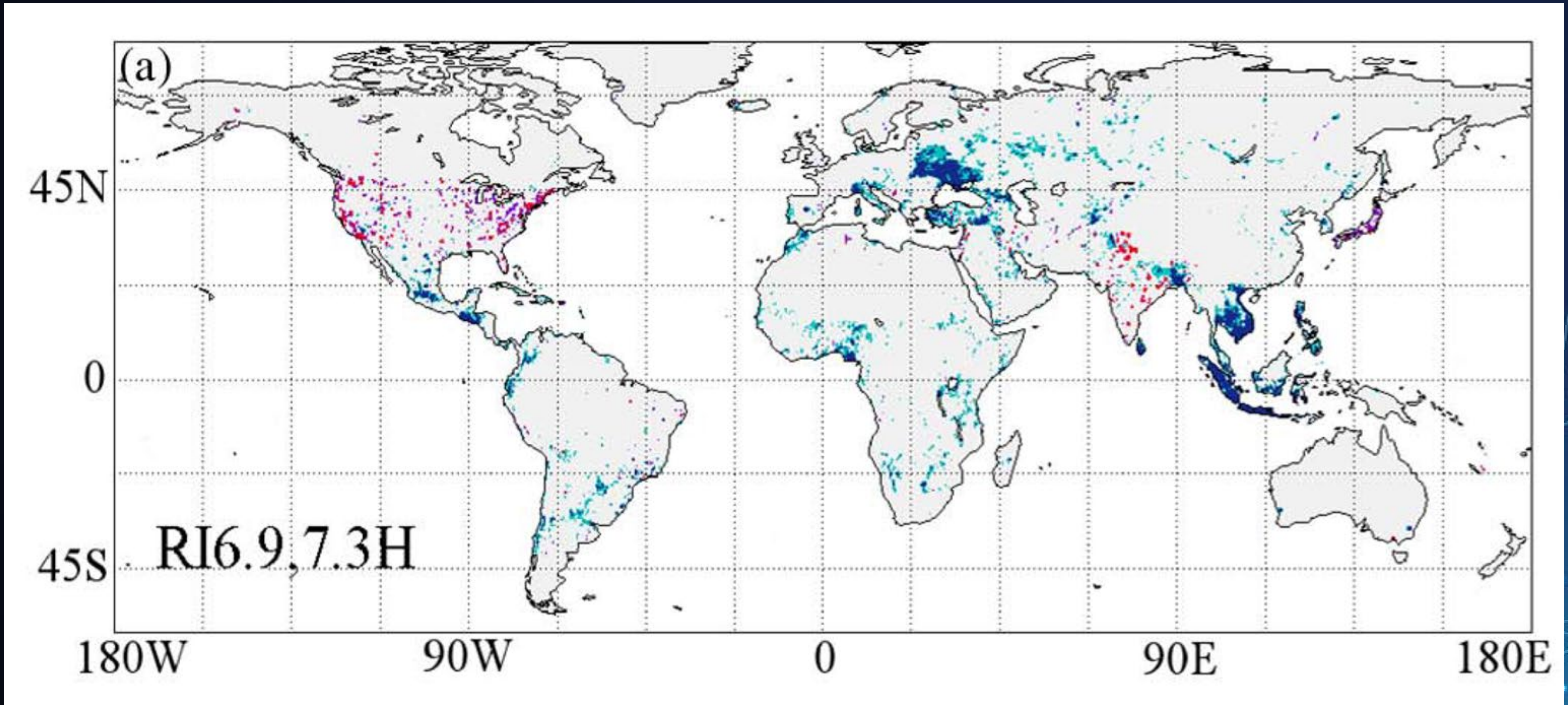
- EESS measurements are not protected in these bands (footnote 5.458 however).
- High potential for interference when IMT and EESS use overlapping spectrum + potential for out-of-band interference
- WRC-23 indemnification for Europe, Middle East, Africa, Brazil, Mexico, Cambodia, Laos, Maldives.

Active & planned radiometers between 2 and 10 GHz

ID	Name	Operator	Launch	EOL	Sounder	CF (GHz)	BW (MHz)
3174	HY-2B	NSOAS	10/25/2018	≥2025	MWI	6.6, 10.7	350
4181	CIMR-A	ESA	≥2029	≥2036	CIMR	6.875, 10.65	400
4565	CIMR-B	ESA	≥2035	≥2042	CIMR	6.875, 10.65	400
2167	GCOM-W	JAXA	5/17/2012	≥2025	AMSR2	6.925, 7.3, 10.65	350
4047	GOSAT-GW	JAXA	6/28/2025	≥2032	AMSR3	6.925, 7.3, 10.65	350
3500	Meteor-MP N1	RosHydroMet	≥2033	≥2040	MTVZA-GY-MP	6.9,10.6	400
3521	Meteor-MP N2	RosHydroMet	≥2033	≥2043	MTVZA-GY-MP	6.9,10.6	400

Current RFI for C-band radiometers

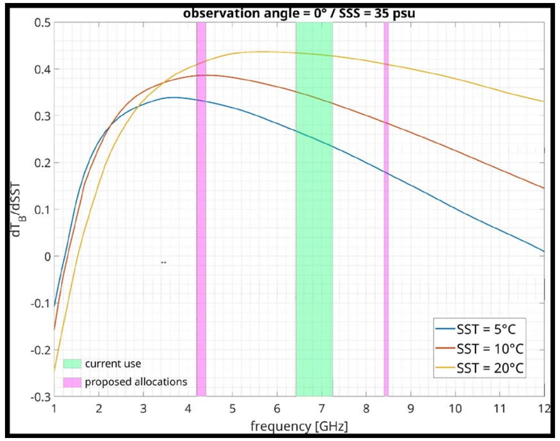
RFI near 7 GHz affects multiple EO missions, and has been widely documented in the science literature.



RFI at 6.9 GHz (Red) and 7.3 GHz (Blue) (de Nijs et al., 2015)

Yan Soldo, Flávio Jorge, Josep Roselló, and Craig Donlon, *Radiometry in C-band – current and expected RFI, and possible long-term solution*, RFI 2024 Workshop

How to address the problem?



P. Matthaeis et.al., *Passive Remote Sensing of Sea Surface Temperature*, RFI Workshop 2024

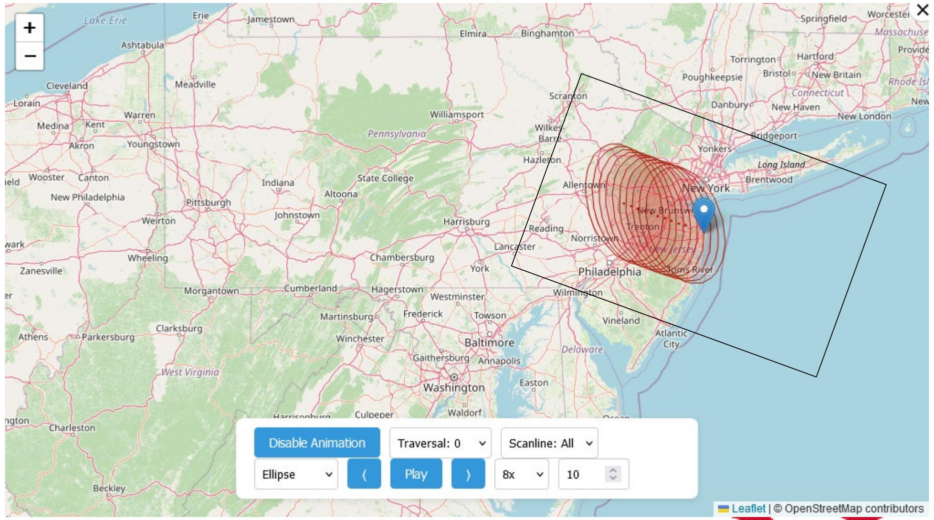
- Find new spectrum and protect it from interference (WRC-27 AI 1.19 study: 4.2-4.4 GHz and 8.4-8.5 GHz)

- Add signal processing (and potentially additional frequency channels) to radiometers to detect interference.

S.S. Kristensen et.al., *CIMR RF Interference Processor*, RFI Workshop 2024
A. Bringer, *Detection of 5G signals: detection & limitations*, RFI Workshop 2025

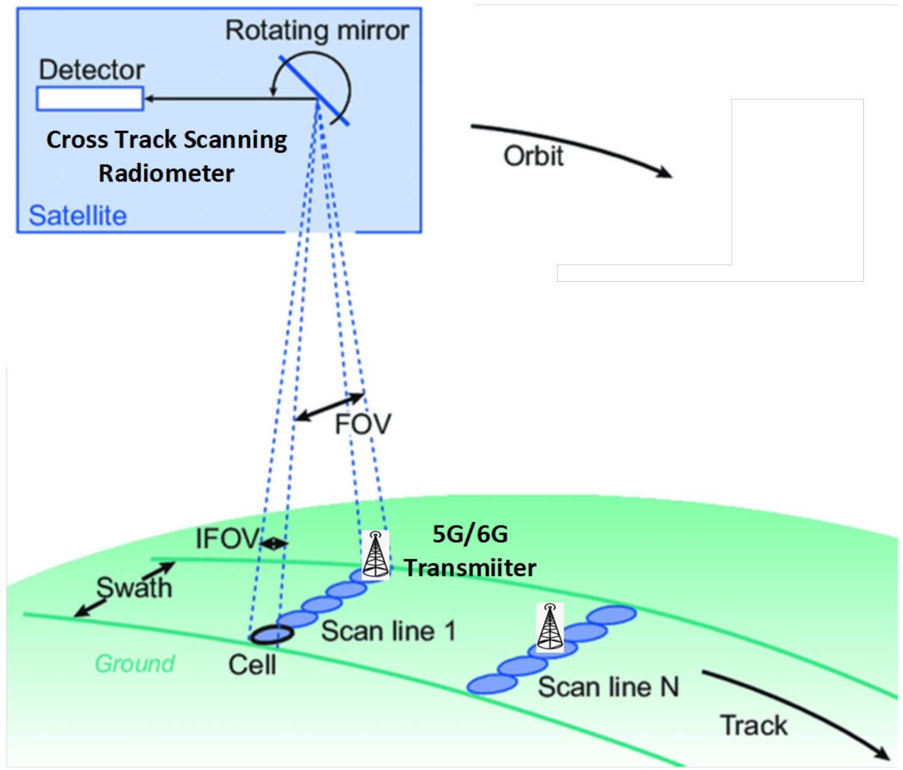
- Modify IMT transmissions to prevent interference during the radiometer's scanning window.

E. Eichen et.al, Dyspan 2021,2024

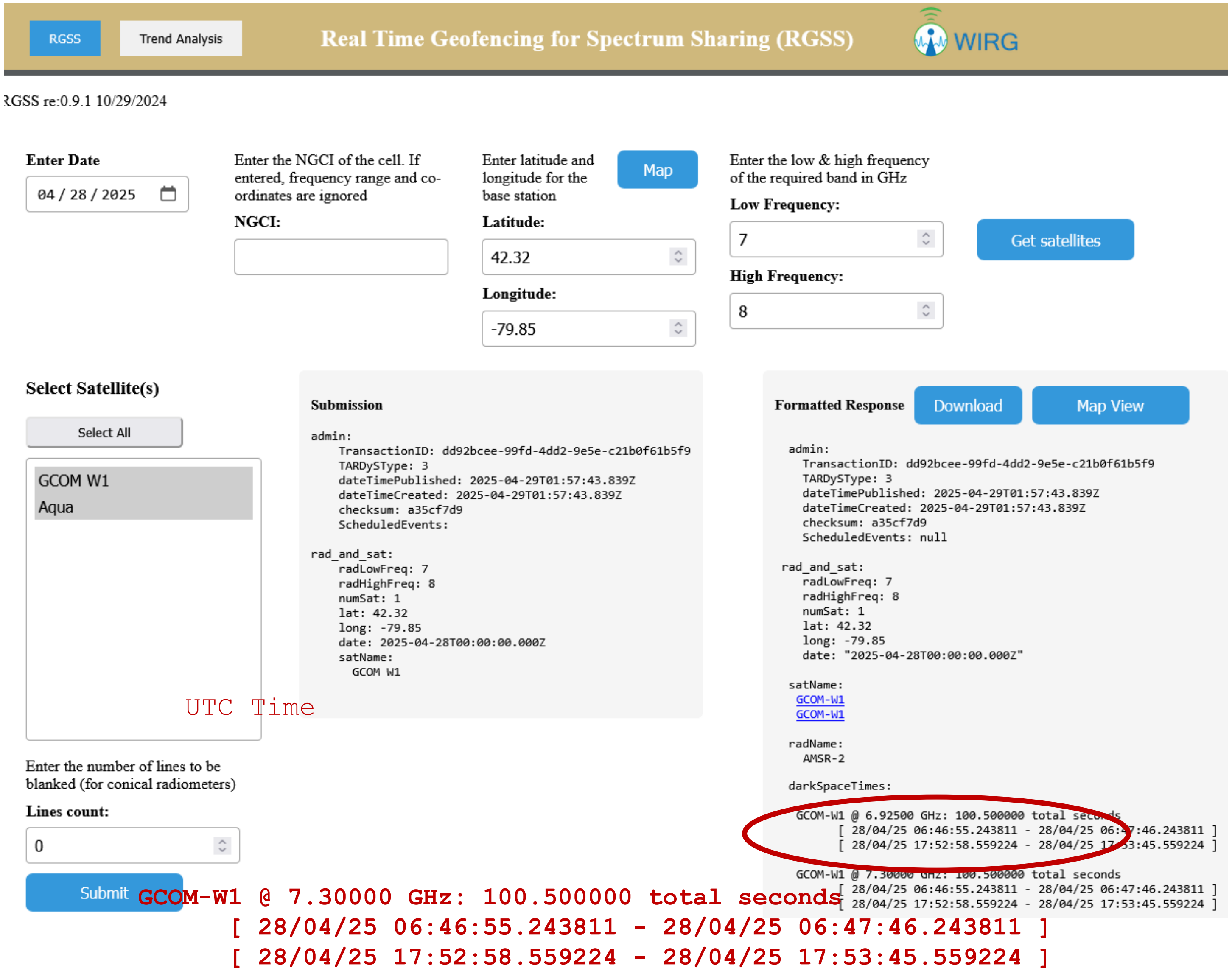


- Use economic incentives to increase spectrum usage efficiency, and/or potentially pay a penalty for interference

Real Time Geofencing

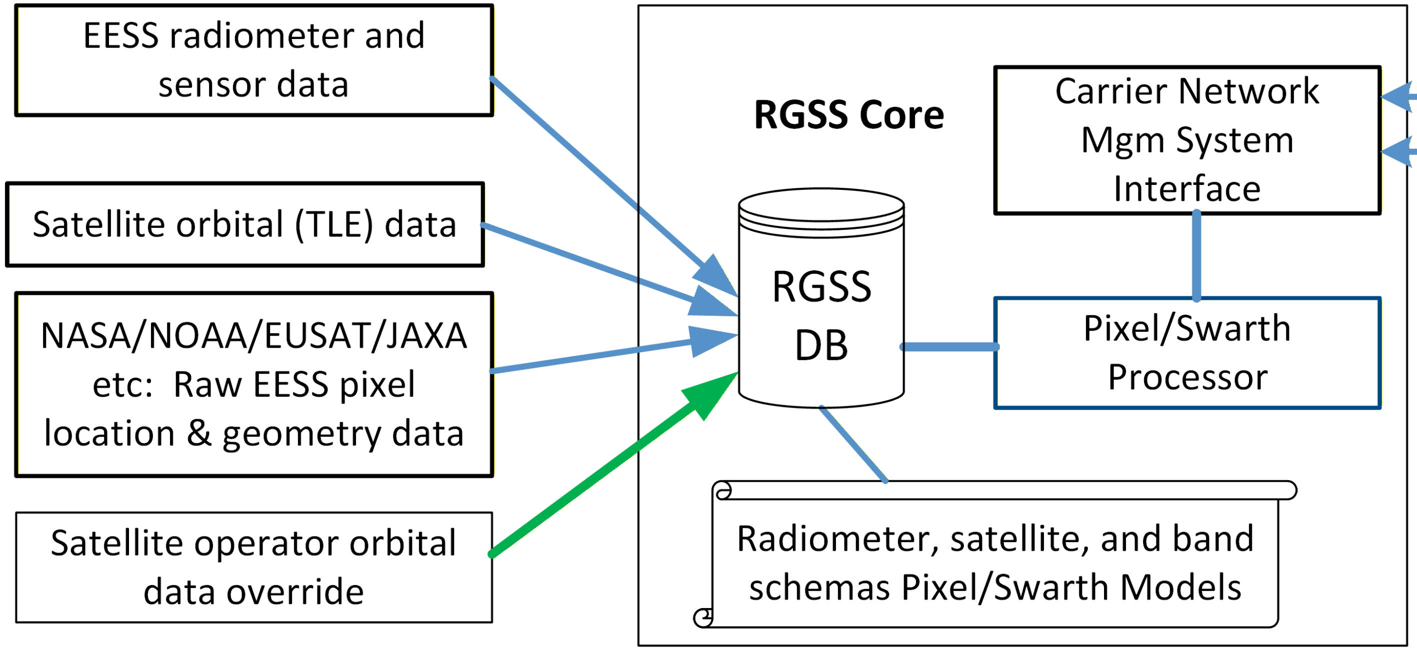


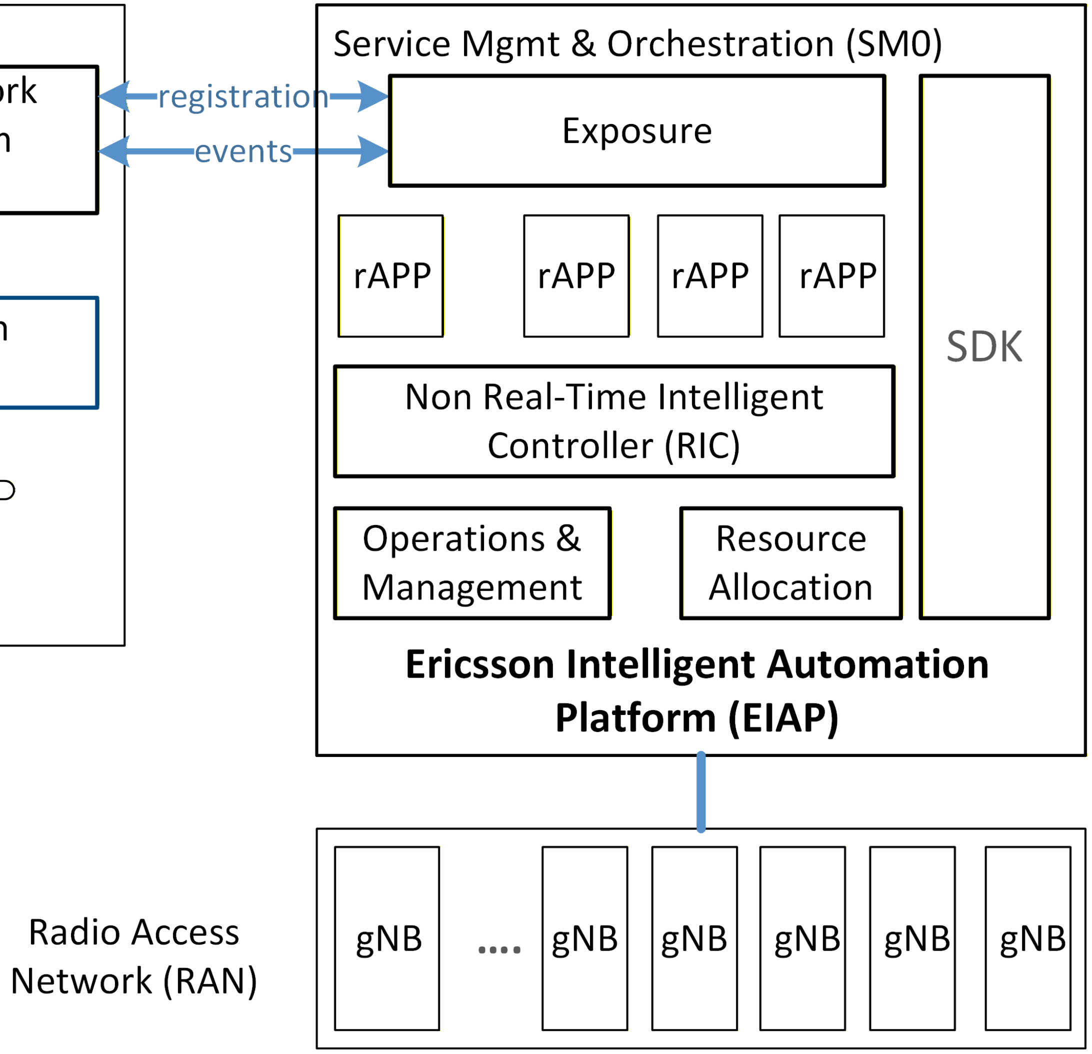
Cross-track or conical sounders



- Currently supports ATMS, AMSU, AMSR2/3.
  Web and programmatic (JSON) interfaces available.
- Accurate prediction of location, size, and timing of pixels verified by comparing predicted vs actual data from satellite downloads
- Short geofencing times => wireless network availability >99% w/o traffic migration to alternate bands.

CU Boulder et.al. + Ericsson Proposal





- rAPP to control base station (gNBs) and endpoint (UEs) transmissions + traffic migration to alternate bands
- Quantify performance (geofencing windows, network availability by CoS, % traffic migration, etc.). Include compliance data reporting to regulatory agencies for policing.
- Demonstration to stakeholders (FCC, NTIA, NOAA, etc., and wireless service providers).

Comparing Methodologies (somewhat subjective)

	New Spectrum	Signal Processing	Modify IMT Transmissions
Time Line	~ 2032 at best. (new satellite-sounders, perhaps 5 years after ITU 27).	~ 2031 (ESA CIMR)	~ 2027. Software implementation
Detect or Protect	Protects Against Overlapping and potentially OOB Tx	Detects interference but does not compensate for it.	Protects against overlapping and OOB Tx
Existing Assets	Does not protect existing assets	Does not protect existing assets	Protects existing and future assets
Technical Risk	Low.	Moderate to High	Low to Moderate
Non-Technical Risk	High. Competition for spectrum will play out at WRC-27	Low. This solution is completely in hands of the EESS community.	Will the wireless vendors/carriers support and comply.
Cost	Not sure how to quantify. The cost of new satellite/radiometers? Or the opportunity cost for 200-400 MHz of C band spectrum ($10's B)??	Development costs ?? Implementation costs ? (private estimate of $2 -5M per satellite ??).	$5-10M development & deployment. Typically maintenace costs are 15% of dev.
Broader Perspective	BAU model. *Does not provide a path for other frequencies.* May be vulnerable for OOB emissions and continuting appetite for mid band spectrum	*Provides a path for implementation at many frequencies.* But does not prevent or compensate for interference => large swarths of data corrupted if 5G networks heavily populated.	*Provides a path for implementation at many frequencies; a single system can be reused at other frequencies* . 6/7 GHz straightforward to implement. As the # of operational radiometers increases, the timing constraints for geofencing becomes more difficult.

RFI Analysis in the 7 GHz Band

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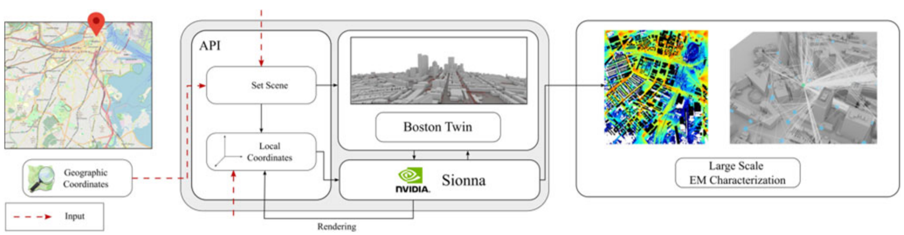
Overview

Goal:
Characterize the interference from an IMT network operating in the 7 GHz band to EESS

Interferer

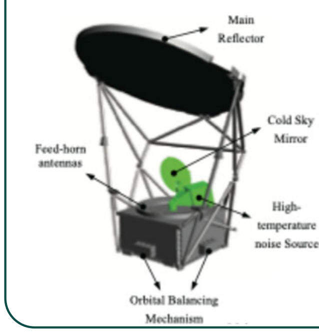
IMT Terrestrial Network



Incumbent

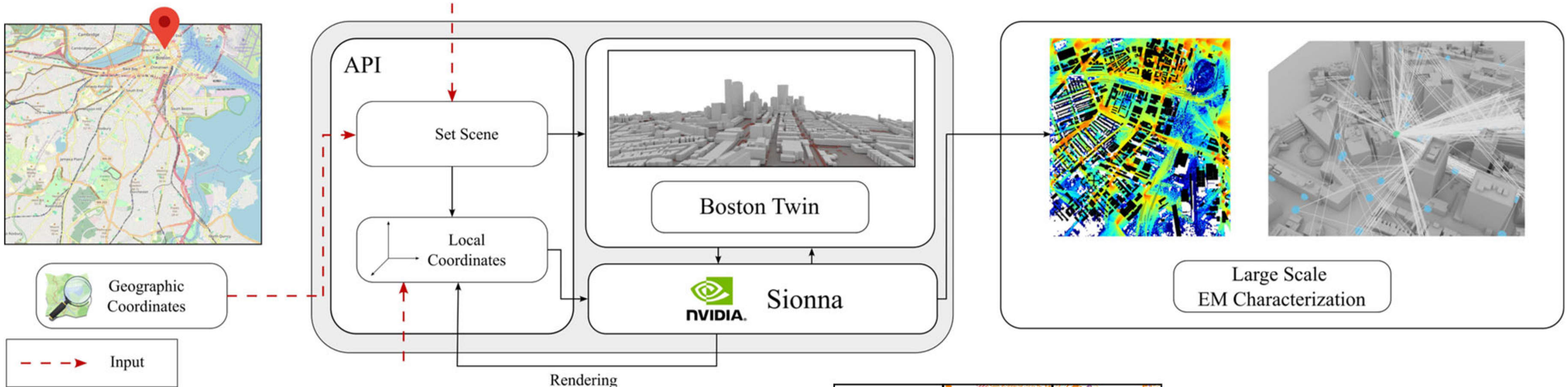
Advanced Microwave Scanning Radiometer (AMSR-2)

by the Japan Aerospace Exploration Agency (JAXA)



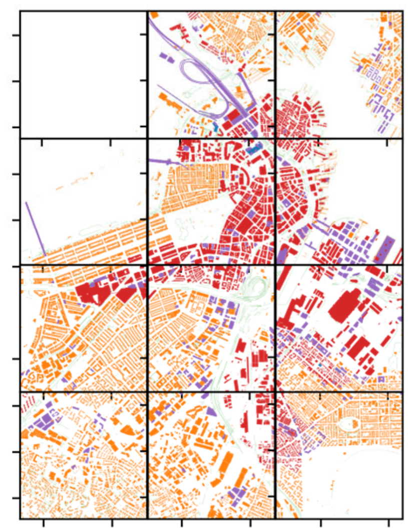
Center Freq. (GHz)	Band Width (MHz)	Beam Width (3dB, deg)	Ground IFOV (scan x along track, km)	Sampling Interval (km)
6.925/ 7.3	350	1.8	35 x 62	10
10.65	100	1.2	24 x 42	
18.7	200	0.65	14 x 22	
23.8	400	0.75	15 x 26	
36.5	1000	0.35	7 x 12	
89.0	3000	0.15	3 x 5	5

Large-scale Ray Tracing with Real-World 3D Models



Boston Twin

- Format compatible with multiple ray tracers
- Geolocated → easy to interface from OpenStreetMap, SUMO, etc..
- Add your points of interest (base stations, RF sensors, RA antennas, EESS satellite, …)



P. Testolina, E. Beshaj, M. Polese and T. Melodia, "Spectrum Sharing Across Terrestrial and Non-Terrestrial Services in the FR3 Upper Midband," *2025 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*, London, United Kingdom, 2025, pp. 1-9

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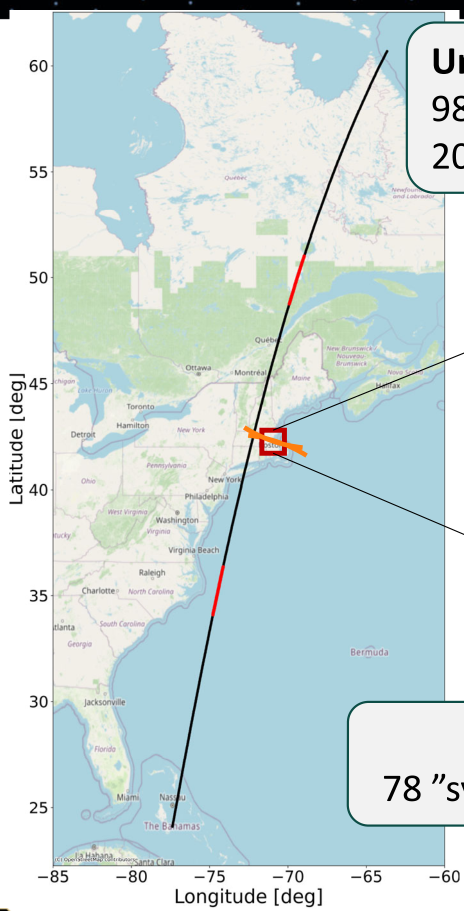
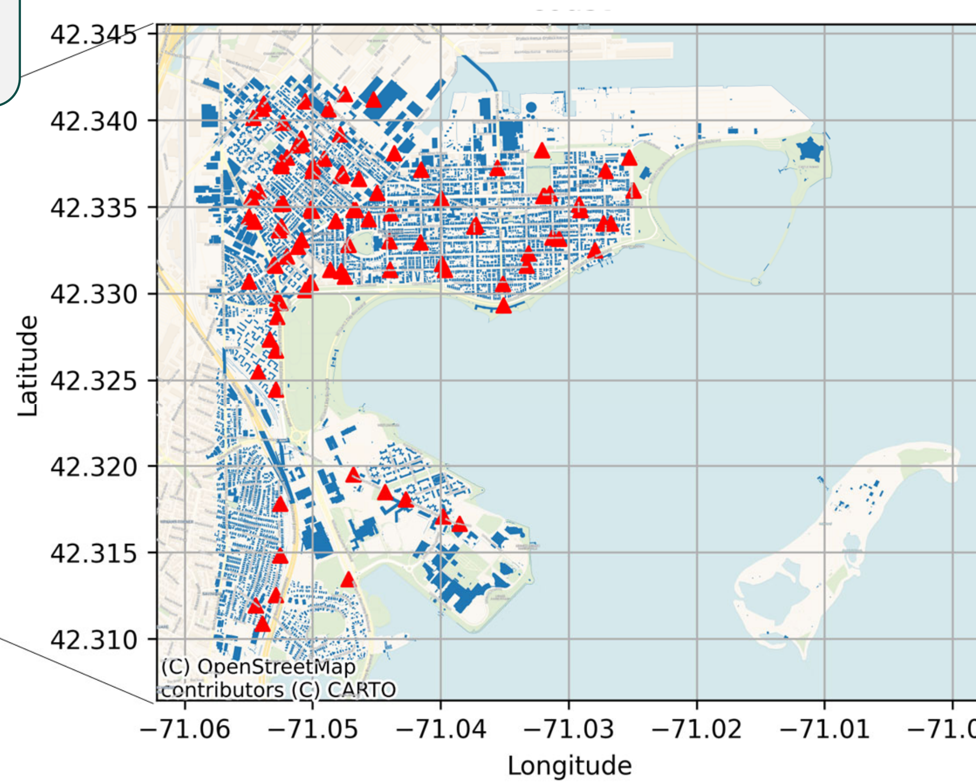
Considered Scenario



Urban Scenario
98 gNBs – real locations
20 km^2 – 3D building models

AMSR-2
78 ”synthetic” pixels



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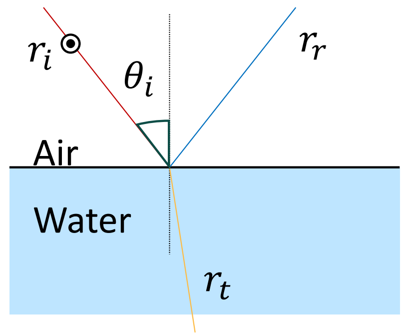
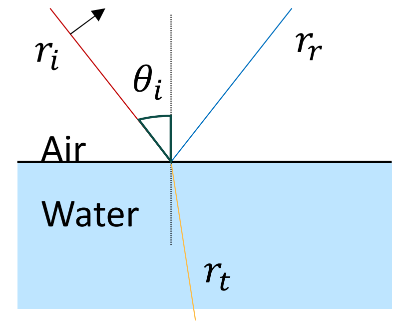
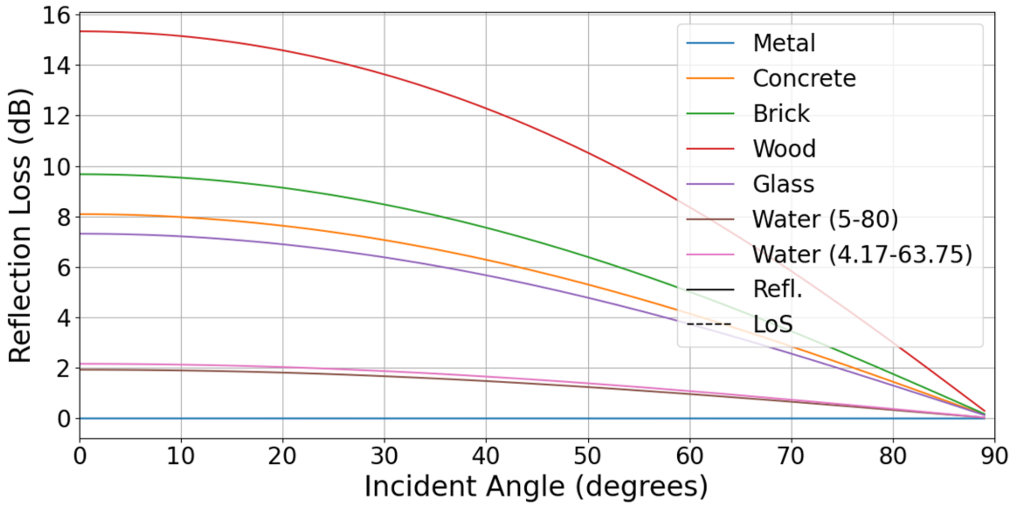
Modeling the Sea Water Reflection - Fresnel Reflection Coefficients

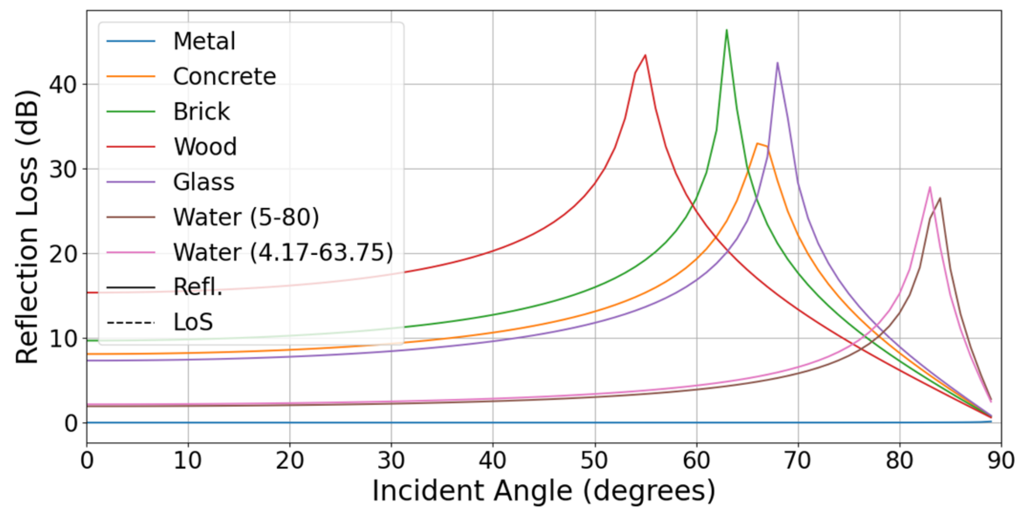
Horizontal Pol.



Vertical Pol.







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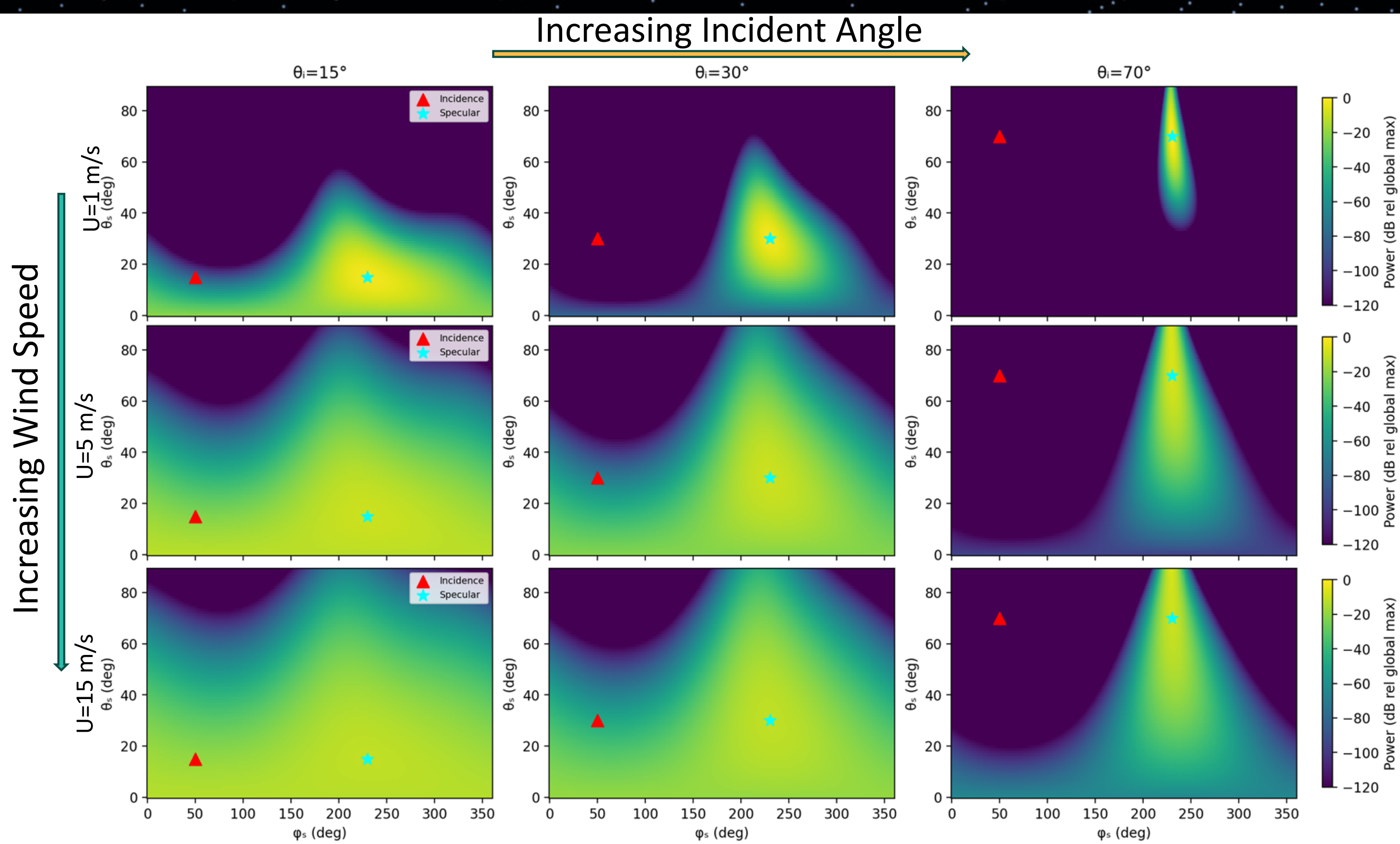
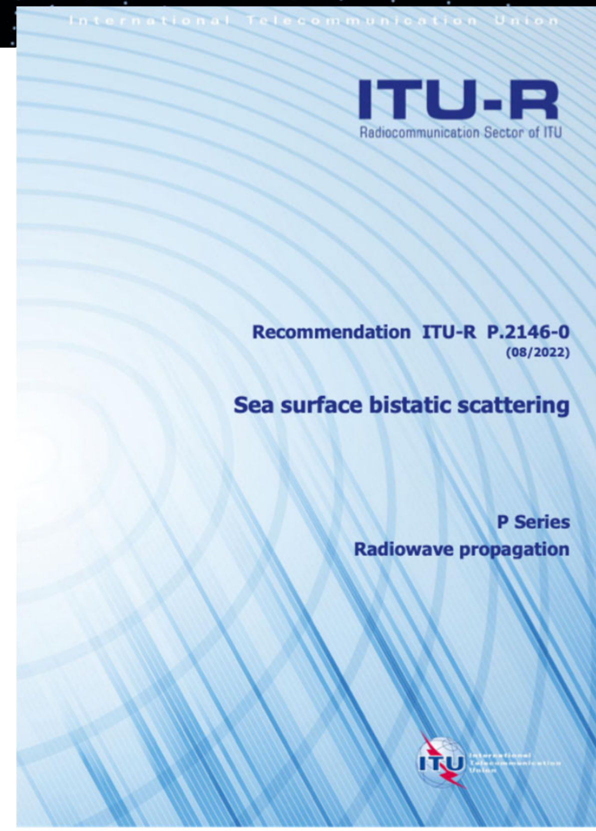
Modeling the Sea Water Reflection – Surface Roughness





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ITU, "Recommendation ITU-R P.2146-0: Sea Surface Bistatic Scattering," International Telecommunication Union, Recommendation ITU-R P.2146-0, August 2022

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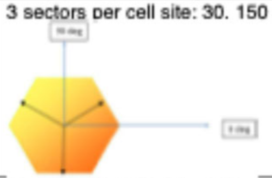
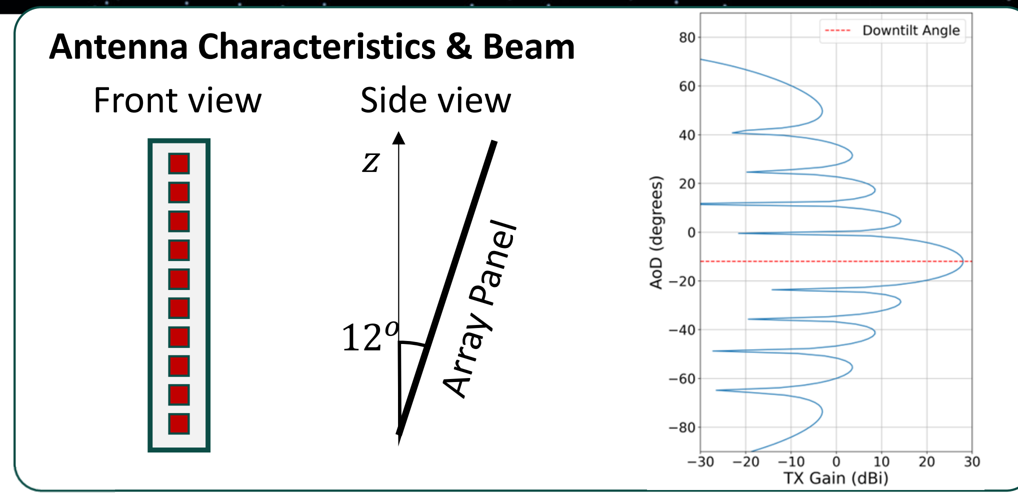
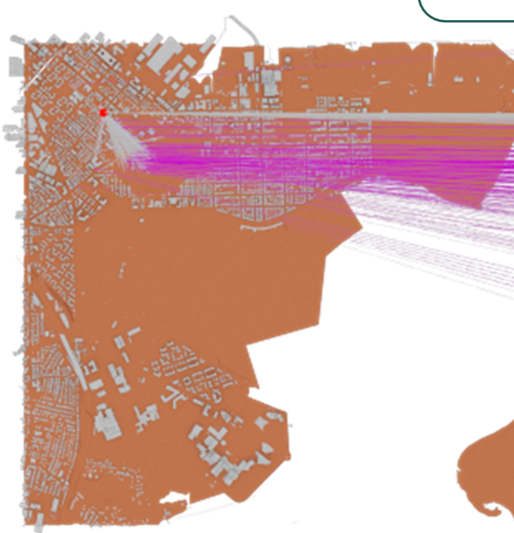
Interference – Single gNB

Parameter	Values
Scenarios	UMa, UMi-Street Canyon, Indoor-office (open office)
Sectorization	3 sectors per cell site: 30, 150 and 270 degrees 
BS antenna configurations	$M_g = N_g = 1$; $(M,N,P) = (10, 1, 1)$, $d_V = 0.5\lambda$
BS port mapping	The 10 elements are mapped to a single CRS port
BS antenna electrical downtilting	102 degrees for UMa and UMi Street Canyon 110 degrees for indoor
Antenna virtualization	DFT precoding according to TR 36.897 with application of panning and tilting angles
BS Tx power	44 dBm for UMi-Street Canyon, 49 for UMa at 6GHz 35 dBm at 30GHz and 70 GHz for UMa and UMi-Street canyon 24 dBm for Indoor for all carrier frequencies

3rd Generation Partnership Project (3GPP), "**Study on channel model for frequencies from 0.5 to 100 GHz**," 3GPP, Technical Report TR 38.901, 2024, Release 18.0.0.





MPC from gNB i:

$$y_{i,k} = \alpha_{i,k}\, g_{sat}(\alpha_{i,k}) g_{gNB}(\alpha_{i,k}) x_i$$

Total Interference Power generated by gNB i:

$$I_i = \sum_{k=0}^{M_i - 1} \left| y_{i,k} \right|^2$$

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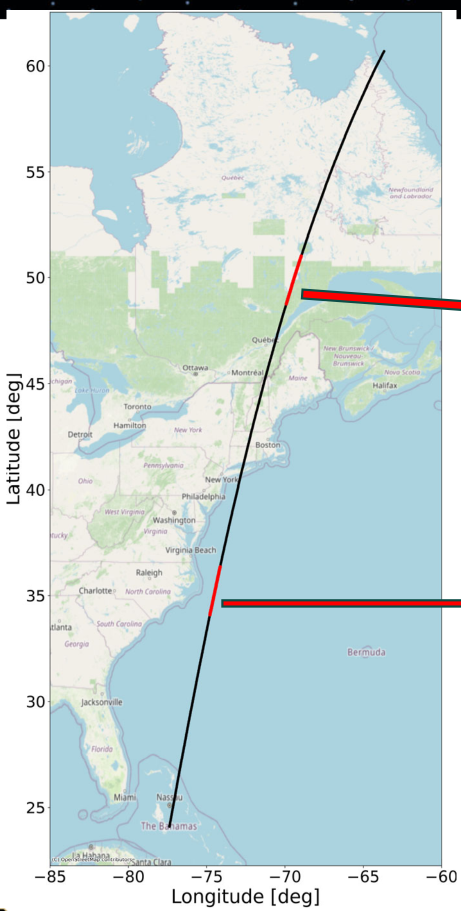
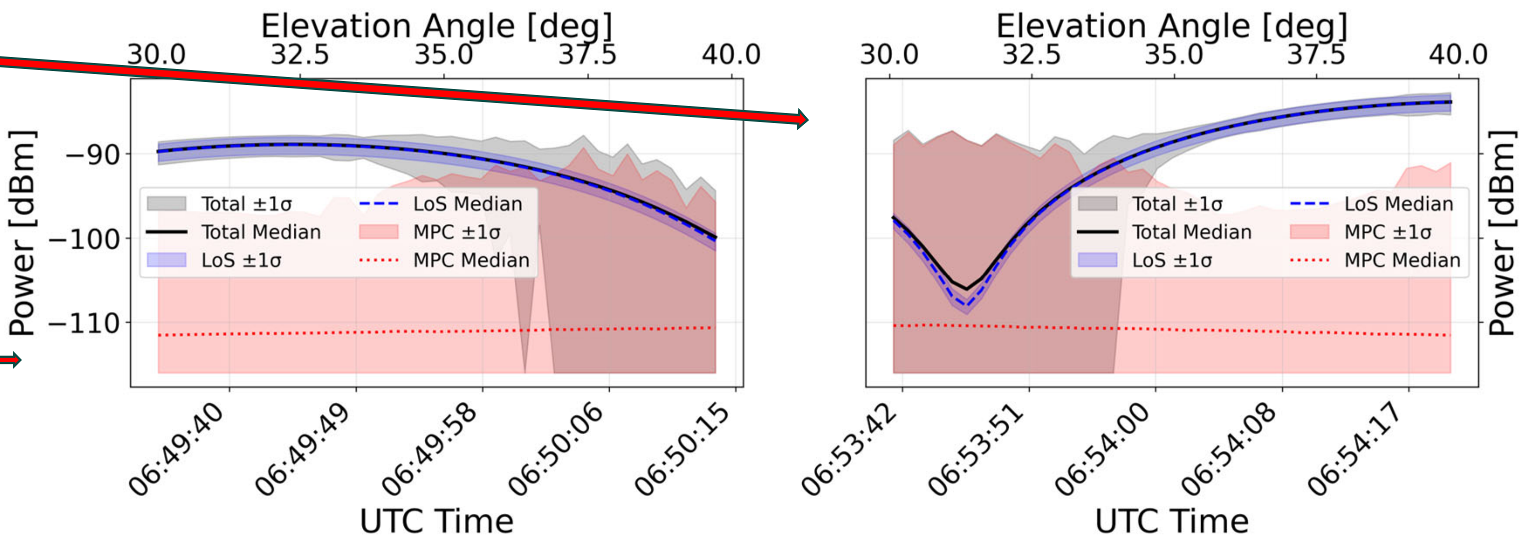
Interference – Single gNB Statistics

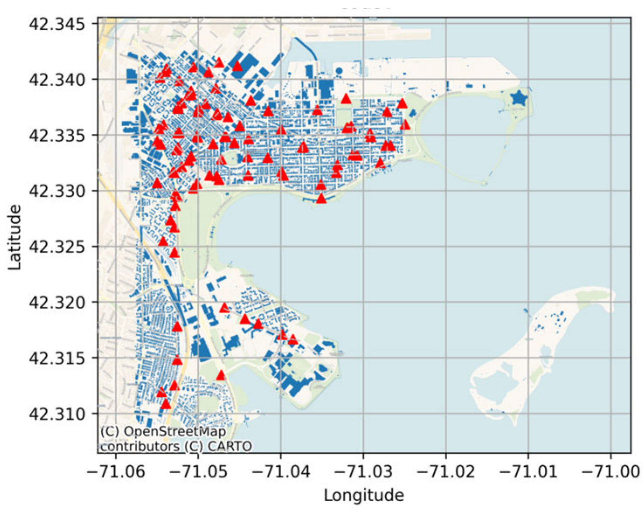


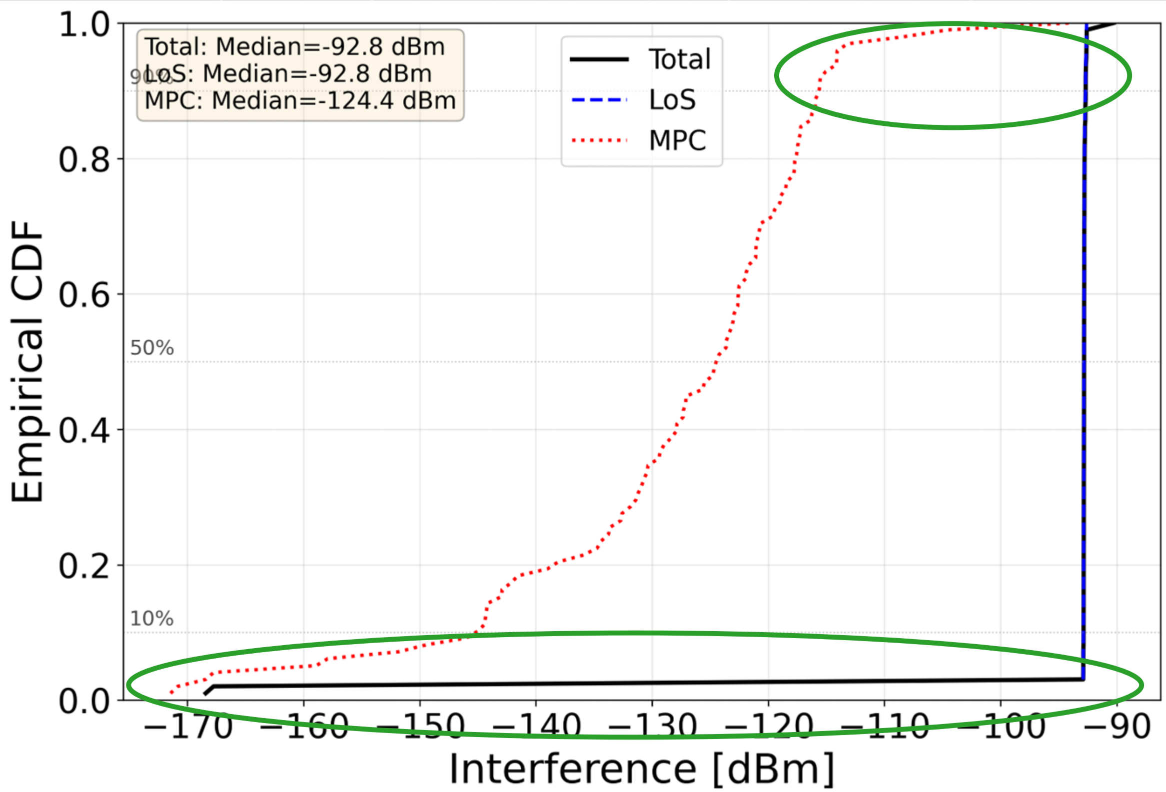
- The LoS contribution of a single gNB through sidelobes is significant
- The secondary MPCs contribute to a lesser extent, but can overtake the LoS due to the different geometry



- Clutter on the MPCs is not symmetrical or uniform

Interference – gNB Statistics





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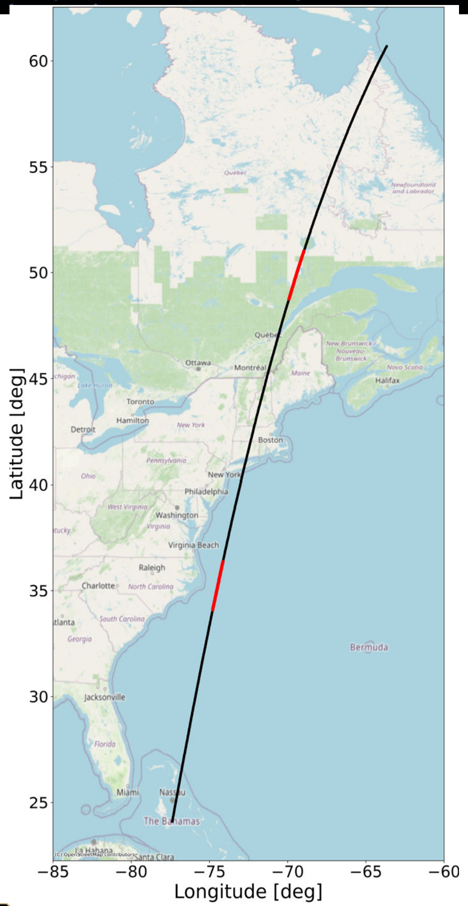
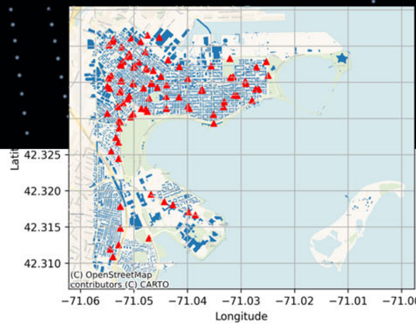
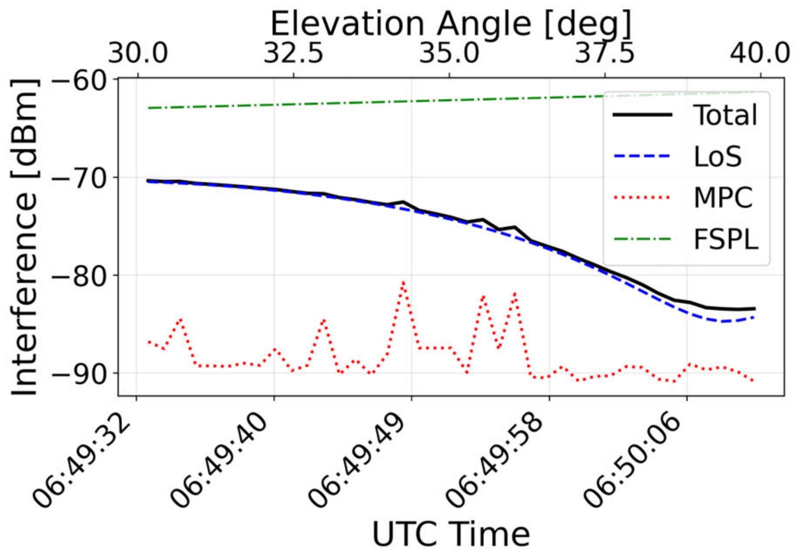
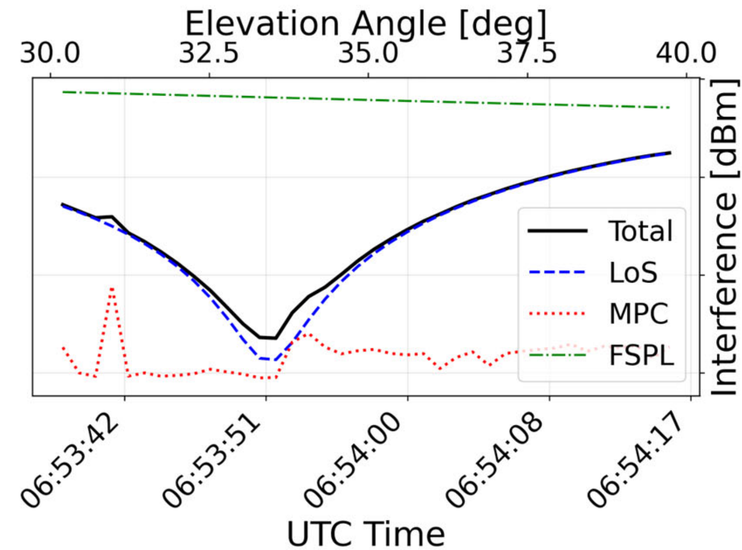
Aggregated Interference Power – In Band





Aggregated Interference Power: $I = \sum_{i=0}^{N_{gNB}} |y_i|^2$





Caveat: Worst-Case Scenario

- All gNBs are transmitting at the same time

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Differences with existing approaches

- LoS-only channel model is the standard for RFI analysis
  - Probably enough for active incumbents
  - Secondary MPCs carry enough power to be a problem for passive ones
- Site-specific simulation offers additional insights
  - E.g., particularly problematic locations, possible to identify/locate interferers
- Ray-Tracing on GPU is “natively” parallel

Limitations and Future Works

- We considered a limited urban area of 20 km^2
  - Extend to the actual pixel size (35x62 km^2)
    - Explore the limits of GPU parallel processing
  - Consider Satellite sidelobe contribution
- UE contribution might not be negligible
- OOB Emissions look above the margin – further analysis needed
- Keep expanding the framework to increase accuracy and fidelity to the 5G operations (e.g., duty cycle, OFDM, symbol duration, etc..)
  - Hopefully pave the way to sharing studies

Conclusions

- As expected, in-band emissions by IMT networks can saturate EESS radiometers such as AMSR-2
  - Key Sea Surface Temperature measurements might become inaccessible

- Non-direct paths and site-specific characteristics should be considered for future RFI analysis studies

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