NRDZ Partnership and Workshop Series

NRDZ Workshop-01: Passive/Active communities working together: Understanding each other's needs, concerns, and capabilities

Held virtually on 17-March-2021
http://www.cs.albany.edu/nrdz-ra/meetings/workshop1/
Workshop organizers:

- Christopher R. Anderson, Electrical and Computer Engineering, USNA.
- Mariya Zheleva, Computer Science, University at Albany - SUNY.
- Kevin Gifford, Computer Science, University of Colorado Boulder.
- Eloise Morris, Computer Science, University of Colorado Boulder.

I. Opening remarks from Dr. Ashley VanderLey, NSF, Division of Astronomical Sciences

- Emphasized that the NSF is considering spectrum across all Programs and disciplines (e.g., Spectrum Innovation Initiative, SII)
- Noted that scientists use the entire spectrum, have obligation to site R.A. facilities at geographically isolated locations
- Highlighted ITU-R RA.769-2 document which specifies passive user RF protected bands
  - Any efforts to reduce transmissions towards Radio Astronomy (RA) sites are still helpful to avoid saturation at the receiver such that other RFI excision techniques may be employed (e.g., reduction of transmit power, highly directional beamforming)
- There are improvements in RA capabilities: increased receiver/system sensitivity and bandwidth; leads to new opportunities
- Interference is now more pervasive: increase in wireless devices (mobile and stationary)
- Utilize the NRDZ concept to foster research focusing on methodologies to enable coexistence across the broader RF user community
  - The NSF seeks to establish/carve out special NRDZ zones
  - Consider mechanisms to address satellite and HAPS interference as well as terrestrial surface emitter interference
  - There is increasing RFI (spectrum congestion) everywhere
  - Astronomers commonly excise known interference bands
  - RA senses outside of protected bands to compensate for Doppler shift
    - RA, while allocated less than 2% of the spectrum below 3 GHz, utilizes all of the spectrum

    - Astronomy observations also include *continuum* emissions across wide frequency bands
- Highlighted that geolocations only help to a certain point
    - Consider, e.g., wearables, moving devices, satellites, HAPS
- Future strategies
    - Keep protected allocations as RFI-free as possible
    - Utilize technology developments and advancements to increase spectrum availability, especially in strategic geographic locations
    - Coordination with academia and industry for innovative solutions
- Challenges are different for Earth Observing Satellites (EOS)
- NSF is working with NTIA and the FCC on the NRDZ formal concept

II. Fireside Chat: "First Do No Harm, now how do we exist together?"

Moderator: Dr. Keith Gremban, DoD

Participants: Dr. David DeBoer (University of California, Berkeley)
Dr. Andrew Clegg (Google)

- The current spectrum challenges are well-established, and the US faces a need for spectrum to support science, the economy, and national security. The country needs both increased access to spectrum as well as increased efficiency in how spectrum is utilized.

- Dr. David DeBoer topical overview
    - Doesn't like the word passive users (don't step on other users)
    - Epoch re-ionization detection project (South Africa)
    - Need to keep the full picture in mind and remember Electromagnetic Co-existence (EMC) within and between services
    - Policy and management issues: *Radio Frequencies: Policy and Management,* DeBoer et al, IEEE Transactions on Geoscience and Remote Sensing, Vol. 51, No. 10, October 2013. High-level overview for RF passive services
    - EOS: Understand the planet we are living on (atmosphere, weather, moisture, sea ice, sea levels, etc.)
    - The Wi-Fi concept evolved from RAS
    - EESS cannot "hide" from ground-based interference in the way that Radio Astronomy Services (RAS) observatories can
    - Conversely, RAS observatories cannot "hide" from satellite-based interference, e.g., Starlink
    - Concept of "Olbers' Paradox" in reverse: If we aren't careful, every frequency and line-of-site will end in a cacophony of noise that renders the bands unusable for passive services (RAS/EESS as the canary in the coal mine)
    - RAS/EESS Receiver Sensitivity:

                - Very low-noise, long integration times, bandwidth as appropriate
                    - A Wi-Fi device on Mars would be easily detectable by RA
                - EESS: Looks everywhere, *timing and coordination is possible*
                - RAS: Location is paramount, have some protected frequency band allocations, but observe across the RF spectrum for science, *timing and coordination is possible*
                - Technology improvements will assist (filters, bits, real-time)

        - Coordination is hard, utilize an NRDZ to experiment with spectrum sharing for the benefit of EESS and RAS
        - RAS would even benefit from a NRQZ/NRDZ on the far side of the Moon

- Dr. Andrew Clegg topical overview
    - Opportunistic access for bi-directional spectrum sharing between passive and active systems that benefit both communities
    - Commercial spectrum sharing frameworks success in the last two years:
        - 3.5 GHz Citizen's Broadband Radio service, CBRS
            - Fixed-satellite service, DoD Navy radars, commercial broadband
            - Protect the incumbent services when incumbent in-band
                - In 18 months of commercial operation, not one case of interference from CBRS to the incumbents
            - Coordinated by a Spectrum Access System (SAS)
                - Also protects NRQZ, PRCZ, Table Mountain (Boulder) NRQZ passive and scientific services
        - 6 GHz Automated Frequency Coordination (AFC)
            - Potentially millions of unlicensed access points sharing the 6 GHz band with ~100,000 fixed service stations (point-to-point microwave) and radio astronomy on a non-interference basis
        - Both CBRS and AFC utilize affirmative control of underlay services
    - Radio astronomers do not always "stay in their lane (protected bands)"
        - Interference from satellite downlinks, cellular bands, especially in locations that are near any populated locations
        - How often to RA observe in a protected band and how often outside of the protected bands?
        - Basis: Green Bank Telescope, in a NRQZ, 2003-2011, 1-MHz bins
        - Able to more easily observe outside of RA protected bands in an NRQZ
        - Bands below 50 GHz results:
            - ~19% of the time, an observation was entirely within an RA allocation
            - ~37% of the time, an observation made partial use of a RA allocation
            - ~81% of the time, an observation is at least partially outside of a RA allocation

        - ~44% of the time, an observation was completely outside of a RA allocation
        - Conclusion: There is significant demand for RA observations outside of RA allocations
  - Could spectrum sharing systems (e.g., such as a SAS, AFC) enable broader access to active bands by passive services, outside of Quiet Zones?
  - Could the systems enable active use of passive bands when/where possible?
    - Even the most popular RA allocation is used only ~10% of the time
    - Is coordination with other passive systems (e.g., EESS) feasible?
    - Could passive services be compensated for providing opportunistic access?
  - Could an NRDZ be utilized to experiment?

- Fireside Chat participants (David DeBoer, Andrew Clegg) moderated discussion

  - **Q1**: What could be the benefits to both passive and active users for an NRDZ; what incentives would encourage passive users to participate in an NRDZ?
    - Clegg: Need consensus interference protection criteria (IPC) (e.g., ITU-R parties) instead of <u>self-serving overly conservative IPC</u>.
      - A controlled environment to prove out IPC for passive RA services
      - Need improved RF propagation models; in general in a horrible state; ITM model was written in the 1960s, based on empirical data gathered in the 1950s; ITM does not include terrain clutter, buildings, etc. Google developing RF propagation models based upon their GIS/geospatial data which also applies AI/ML to propagation prediction with very good results (1 dB median, 8 dB RMS)
    - DeBoer:
      - RA scientists are very good at excising interference from observations; though the post-processing takes considerable time (e.g., several months)
      - As digital processing improves, more RFI excision can be accomplished (wide band front-ends and back-end processing)
      - RA recognizes necessity for spectrum sharing in the future; utilize an NRDZ to experiment with wide stakeholder participation

  - **Q2**: Are there lessons learned from previous spectrum sharing efforts (DoD AWS-3, 3-Tier CBRS, 6 6Hz AFC, Incumbent Informed Capability (IIC)) or is there something more that is needed?
    - DeBoer: RA not currently aware of these efforts (NRDZ needs to properly engage the relevant stakeholders); current spectrum sharing methodologies are very specific to the different RF bands

        - Strategies and methodologies to prevent RA receiver saturation (need to account for aggregate interference including sidelobe interference prediction)
        - Identify an area to trial NRDZ concepts
    - Clegg: With the Google SAS there are practical challenges to address that could be explored in an NRDZ:
        - Vast area (e.g., state of New Mexico); a grand scale testbed playground to experiment and prototype advanced concepts without worrying about excess interference to evaluate bi-directional sharing between active and passive systems without harmful interference taking passive systems (receiver saturation) off-line
        - CBRS SAS enables spectrum sharing, including enforcing national Quiet Zone regulations, in an automated system
            - Need to integrate the manual policy/regulations process to support Quiet Zone stakeholders as a capability of the **automated** system; this is a challenge to be addressed

- **Q3**: What is the right size for an experimental NRDZ?
    - Clegg: A large (e.g., New Mexico) sized NRDZ could be necessary as the current RF models, i.e., ITM: predict consistent tropospheric-scatter interference
        - Many spectrum sharing scenarios are driven by predicted long-range RF interference from the ITM model
        - ITM model of persistent tropospheric scattering interference is an issue; need to prove out the long-distance interference statistics in a large area or need multiple areas that are separated by large distances
    - DeBoer:
        - Take advantage or geolocation terrain shielding to optimize NRDZ size; take advantage of NRDZ location topology and provide ample buffer/margin
        - Large NRDZ size has advantages over smaller zones
        - Even ITU-R RA-769 states RA not protected all of the time

- **Q4**: Are there opportunities (in/with an NRDZ) to provide inputs to regulators?
    - Clegg: FCC enforcement bureau is very resource constrained
        - Needs to be a more concerted effort to classify (harmful) interference
        - NRDZ experimentation could inform policy regarding tracking down and dealing with interfering emitters
    - DeBoer:
        - Three-legged stool analogy to important NRDZ research concepts: Technology, Policy, Enforcement

- **Q5**: Could an NRDZ provide the opportunity for a clear demonstration of aggregate interference impacts to passive RF users?
  - DeBoer: Critical to measure/characterize aggregate interference
    - Will be easier to get a NRDZ as compared to a Quiet Zone
  - Clegg:
    - CBRS takes aggregate interference into account; complicates the spectrum sharing system because requires inter-SAS communication and coordination (is a one-off business relationship between the multiple SAS vendors)
    - 6 GHz AFC does not take aggregate interference into account

- **Q6**: Could one concept for an NRDZ be that it is an automated National Radio Quiet Zone, NRQZ?
  - DeBoer: A NRQZ has certain levels of protection (a policy distinction); this could be a model to evolve towards as a goal for a fully automated NRDZ
    - Will be easier to get a NRDZ as compared to a Quiet Zone
    - A subtle, perceptive, question
  - Clegg: This is one of the benefits of bi-directional spectrum sharing
    - Passive services could provide opportunistic access to active services
    - Moves the concept of a quiet zone goes from a regulatory concept to a software construct
    - Opportunity for the passive users to coordinate with the active users and potentially “horse-trade” for spectrum sharing that is mutually beneficial; implement a Quiet Zone via software automation and experiment with stakeholder inputs, requirements, and coordination for results and feedback for system evolution; Use an NRDZ to experiment and test sharing scenarios so can get real-world answers

- **Q7**: Does a NRDZ have more of a scheduling concept involved?
  - Clegg: CBRS has implemented a scheduling capability as well as spectrum sharing allocation between user classes
    - Simplified Incumbent Informing Capability (IIC) (Built on top of Google calendar)
    - Load in observing schedules of the VLA, GBT, HCRO and protect on demand
  - DeBoer: Would be attractive capability for RA users

- **Q8**: In an NRDZ spectrum sharing systems is compatibility with a CBRS SAS, AFC or IIC a concern? Is CBRS a model for how we could potentially manage an NRDZ?

    - Clegg: The CBRS SAS architecture could support the integration of passive users into the sharing system
        - The satellite (EOS) remote sensing systems are the most challenging (but is doable)
    - DeBoer: Perhaps an NRDZ will advance spectrum sharing to evolve beyond today's current systems

- **Q9**: Any recommendations for documented interference scenarios that the community could build off of?
    - DeBoer: Involve researchers in the RA community that are examining this issue; there is a lot that can be done in this area to assist RA
    - Clegg: Nothing to add to David's response

III. NRDZ Workshop Panel Summary

Moderator: Eloise Morris

Panelists: Steven C. Reising, Josep Jornet, Michael Marcus, Charles Powell, Dennis Roberson, Frank Lind

Steven C. Reising, Electrical and Computer Engineering, Colorado State University

- Passive microwave sensors are on orbiting satellites and available globally, extremely important to accurate weather forecasting.
- Use small satellite constellations to augment polar orbiting weather observation satellites; many of these expected to be launched in the future.
- Frequencies from ~90-180 GHz.

Josep Jornet, Electrical and Computer Engineering, Northeastern University

- Wireless communications industry is continuing to grow; more devices connected with each device demanding a faster connection. How do we enable a 1 Tbps link?
- Where are we going to find the bandwidth necessary to enable 6G communications?
- Can we share some of the passive community some of the time to get large (30+ GHz) contiguous bandwidths?

Michael Marcus, Marcus Spectrum Solutions LLC

- In 2000, most of the passive bands above 100 GHz were allocated with an additional regulation of "all emissions are prohibited".
- Below 100 GHz, it makes sense to prohibit emissions in those bands because sharing (in general) is very, very difficult.

- The prohibition on sharing is not a “permanent truth”, the rules contain interference limits that must be met in any sharing scenario.
- In the long term both terrestrial and satellite users need to establish a dialogue that allows each to perform their desired functionality without degradation in performance.
- Mutual respect and communication between the communities is needed to make sharing above 100 GHz happen.

Charles Powell, Climate and Space Science Engineering, University of Michigan
- Earth Science sensors involve both passive and active sensing as well as communications links between assets.
- Passive earth science sensors are extremely sensitive with high susceptibility to RFI. To increase forecast accuracy, you need to increase the accuracy/fidelity of the input data.
- We can’t move the sensing lines (the water vapor or oxygen absorption lines are where they are and we need to be able to measure there).
- Advantage of an NRDZ is an opportunity to quantify/characterize RFI and net harm from out of band and in-band emissions.

Dennis Roberson, Roberson and Associates, LLC
- Reminder – spectrum is a scarce natural resource, but we are dealing with great spectrum demand.
- Broadband has become a necessity of modern life – we are dependent on broadband to conduct all aspects of our life.
- Machines talking to machines is the future driver of demand and putting huge pressure on the needs of the spectrum.
- History of geographic, temporal, and frequency-based spectrum systems, need to evolve that to an idea of dynamic and heterogeneous spectrum sharing.
- Need to be able to establish an architecture where everyone can share all of the bands all of the time; no need for dedicated areas, dedicated times, or dedicated bands.

Frank Lind, MIT Haystack Observatory
- Need to control energy in the frequency band one is operating in as well as where that energy is directed in space.
- Most radio astronomy observatories are built in really remote locations precisely to avoid RFI, but this comes with a significant economic cost.
- With increasing satellite communications, we are running out of true radio quiet zones.
- Next generation instruments have extremely wide bandwidths which will be a challenge to mitigate RFI (narrowband techniques no longer work).
- Spurious components, harmonics, antenna sidelobes, out-of-band emissions all cause RFI problems for radio astronomy receivers.

Panel Questions

1. A NRDZ could potentially benefit Radio Astronomy/Passive Users just as much as active users. What thoughts do the RA community have about this prospect?
    a. Easiest way to create a low RFI environment (improve dynamic range) is to simply turn everything off. That is possible inside an NRDZ with space-time adaptive tasking (at least at the 1 sec level, potentially down to 1 msec level).
    b. Doesn't necessarily help for continuous observing stations. Could be of value to finding transients.
    c. How can we create an environment that allows us to evolve towards a more wide-ranging sharing regime?
    d. Can we create a CBRS/SAS type system that works for all spectrum, all time, and all geography?
    e. Don't forget that some users will be in orbit – figuring out exactly where they are and what they are looking at is a challenging problem to solve.
    f. Why is it difficult to get authorization to operate even limited intermittent experimental systems above 100 GHz?

Audience Questions and Answers

2. How do public safety and first responders fit into this vision of spectrum sharing?
    a. If you share on a very small time scale (everything is in packets anyway), you can dedicate specific packets/instances in time to public safety systems.
    b. SAS systems are designed to handle priority interrupts; when a priority user comes in, they can quickly get access to the spectrum in near real-time.

3. Why not move NRQZ to Space?
    c. It adds an order of magnitude cost to the price of an observatory.
    d. Development costs and maintenance costs are huge.
    e. Future of radio astronomy is probably in space, but the resources to do that (e.g., James Webb Observatory) are just not there.
    f. What happens when the infrastructure goes down for some reason? No way to quickly handle maintenance.
    g. What happens when active users (tens of thousands) start malfunctioning and interfering with passive users and there's no good way to turn them off or repair them?
    h. Could we have an "emissions inspection" for radios to ensure they're operating per their approved parameters?
    i. Optical astronomers got very worried very late about light pollution, we don't want the same thing to happen to radio astronomy.

IV. Breakout Rooms

Breakout Session 1: Radio Astronomy and Terrestrial Mobile Broadband

Overview. In this breakout session, the challenges and potential benefits of establishing a National Radio Dynamic Zone were discussed in light of coexistence issues with radio astronomy and mobile communications. Christopher De Pree, from Agnes Scott College, facilitated the session and represented the perspective of stakeholders in the radio astronomy community. An overview of the topics discussed is provided below.

Topics discussed.

What degrees of freedom (DoFs) should be explored for coexistence

- Given that spectrum can be shared in time, space and over frequency ranges, what are the most promising degrees of freedom to explore?
    - Historically, we have been implementing frequency diversity. There is a certain ability to have spatial diversity but there are concerns about how to adapt to this new implementation. Also, a question was raised about giving away degrees of freedom -- all three DoFs should be explored and scheduled and prioritized according to the case.
    - Suggestion that ***CBRS*** is a good beginning to give passive systems what they want and need. Satellites (transmission) would have to be scheduled and would only transmit at a certain time. Don't worry about space and allocation of spectrum and focus on time (which is the one that we have least focussed on). A need to shift to time as being the dominated DoF for sharing.
    - Discussion about potentially merging services such as radar, navigation, and communication in such a way that the utility goes up for everyone but maybe the particular bands they are operating on are not expanding. This can promote scheduling problems with an outlook towards preserving the privacy of some of the coexisting technologies.
    - There were concerns that many users may not have the resources to adapt to a new implementation (structure) and as a result they may become extinct.
    - Potential for radio astronomy in space to avoid RFI on Earth, especially in the lower frequency bands, which are substantially polluted.
    - Traditionally, observatories do not share scheduling information, but if it could be shared more broadly, this may provide a framework for cooperation.
    - Discussion about the ***Indian Radio Telescope*** and issues of scheduling. Critical observations are being scheduled when mobile use is low, which is in the middle of the night. Critical observations are restricted to this time frame.

Principles for data sharing

- What policies regarding spectrum data sharing should be implemented to promote coexistence? What specific information will need to be exchanged in order to facilitate

cooperation? How should these policies account for spectrum coexistence across international borders?
    - The success of coexistence depends on the willingness of different technologies to share data. How to create incentives for disparate users to share data to support coexistence?
    - In addition, what approaches can be used to ensure that the data is trustworthy and complete (e.g. that a set of reported occupied frequencies are really all the frequencies being used)?
    - Create a framework under the assumption that users will behave legally but also consider ways that rules can be broken by malicious users. Have a database of all frequencies and who is operating on what frequency. Set a vision and work towards it.
    - Some necessary information, such as schedules of passive observations, are not centrally recorded now. Even if such a centralized database existed, there would have to be a behavioral change propagated within the community to ensure that data is being recorded.

Data "cleaning" for passive applications

- Are there approaches for scientific data "cleaning" that will allow active transmissions to be removed from the scientific data, so that both scientific observations and active transmissions can happen concurrently?
    - The state-of-the-art is "flag-and-remove": any snippets that are flagged with RFI are removed from the data.
    - Active cancellation is challenging due to signal digitization and time delay issues. In addition, it would require actively-transmitting technologies to share what is being transmitted, which brings up questions around incentives for providers to supply this data and privacy issues this might raise. Who will pay for such data sharing?

Raising public awareness of the impact of mega-constellations on scientific users

- How to enable scientific users of the spectrum, who may not have the necessary capabilities, to raise awareness about the RFI caused by emerging technologies (such as mega-constellation-based Internet access)?

Breakout Session 2: Earth-Observing Satellites

Overview. In this breakout session, the challenges and potential benefits of establishing a National Radio Dynamic Zone were discussed with the perspective of researchers using earth-observing satellites in mind. Charles Powell, a Ph.D. candidate in Climate and Space Sciences and Engineering at the University of Michigan, facilitated the session and represented the perspective of stakeholders in the EOS community. An overview of the topics discussed is provided below.

Topics discussed.

Building Trust

- If there is a technical mechanism for sharing spectrum that has a chance of working, how do we build trust in this mechanism?
    - There is a lot of passive sensing that occurs outside of protected bands. Proving the ability to protect passive sensing in these bands so that interference is not seen during overpass would be a good proof of concept that passive users could also be protected within their allocated bands if they were to open up to sharing. Interference mitigation can start where there is interference in these unprotected bands to build trust.
    - Knowing who is transmitting at any given time is critical for attribution and having this information available will also build trust.
    - There is a need to see this as a cooperative issue with information shared between all parties—unidirectional interference mitigation is important, but won't be a game-changer
    - An NRDZ could work like an NRQZ with sensors on the ground so individual sources of interference could be isolated as point sources within an EOS beam.
    - There needs to be trust that the information that is received about transmitters on the ground is accurate and complete.
    - Innovative licensing and regulatory regimes can be tested in an NRDZ.

Size of NRDZ

- How small of a ground spot can sensors on earth-observing satellites resolve?
    - The size depends on the technology and varies greatly between satellites
    - Mr. Powell works mainly in the L-band with satellites that have a beamwidth of approximately 50x50 km
    - There is some amount of beam smearing that must be accounted for, but the necessary size of an NRDZ to be useful to EOS is a smaller area than mentioned by other NRDZ stakeholders.
    - ~100x75 km along the satellite track should be sufficient to provide the data needed for identifying interference from ground transmissions seen in satellite measurements

Identifying Radio Frequency Interference in EOS Observations

- RFI identification is largely done through statistical processes: if it looks statistically like thermal noise should, there is an assumption that there is no RFI present. Any deviation from this statistical base is seen as evidence of RFI. These kurtosis-based mechanisms work well if there is a high enough power level and if the transmission is abnormal enough to be detected, but sometimes there is interference that looks close to normal and is difficult to detect this way.
- It takes several months of data to build historical records to compare against potential interference.

- There is a resource allocation aspect to the problem of mitigating interference. Having access to data on interferers is great, but often there is a lack of manpower to make changes to the observation code to account for this information.
- Earth-observing satellites are not as sensitive as radio astronomy but have shorter integration times.
- RFI can often not be detected until compared to climatology. This is especially true for large-scale changes over time, which tend to be subtle.
- Not all RFI is the same, but there are general classes of RFI. Stationary point sources are the easiest to detect, but other sources can be complicated or nearly impossible to determine.
- Not a lot of funding for RFI mitigation (though the SWIFT program has been generous in this area).

Ground Truthing Radio Frequency Interference

- Some government entities ground truth RFI for licensing requirements, but most passive EOS users do not currently ground truth for RFI.
- Controlled RFI: inserting controlled RFI into a measurement could be useful to researchers. This allows them to know what is emitted in a region and to correlate between what the beam picks up and what is known to be there. This can create trust in the dataset for ground truthing.

<u>Breakout Session 3: Passive weather sensing and THz communications</u>

Overview. In this breakout session, the challenges and potential benefits of establishing a National Radio Dynamic Zone were discussed in light of coexistence issues between passive weather sensing and emerging terahertz communications. Josep Jornet from Northeastern University and Steven Reising from Colorado State University facilitated the session and represented the THz communications and the weather sensing community, respectively. An overview of the topics discussed is provided below.

Topics discussed.

Degrees of freedom for spectrum sharing

- How can we use time, frequency and space to share spectrum across passive weather sensing and active communications?
  - Atmospheric features cannot be moved - if weather monitoring requires observation of a particular frequency, there may not be artificial means of avoiding this need for spectrum. Thus, frequency ranges cannot be explored as a degree of freedom.
  - Spectrum occupancy prediction will be necessary. Improved propagation modeling should assist users with modeling accurate spectrum usage, which will result in accurate synchronization.
  - How to regulate/coordinate? Licenses, database, manual coordination, etc.

- If sharing was to happen, how can the sharing framework ensure that earth observation services are being protected?

Temporal granularity for sensing

- This topic was discussed under a hypothetical scenario where passive observation services were given a fixed perioding time slot to sense the spectrum (e.g. once every 30ms). Will this be feasible?
    - Weather services require near-continuous sensing. Satellite-borne sensing instruments move at a high speed passing over entire metropolitan areas within 30ms. How to decide which areas to skip? Thus, the feasibility of such an approach might be limited.

Sharing satellite infrastructure for passive sensing and active communications

- Can telecom stakeholders pay weather satellites to share infrastructure on a TDMA basis?
    - Telecom industry is developing technology that can process messages that last ~100 nanoseconds, so sharing at very fine granularity might be possible.
    - Passive applications' high-sensitivity receivers, if employed for active communications can further enable low-power and fast communications.
    - The intervals for sharing would have to be very short (possibly 1 ms intervals)

New frequency ranges and technologies for weather sensing

- What new higher bands will be used for weather sensing
    - Ice Cloud Imager in development, will measure particle size of ice in the atmosphere; high uncertainty from radar; using frequencies (atmos. windows) - will use 240 GHz, 325 GHz, 448 GHz, each one is a couple GHz wide
    - **CubeSat**: type of miniaturized satellite used for space research. First one launching in 2022, will use similar frequencies to what the US already uses. Higher sensitivity; sensitivity needed is a fraction of a Kelvin, requires some conversion. Limited in terms of duty cycle.
    - International synchronization of efforts.

Radio frequency interference (RFI)

- What does RFI look like on a weather satellite?
    - If THz wireless communications are short-lived (i.e. 100ns) will this impose RFI problems? Weather satellite measurements are performed every 5ms, but other aspects such as satellite speed, terrestrial footprint, observed feature (i.e. frequencies) etc. should be considered in devising the effects of interference. Meso-scale forecasting will require increasing the frequency of fly-over, so sharing frameworks should be flexible.
    - Interference and energy could be reduced by making very sensitive receivers available to everyone. Issues of high cost were raised.