RGSS: Real-Time Geospatial Spectrum Sharing

SpectrumX: 5/2/2022

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RGSS: Intro (me)

- BS Physics (SUNY Stony Brook), PhD Optics (University of Arizona)
- 1982-1999: Physical & quantum optics, optoelectronics, optical networks – GTE Labs & Tufts University (Visiting Prof)
- 2000-2017: IP/wireless network architecture & services – [GTE(+BBN), MIT (staff), Verizon] & Northeastern University (Adjunct)
- 2018-2019: Spectrum management, 5G/6G overlap with mm-wave science applications – IEEE/AAAS Congressional Fellow
- 2020-present: 5G/6G spectrum sharing – Choyu Networks & University Colorado Boulder (Research)

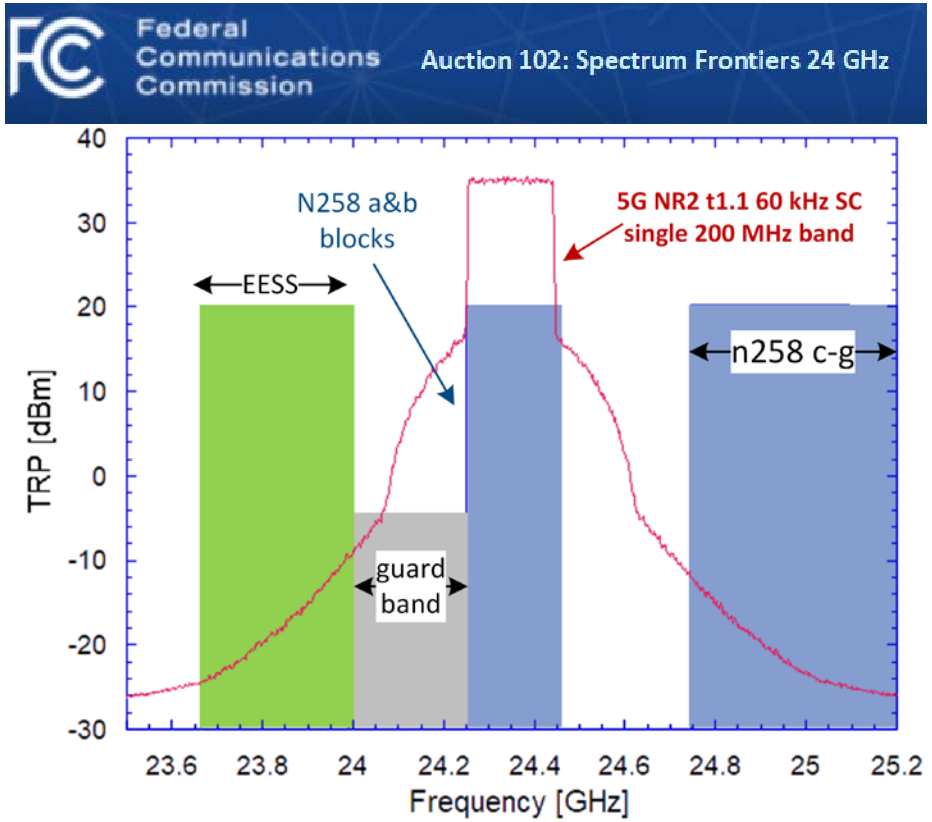
IEEE

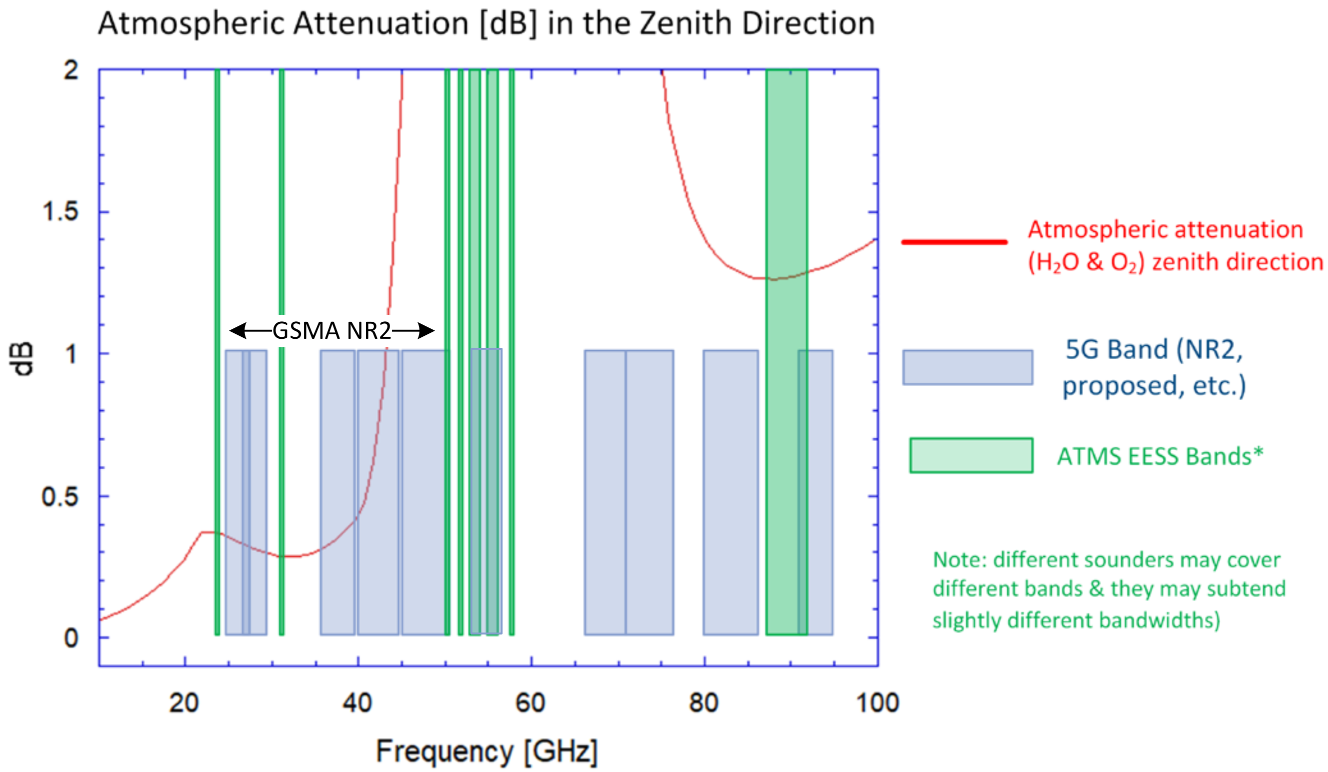
AAAS
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

- Advocate for the AAAS congressional fellow program
- AAAS managed, financed by IEEE, OSA, APS etc.

RGSS: Competition for spectrum

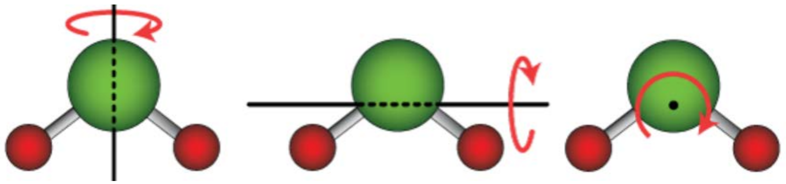
- Competition for spectrum between “legacy” users (DOD, NASA, NOAA, Radio Astronomy, DOT, etc.) and new entrants (wireless communications) @ all frequencies: mid-band 5G (NR1), mm-wave 5G (NR2), sub-mm wave 6G
- RGSS enables spectrum sharing between 5G/6G & microwave sounders (NOAA, NASA, DOD + many international agencies)
  - Example: Spectrum Sharing in n258 (24GHz NR2 band) with microwave sounders (EESS) @ 23.8 GHz.





RGSS: Microwave “Sounders” 101

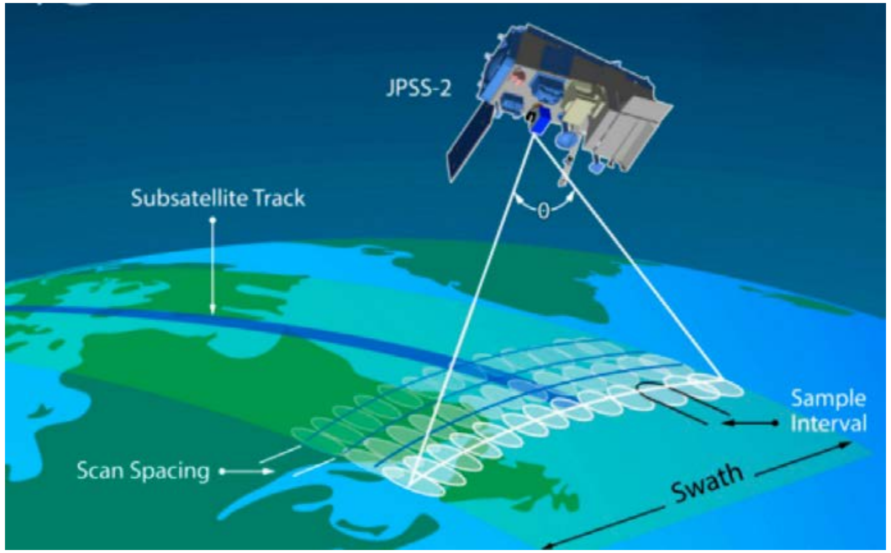
- Earth Exploration Satellite Services (sounders) measure RF from rotational transitions of atmospheric H_2O at many frequencies between 10 & 200 GHz,
  - Generates temperature and water vapor profiles (x,y,z,t): critical data for weather forecasts & as baseline data for climate models.
  - LEO (~ 800 km), polar (North to South) orbits, about 2 hours/orbit.

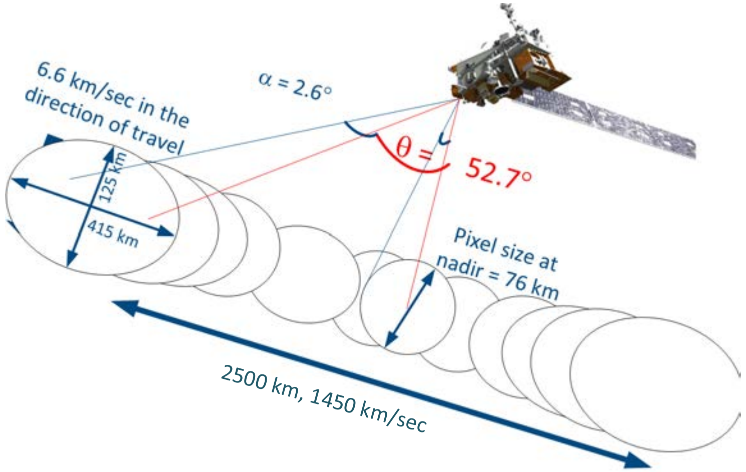


- Microwave “sounders” (aka - radiometer) = front end of radar or communication receiver
  - Sounders measure average power, have very long integration times. Data corruption when S/N =1
  - Communication receivers decode signals, have short time integration times, require S/N >>1.

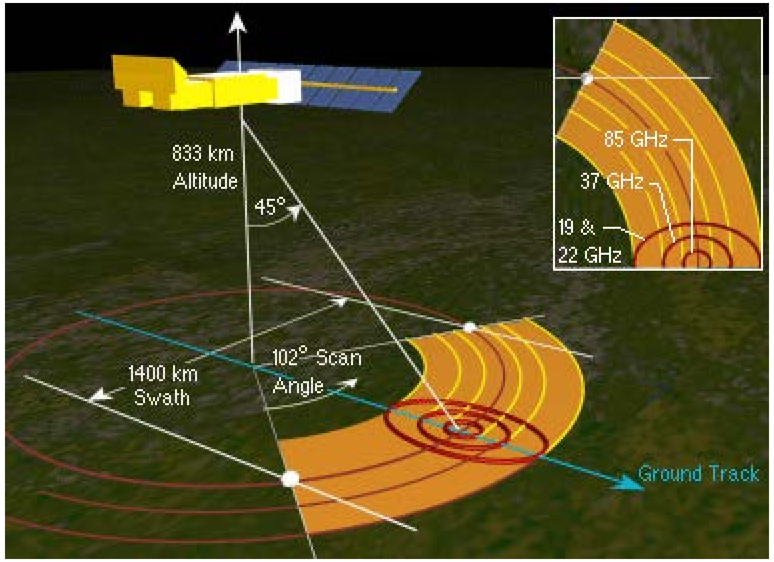
- Sounders are extremely sensitivity compared with receivers:
  - Sounders: Noise Equivalent Temperature (N_{eT}) := received power expressed as a temperature ($P_r = k_b N_{eT} \Delta f \ \ [watts]$) when S/N = 1).
  - Communications: Detected Power (P_r) = power needed for to achieve a desired CNR (e.g., to achieve an acceptable output BER).
  - Sounders 10^4 to 10^5 more sensitive than communication receivers. ($P_r^{receiver} = 10^4 \ to \ 10^5 \ P_r^{sounder}$)

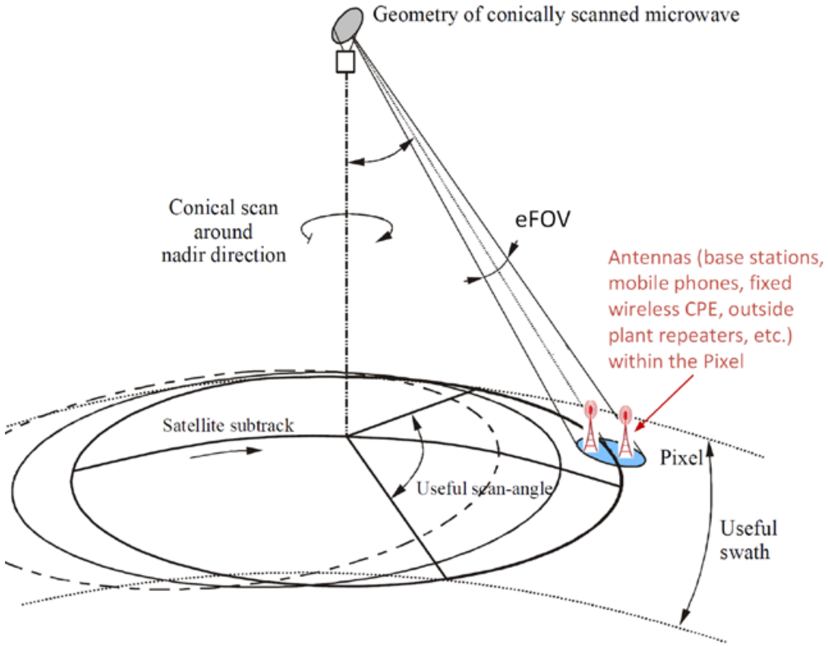
RGSS: Microwave "Sounders" (Radiometers) 101





ATMS (NOAA): example of a cross-track sounder

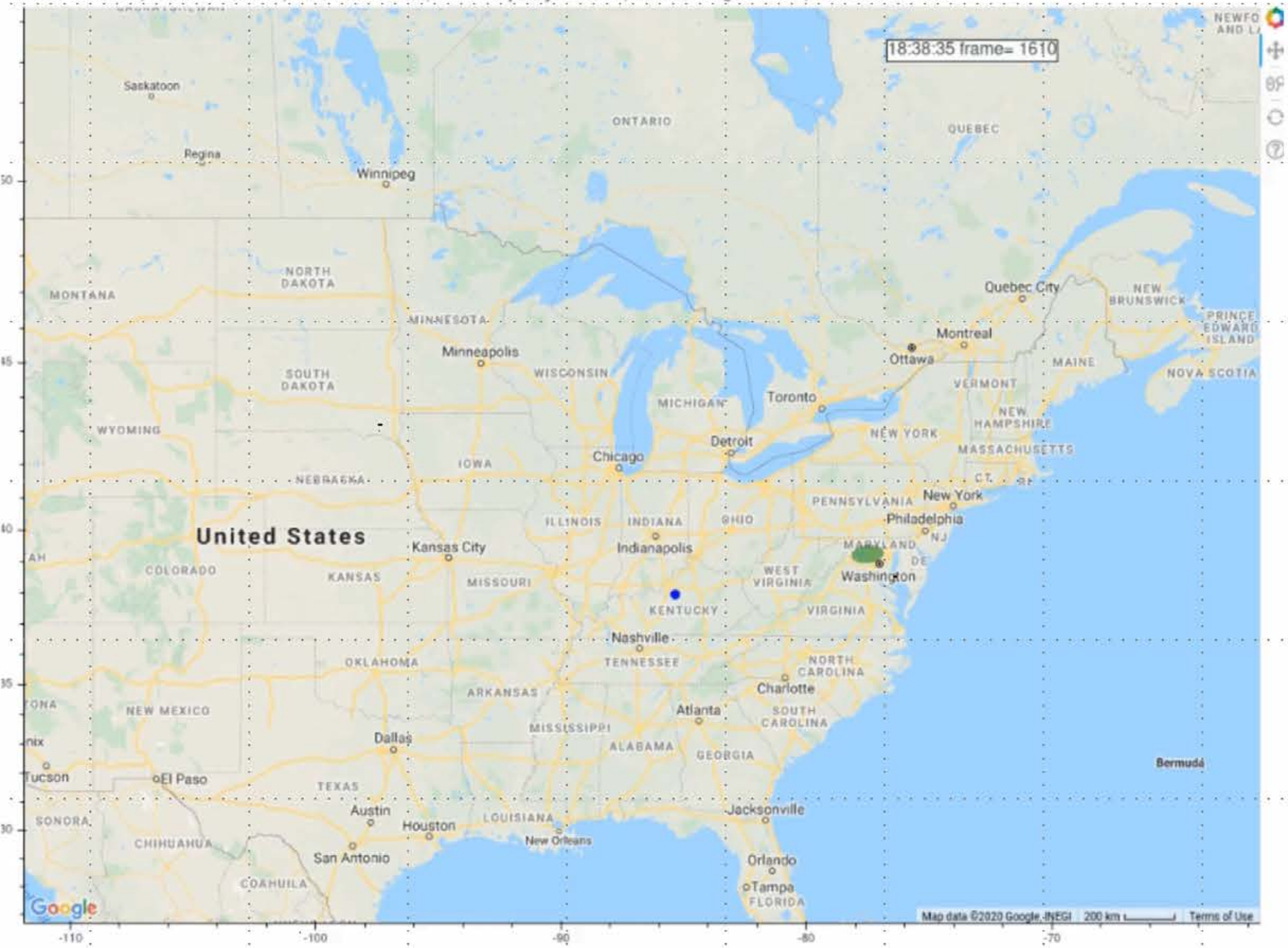




SSMI (DOD): example of a conical scanned radiometer.

• ATMS: Example of a cross-track radiometer

Date = 11 30 2020, Satellite = NOAA 20, Radiometer = ATMS, Center Frequency = 23.8GHz, Max Scan Angle = ±52.7°, Field of View = 2.60°



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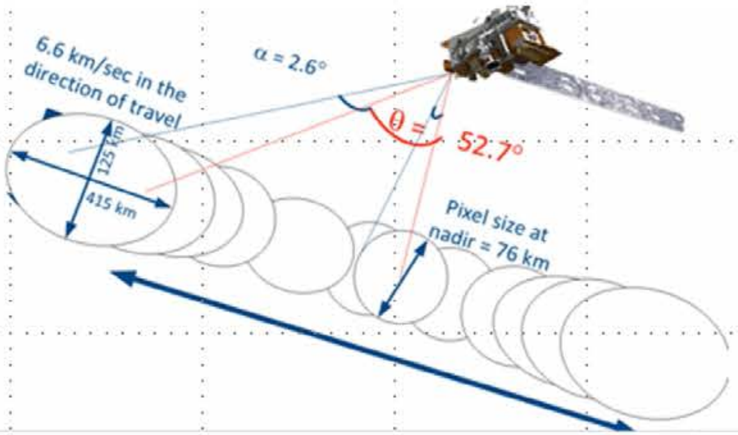
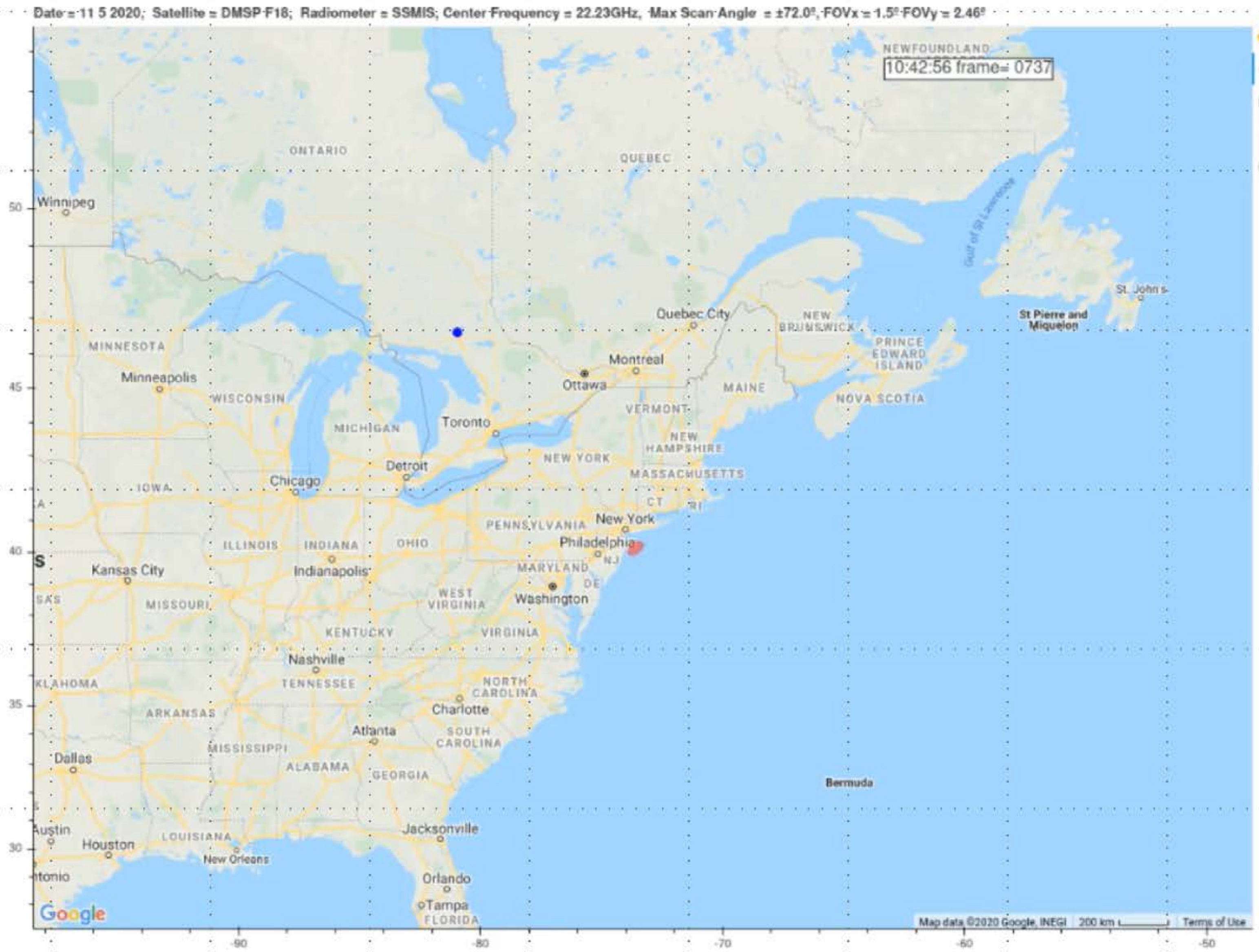
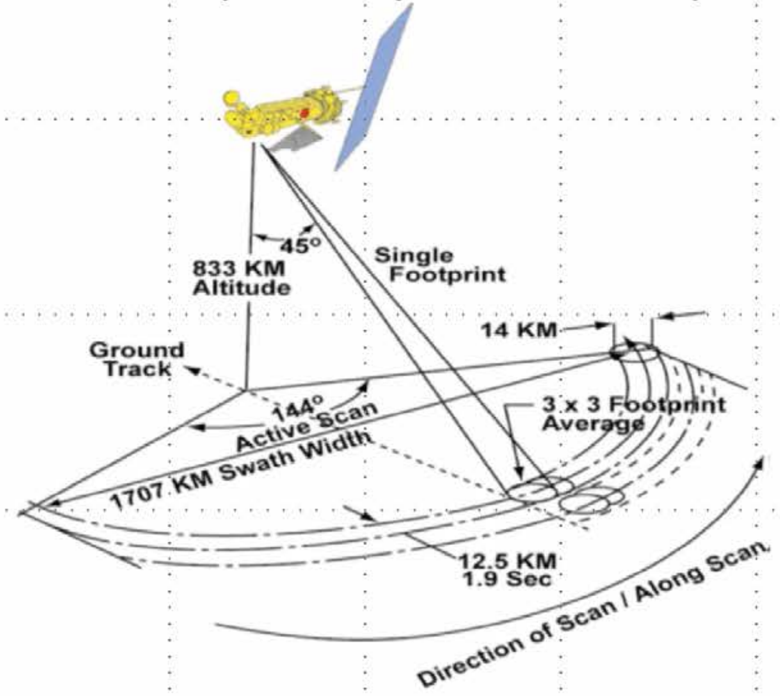
- ATMS is the newest and most advanced (high scan speed, wide scan angle, sensor sensitivity, etc.) operational sounder.
- The pixel size for a cross-track scanner (the "image" size of the detector based on the "effective" field of view of the system) becomes larger and elliptical at the edges of the scan, and smaller and circular at nadir.
- The eFOV of the sounder subtends a point on the earh for about 10-20 msec for each traversal.



- # SSMIS: Example of a conical radiometer



- Zenith angle fixed, scanning is in the azimuth angle.
- Fixed (and moderate) spot size.
- Note that for this particular satellite traversal, it's roughly at 10:40 UTC = 5:40 AM in DC. (relatively low 5G traffic).



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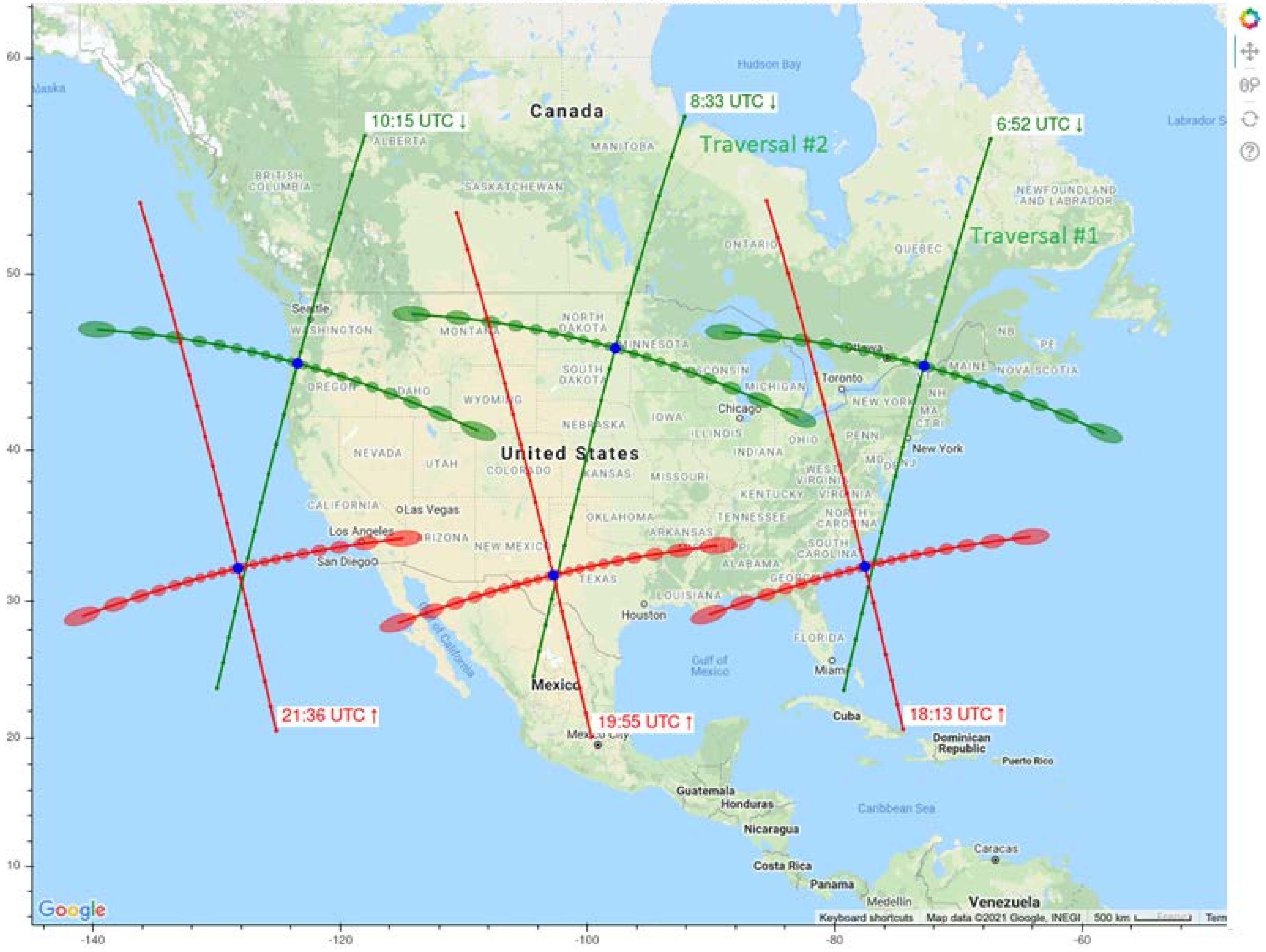
D. B. Kunkee *et al.*, "Design and Evaluation of the First Special Sensor Microwave Imager/Sounder," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 46, no. 4, pp. 863-883

RGSS: Time domain geo-fencing enable spectrum sharing

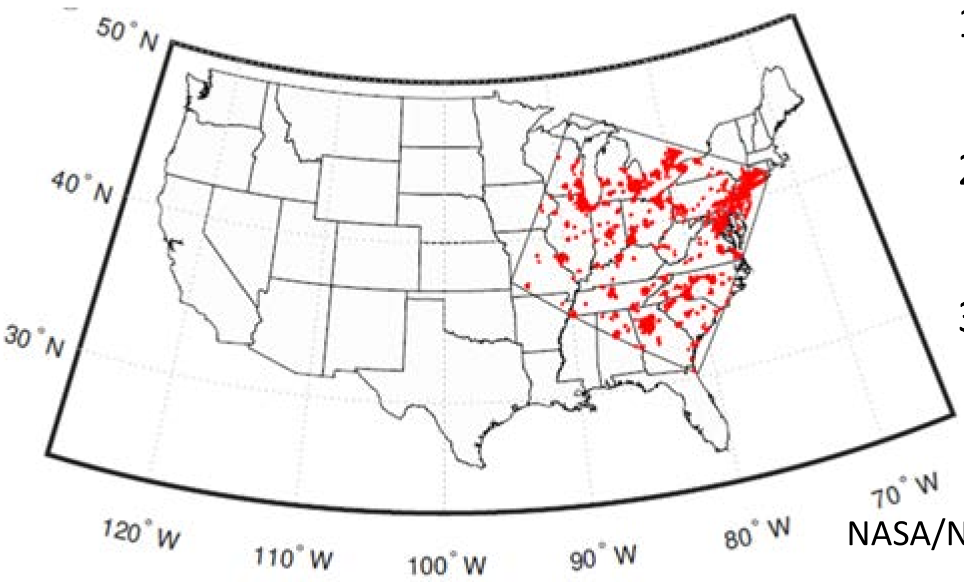
- A 5G/6G antenna on the earth is within a sounder’s eFOV (effective Field of View) for ~10-20 msec.
- A pixel (footprint defined by eFOV) can be predicted with a very high degree of accuracy (e.g. ±1 pixel).
- For a given sounder, traversal & deployed network :
  - o Identify bad pixels (eliminates corrupted data, but does not remove interference)
  - o Pause (or move traffic to alt bands) all network traffic while Tx antennas are within the eFOV
  - o Reduce & move traffic Tx power so that $P_r^{5G} < P_r^{sounder}$.
- Σ over all satellite/traversals

> ➢ Conceptually simple, software based, lots of details
>
> ➢ Compelling compared to traditional hardware based (ITU) methods for preventing inference:
> - o cheap ($)
> - o adopts to new network components & more sensitive (new) sounders
> - o reuses existing (CBRS) spectrum sharing system architecture & protocols
> - o enables carriers to run networks with better performance & coverage while *decreasing* interference.
> - o Single system supports all mm & sub-mm wave bands

Date = 8/9/2021, Satellite = NOAA 20, Radiometer = ATMS, Center Frequency = 23.80GHz, Max Scan Angle = 52.70º, Field of View = 2.6º, <Avg> Delta from TLE Epoch = 2693 hours



RGSS: Current (ITU) recipe for calculating Interference



1. Monte-Carlo simulation of 5G/6G network. **Many assumptions re network, many out of date.**
2. Calculate the RF Power intercepted by the radiometer from all transmitters within a time step (i.e. eFOV pixel) for all steps within area.
3. Limit the Tx OOB emission power (adjacent spectrum) such that the aggregate RF power calculated in (2) is < radiometer NEP **for 99.99% of all time steps** within the defined area.

NASA/NOAA Sharing Studies on WRC-19 Agenda Item 1.13

Using the 24 GHz NR2 band as a model:

Limits performance (coverage) →

- One size fits all: Worst case statical analysis based on many assumptions and high performance sensor, high bar (99.99% of all pixels). Network performance & coverage in large portions of the network limited to accommodate small number of areas

Over estimates interference →

- MIMO: NASA study (at least v2) did not take into account coherent massive MIMO beam forming in the OOB spectrum.

Missing components significantly increase OOB emissions →

- Assumptions quickly outdated: The 24GHz analysis done for WRC-19 does not take into account high power FWA-CPE, outside plant repeaters, 5G backhaul

RGSS: Example of Pausing Transmissions

- Pixel (in red) and Dynamic Protection Zone (DPZ – in blue) from ATMS (Advanced Technology Microwave Sounder) riding on NOAA-20 over Washington DC. DPZ (because of over-sampling) is 9x9 array of actual pixels (9 scan lines and 9 pixels in each scan line). Note that most other sounders do not over-sample.
- Experimental confirmation confirms geolocation accuracy of ± 1 pixel for ATMS based on 12 hour lead time for scan angle(t) within a scan.
- ATMS synchs scan angle with satellite position every 3 scans. Closed-loop provides much tighter DPZ.
- Scan position of mirror for conical scanners is NOT synched to satellite position => buffering by scan line rather than pixel.

- Needs base station locations only - not detail network infrastructure data.
- Does not require/depend on a propagation model. All traffic is either paused or moved.
- *Primary issue is accurate prediction of pixel location (and size of buffer):*
  - *satellite location, scan position w/rspt to satellite location, antenna angle offset error*
- Utilize 3gpp rel 16 & 17 fast handover mechanisms. (TS 38.3 conditional handover & PSCell choice. Make before break paradigm avoids re-registration).

RGSS: worst case network availability (pause transmissions regardless)

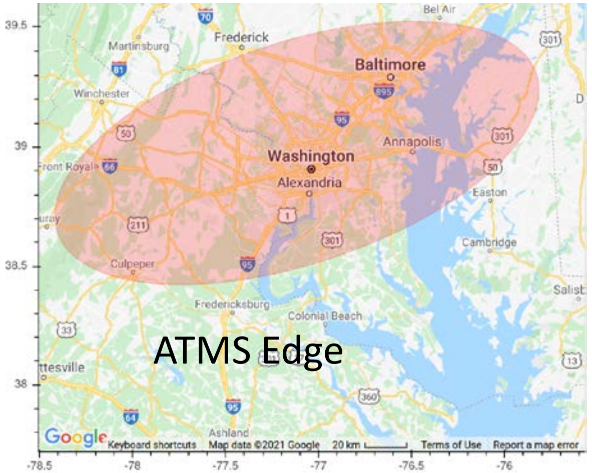
radiometer	radiometer type	# active satellites	Pixel-geofencing [sec/day-satellite]	Line-geofencing [sec/day-satellte]	total pause time/day-rad [sec]
AMSR-E	conical	1		30.8	30.8
AMSU-A	crosstrack	6	4.2		25.2
ATMS	crosstrack	2	9.8		19.6
GMI	conical	1		5.25	5.25
MTVZA-GY	conical	3		128.6	128.6
MWRI (HY2)	conical	2		107.9	107.9
MWRI	conical	4		64.5	64.5
WindSat	conical	1		2.4	2.4
~~AMR~~	~~nadir~~				
~~MADRAS~~	~~conical - equatorial~~	total window pause time [sec]			384.25
~~MWR (Sentinal 3~~	~~nadir~~		network availability		99.6%
~~AMR-C~~	~~nadir~~				
~~Altika~~	~~nadir~~				

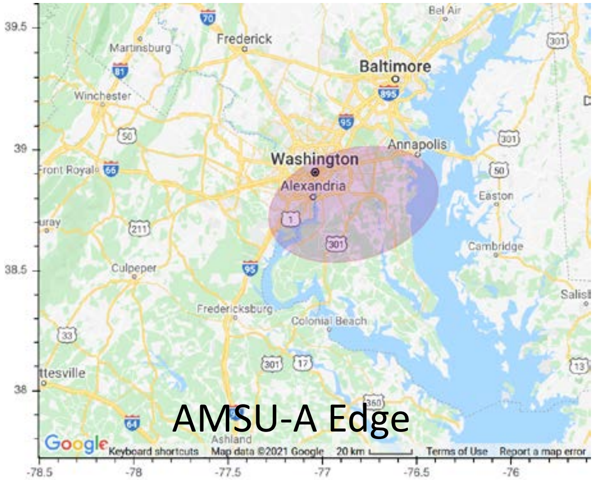
The punchline

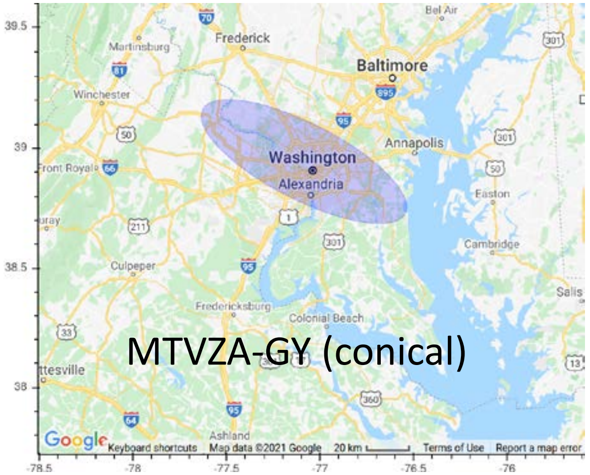
- Traffic is transferred to another band, or paused (choice influenced by Class of Service – CoS)
- 20 active radiometers + time-of-day traffic
- Does NOT include pixel size (bigger pixels => more subtending antennas), integration time, N_{eT}, or Δf

RGSS: Interference estimates per satellite, radiometer, and traversal (time)

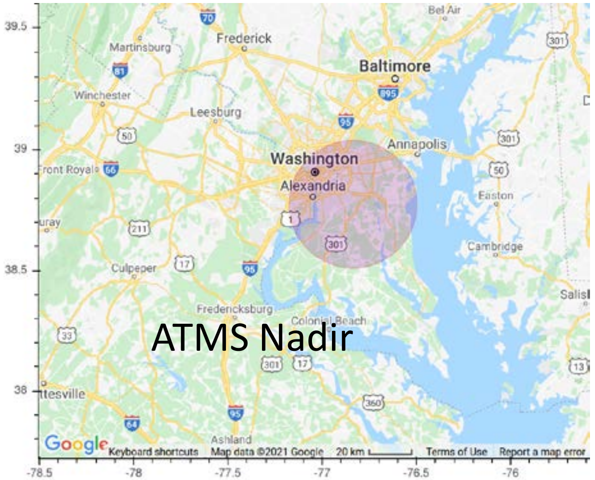
- Calculate interference from subtended 5G/6G Network using actual (deployed) infrastructure. Pixel size dominates the amount of interference.
- Utilizes 3gpp fast band handover algorithm maintains registration, can be used between bands. Use with 5G/6G Class of Service (CoS).



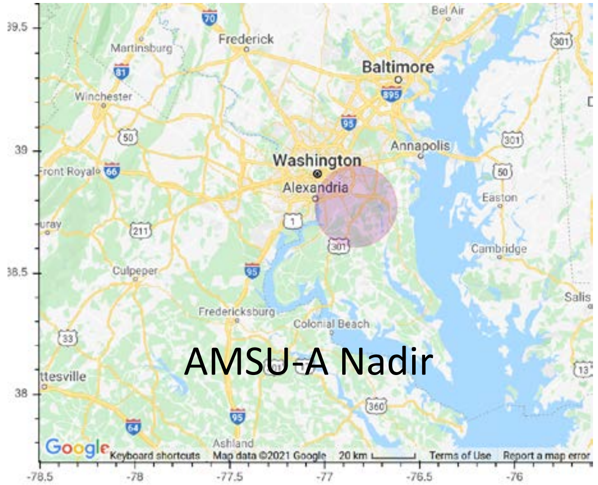




Conical: Wide scan, moderate to large pixels. (pixel areas are constant for all scan positions).



ATMS: Wide scan + large pixels



AMSU: Moderate scan & pixels

RGSS: Predict interference => link-loss budget improvement.

radiometer	bandwidth [GHz}	noise equiv ΔT	radiometer type	OOB emissions reduction compared with ATMS [dB]			Satellites
				nadir	max	average	
ATMS	0.27	0.90	crosstrack	0	0	0	SUOMI NPP, NOAA 20
AMSU-A	0.27	0.30	crosstrack	9	11	9	NOAA 15, NOAA 18, NOAA 19, METOP B, METOP C, Aqua
AMSR-2	0.40	0.60	conical	12	21	15	GCOM W
GMI	0.37	1.05	conical	13	23	17	GPM Core Observatory
AMSR-E	0.40	0.60	conical	13	22	16	Aqua
WindSat	0.50	0.55	conical	8	17	11	Coriolis
MWRI	0.40	0.50	conical	8	17	11	FY-3B, FY-3C, FY-3D, FY-3E,
MWRI(HY2)	0.40	0.50	conical	9	18	12	HY-2A, HY-2B
MTVZA-GY	0.40	0.30	conical	5	14	8	coriolis

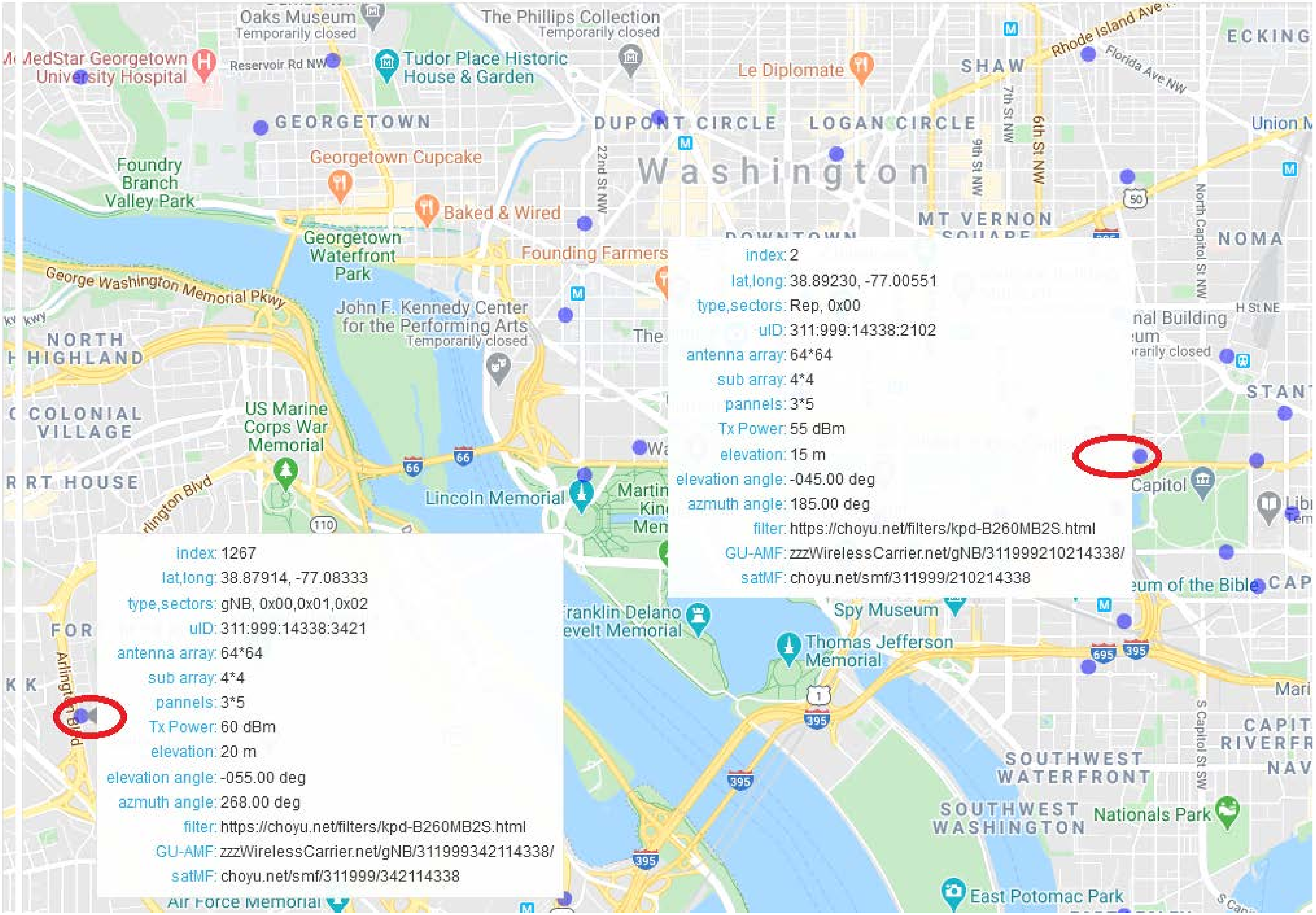
- Uses predicted interference rather than worst case interference estimates.
- Includes the effect of pixel size (DPZ), N_{eT}, and Δf
- Improvement of link-loss budget enables better 5G/6G coverage & performance while providing stronger protection (than ITU) for EESS measurements
- Requires accurate RF propagation model!

Two examples:

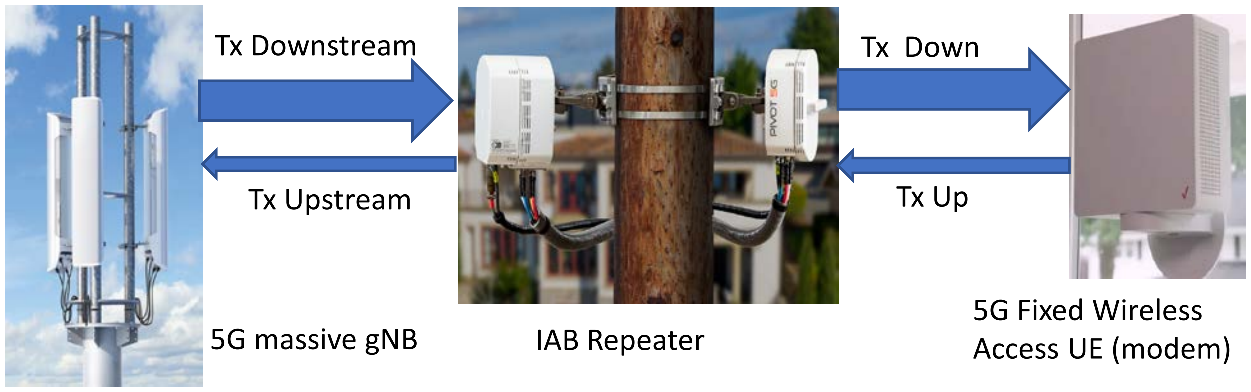
- traversals over New York City metro area (lots of 5G base stations)
- traversals over Aberdeen, South Dakota (lots of farm land – few base stations with much larger cell sizes)

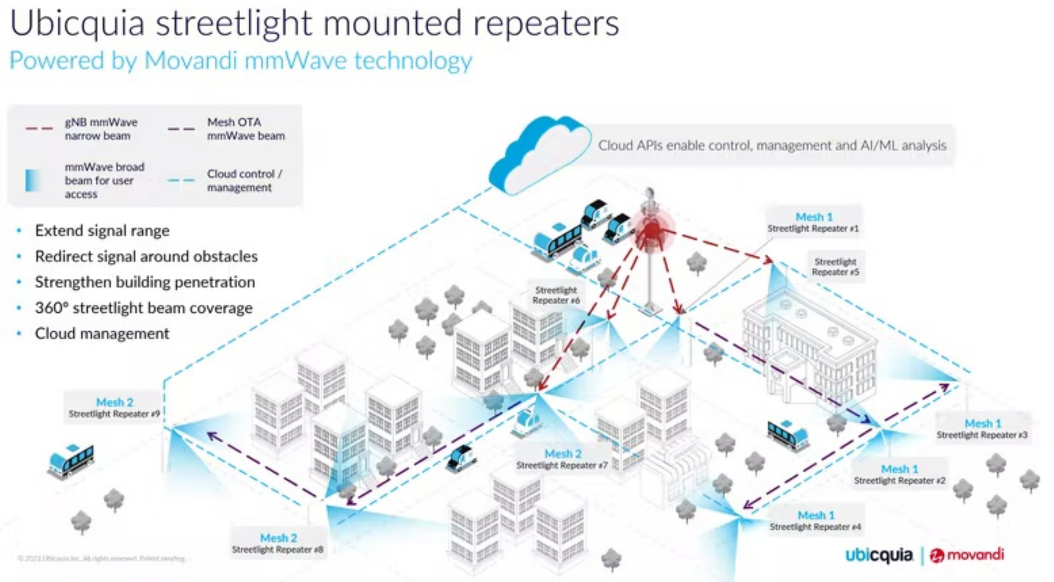
RGSS: uses actual *and extensible* network infrastructure schema

- Infrastructure types (Base stations, conventional UEs, access repeaters & integrated access backhaul, 3GPP power class 1 fixed-wireless UEs)
- TX characteristics: Lat/Long, elevation, angle, azimuth, Tx Power, Tx power filter spectrum, rray & panel size, sub-array size, *far fields,* uID, guAMF, satMF, etc. etc.
- Traffic heuristics (time of day, day of the week, etc.) or real-time profile access for traffic migration by CoS
- Multi-band overlay



5G/6G Network Components not included in ITU recommendations or covered at WRC-19



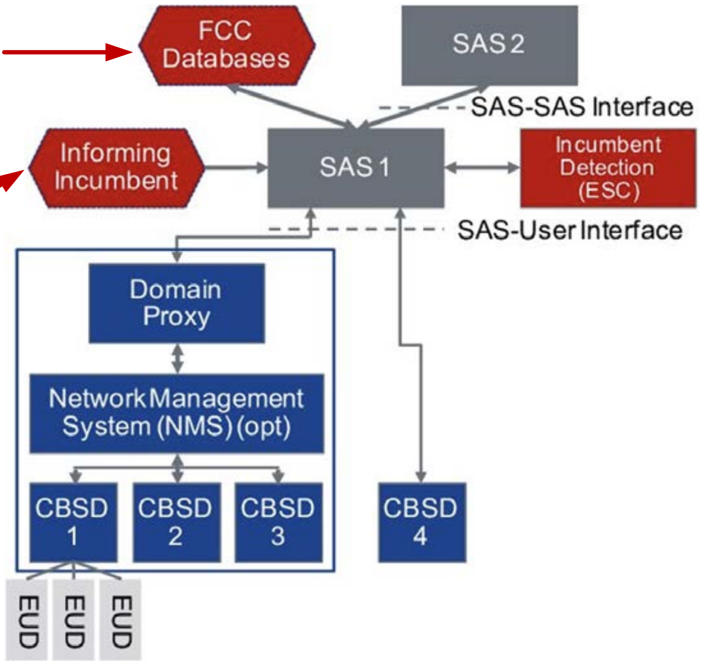


- Integrated Access Backhaul (IAB): (gNB ⇔UE + gNB ⇔ gNB)
  - More base station "like" antennas => more interference than modeled by ITU. Additional interference ~10log(1+F) [dB] where F = the number of repeater transmitters. What is F ? (potential for large F as repeaters become deployed on lampposts – Ericson, Ubicquia, etc.)
  - Significantly improves 5G economics: better coverage + less fiber backhaul. Currently deployed @ 28 and 37 GHz, expected @ 24 GHz.
  - Many vendors. FCC regulates repeaters as "Class B industrial signal boosters ", & has not discussed extending WRC-19 OOB emission recommendations to cover. Potentially even worse!

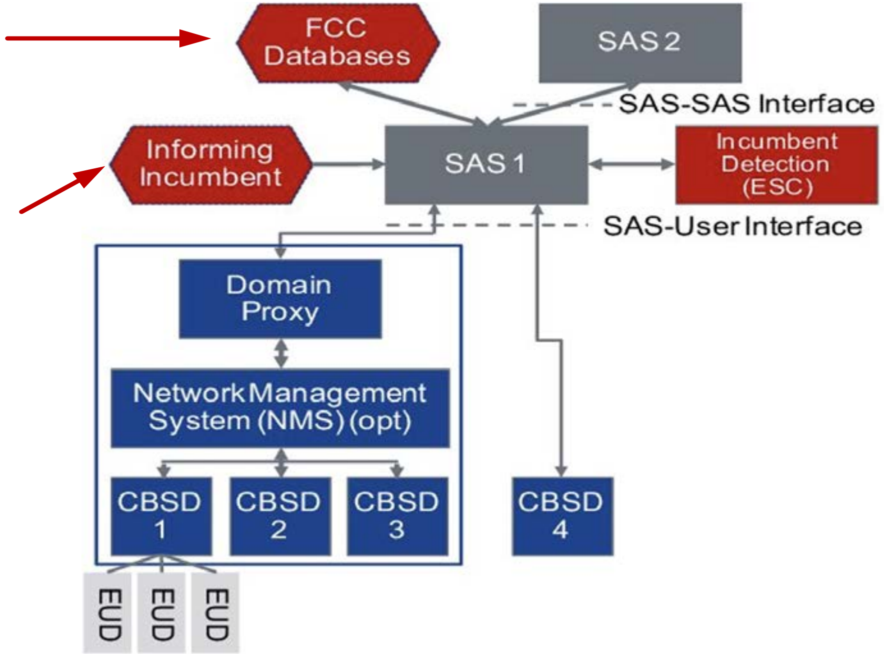
- High Power (3GPP Power Class 1) fixed-wireless access (FWA) UEs
  - ITU assumed smartphone/cell-phone power class 3 (22.4 dBm EIRP). Current FWA UEs are power class I (> 40 dBm EIRP). Because of battery saving UE algorithms, interference for UEs depends on EIRP (see NASA/NOAA studies, or ITU-R
  - If FWA UEs do not implement battery savings, increase in OOB emissions potentially > 10 dB.
  - FWA UE vendors have requested FCC exception from ITU OOB UE emission recommendations. This is a little like setting highway speed limits for cars at 65 MPH, but exempting eighteen wheelers (semi tractor-trailers) from any speed limits.

E.Eichen, "Impact of new 5G network components on out-of-band emissions at 23.8 GHz", The RFI 2022 Workshop at ECMWF, 14 - 18 February 2022 2022 URSI International Union of Radio Science (pre-print)

RGSS: Leverage CBRS Spectrum Access System (SAS)

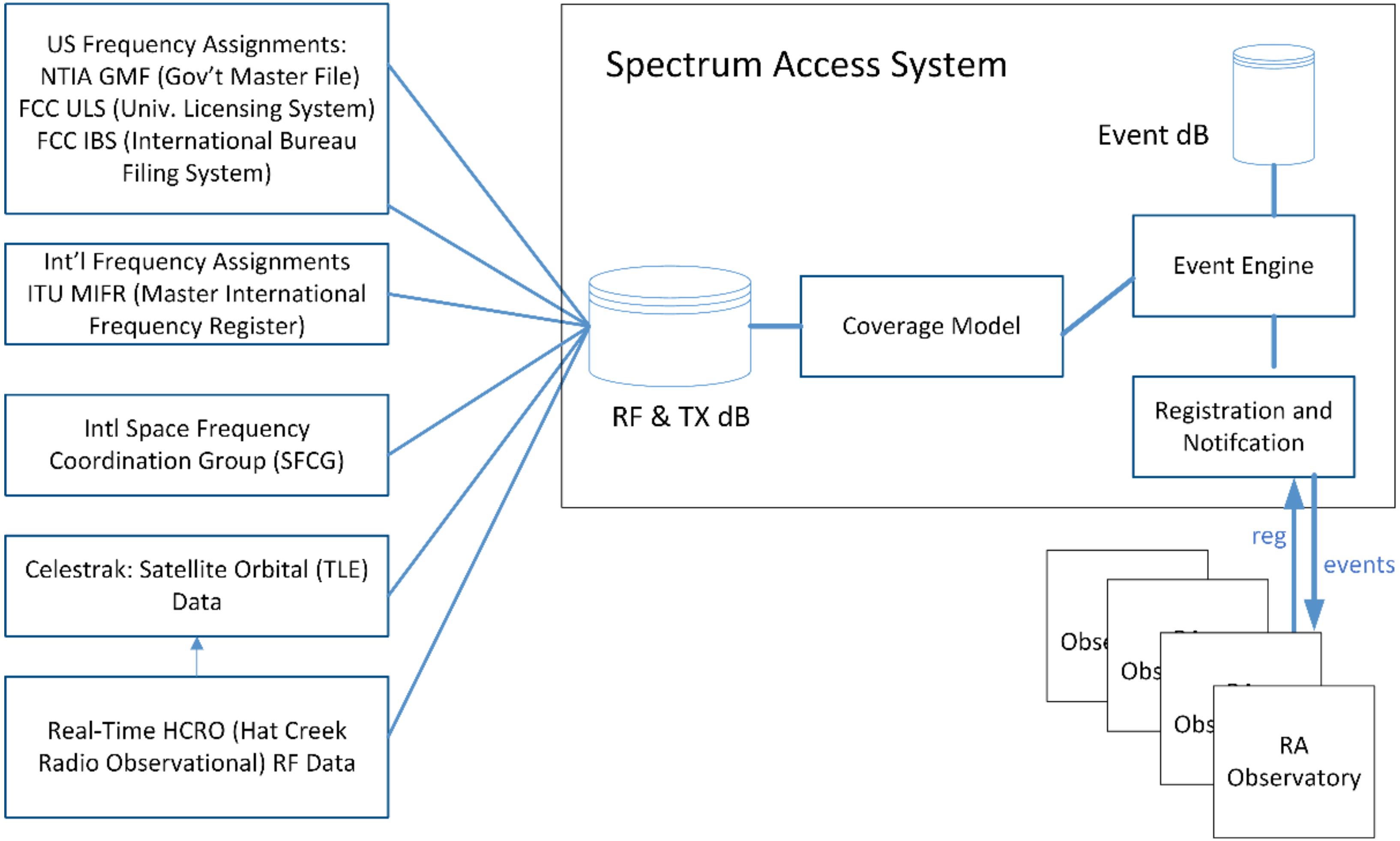


Currently deployed CBRS (3.55-3.7 GHz) Spectrum Access System architecture



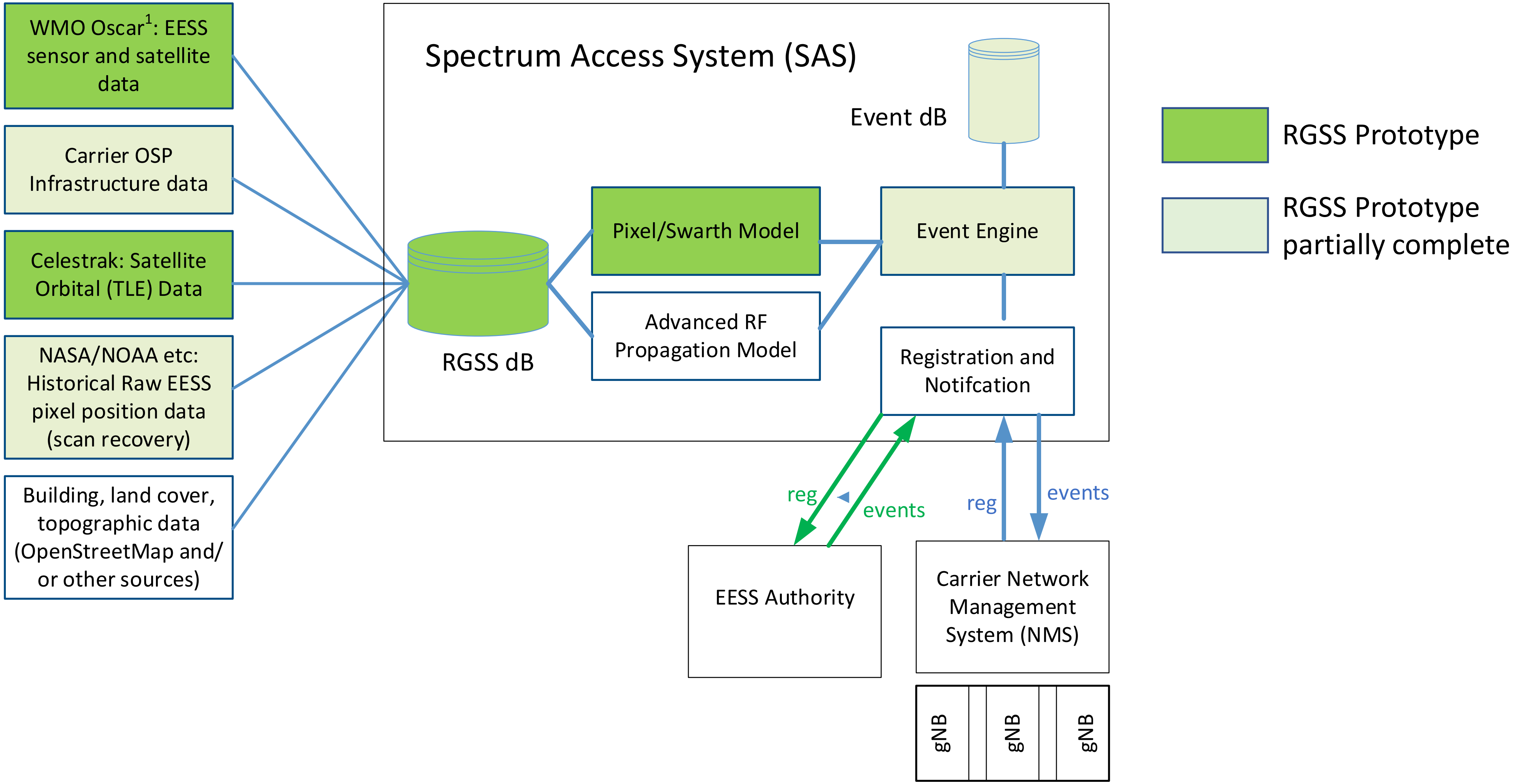
Potential Spectrum Access System architecture extended to mm-wave and submm-wave frequencies

CBRS: Protect Radio Astronomy Observations



Enable frequency and location specific geo-fencing: RA location and instrument data is combined with satellite position + RF communication band & transmission characteristics to project time window events when satellite transmissions will interfere with observations at specific RA observatories.

CBRS SAS: Protecting EESS passive measurements



Enable frequency and pixel specific geo-fencing: 5G/6G deployed network infrastructure data is combined with EESS sensor data and satellite position data to project time event windows when 5G/6G network transmissions will impact EESS measurements.

[1] incomplete data in Oscar supplemented by external sources

Comments & Concerns from colleagues[1]:

		EESS Perspective	Network Perspective	
		NOAA/NASA (EESS)	Carriers (VzW) & Vendors	Wireless Innovation Forum
Technically Viable		√	√	√
RF Propegation Model		concerns over accuracy [2]	-	-
Usefulness:	Identify Bad Pixels	√ requires test validation	-	-
	Pause or Reduce P_{TX}	√ requires test validation	√ potential for increasing coverage & performance	√ could improve spectrum availability
Architecture: SAS (CBRS)		-	-	√
Adoption:	carriers	carriers will not adopt	possible but EESS community will never adopt	-
	NTIA/FCC	-	-	√ FCC could adopt [3]
	other	if adopted, would carriers would use as a shield ?	-	-

1. **Not institutional feedback**, comments from colleagues at: NOAA/NASA (EESS eng group), carriers, equipment vendors, & the WInnForum.

2. The proposed RF propagation model is an improvement over the ITU model that is used to set emission standards.
   - Actual network deployments and Tx hardware used rather than Monte Carlo simulation of a potential network based on many assumptions. RF Propagation Model can be Tested!
   - Incorporation of network elements (Access and IAB Repeaters, 3GPP power class 1 UEs) not considered by ITU
   - Topology and Buildings incorporated in likely hotspots.

3. The FCC could allow carriers/vendors to adopt an RGSS type solution in lieu of the ITU's recommendations (presumably with the understanding that interference with sounders would always be below the ITU emission recommendations). This would enable better coverage and economics for rural and suburban 5G deployments.

Summary:

- Temporal/Geospatial Spectrum Sharing: identify bad pixels, pause/move traffic to alt band, or reduce Tx and/or move limited traffic so that $P_r^{5G} < P_r^{sounder}$

- Potential Advantages:
  - Cheap: software solution $O\{\$M\}$ vs hardware solutions $O\{\$10M - \$100M\}$.
  - Flexible: Fast to develop and adopt to changes (software: internet time vs hardware: PSTN time).
  - Leverage: Use existing (CBRS) spectrum sharing system assets, methodology, & cooperation paradigm.
  - Protects EESS assets: Enables better protection from interference for EESS than the protection codified in existing ITU recommendations.
  - Improves 5G networks: Enables 5G/6G networks with better performance and coverage than allowable under existing ITU recommendations. Supports rural and suburban deployments currently.

- Hills to Climb:
  - System development, *testing and validation* (including an advanced RF propagation model).
  - Adoption requires access to carrier network infrastructure data.
  - Identifying bad pixels does not require 5G network integration. Pause/move traffic to alt band, or reduce Tx and/or move limited traffic so that $P_r^{5G} < P_r^{sounder}$ requires 5G network (e.g. O-RAN) integration.

E. Eichen, "Performance of Real-Time Geospatial Spectrum Sharing (RGSS) between 5G Communication Networks and Earth Exploration Satellite Services," *2021 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*, 2021, pp. 73-79, doi: 10.1109/DySPAN53946.2021.9677268.