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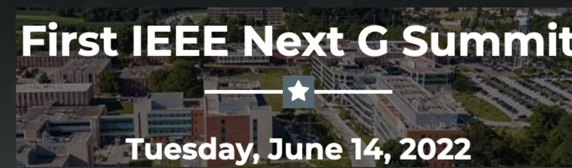

Spectrum Sharing Requirements to Enable Wide Bandwidths Above 100 GHz

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Spectrum policy impacts new technology and is just as real as Maxwell's Equations for implementers of innovative technology

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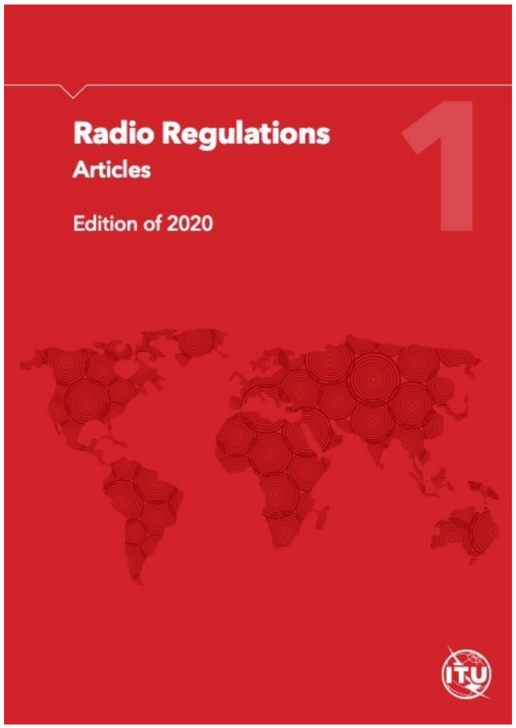

ITU Radio Regulations are generally a treaty obligation of 193 ITU member nations
https://www.itu.int/pub/R-REG-RR-2020

Both have large impact on designs

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

What is special about >100 GHz?

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- Spectrum above 100 GHz is the next frontier for wireless technology although it is very different than lower bands for several reasons:
  - Has the theoretical potential of contiguous bandwidths >10 GHz for high speed low latency fixed and mobile links - also unusual UWB-like short range sensing applications
    - **But also has unique complex issues of sharing with key passive uses**
  - Atmospheric absorption is a major factor in propagation - particularly at low elevation angles
  - Very small wavelengths permit complex antenna functions in moderate sizes and quasioptical antenna designs
    - But **all** finite sized antennas must have ***some*** sidelobes
    - Antenna designers can seek to move sidelobes to least harmful directions

Possible Active uses of >100 GHz

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- Fiber optic-like connectivity/latency
  - FO is generally less expensive in hardware cost, but depending on locations can have high installation costs and longer installation times
  - THz alternative may be advantageous for
    - Temporary installations
    - Emergency service restorations in disasters
    - Locations where FO installation is very time consuming or expensive
- Nondestructive testing applications involving "Terahertz Time-Domain Spectroscopy"

What is special about >100 GHz?

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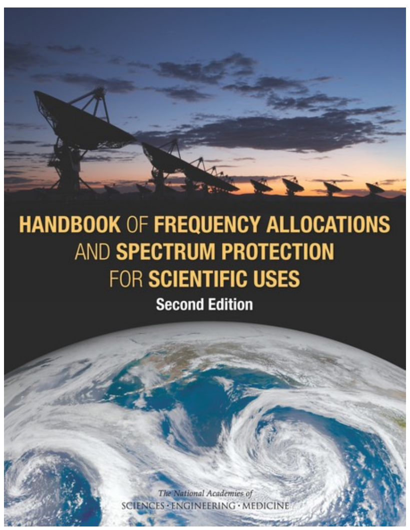
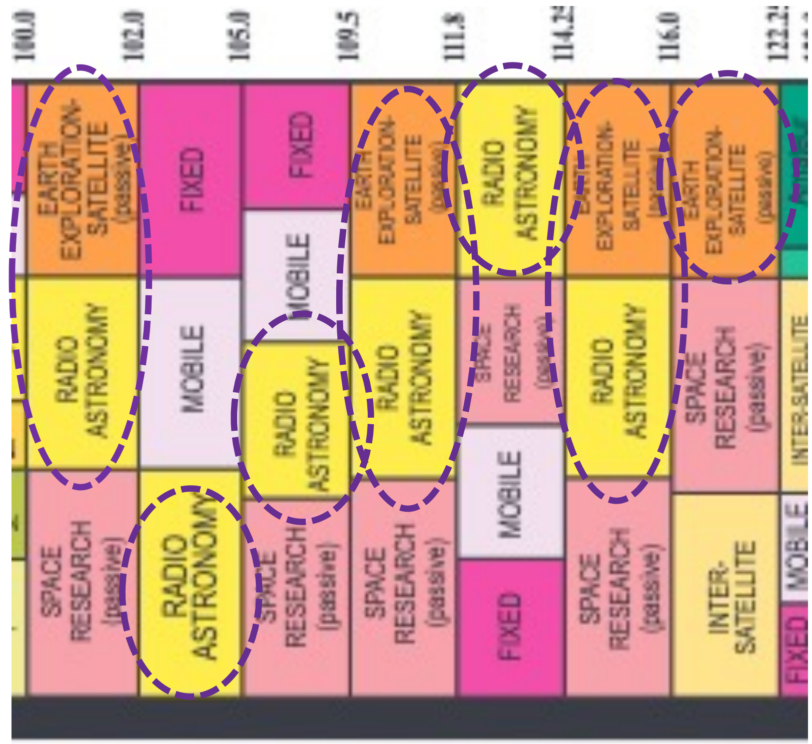
- Compared to lower bands, contains **a large number of** molecular resonances necessitating higher density of passive bands and a greater fraction of bandwidth needed for important passive applications such as environmental sensing and radio astronomy
  - Leads to unique spectrum sharing challenges
- Good reference on passive band issues:





https://www.nap.edu/catalog/21774/handbook-of-frequency-allocations-and-spectrum-protection-for-scientific-uses

Regulatory Issues

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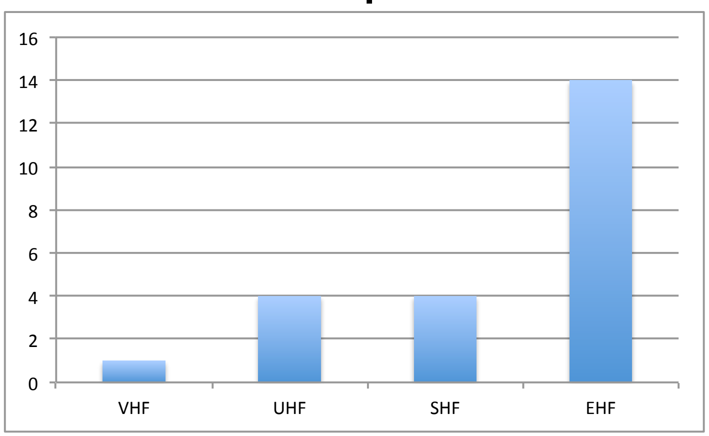
- ITU Rules contain 10 "prohibited bands" in 100-275 GHz
- Plus additional bands where passive services are co-primary but fielded and mobile uses are not allowed or are secondary

ITU Radio Regulations:

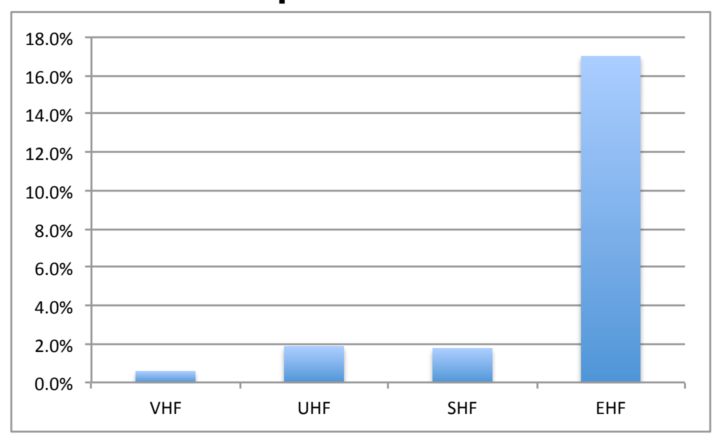
5.340 All emissions are prohibited in the following bands:

… 100-102 GHz, 109.5-111.8 GHz, 114.25-116 GHz, 148.5-151.5 GHz, 164-167 GHz, 182-185 GHz, 190-191.8 GHz, 200-209 GHz, 226-231.5 GHz, 250-252 GHz

Number of 5.340 passive bands



Fraction of spectrum in 5.340 bands



How did this come about?

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- For decades there are have radio astronomy and then passive satellite bands with various degrees of protection including some with 5.340-like total prohibitions
- Most of the passive bands above 100 GHz were created at ITU's WRC-2000 at the request of both USA and CEPT – the union of FCC-like agencies in Europe and Eastern Europe
- At that time both USA & CEPT were uncertain if sharing between passive services and active services might be possible under carefully controlled conditions due of the physics of this upper spectrum and **both** requested studies of future sharing potential
  - WRC-2000 adopted Res. 731 with terms for such studies
    - At WRC-19 this was amended with requests for additional sharing studies in 275-450 GHz
  - While little was done for 20 years such studies are now underway in ITU-R SG5 & SG7

Res. 731

https://www.itu.int/dms_pub/itu-r/oth/0C/0A/R0C0A00000F00149PDFE.pdf

- States that sharing with passive is a goal *if* technical means can be found
  - WRC-2000 version gives range as 71-275 GHz
  - 2019 update deals with 275-1000 GHz somewhat differently
- "Take into account the principles of burden-sharing to the extent practicable"
  - **Both** active and passive services should consider modifying their long term designs to facilitate sharing, *e.g.* antenna patterns
- Any *general* permission for sharing, outside terms of RR4.4, requires action by a World radio Conference – held every 4 years

RESOLUTION 731 (REV.WRC-19)

Consideration of sharing and adjacent-band compatibility between passive and active services above 71 GHz

The World Radiocommunication Conference (Sharm el-Sheikh, 2019),

considering

a) that the changes made to the Table of Frequency Allocations by WRC-2000 in frequency bands above 71 GHz were based on the requirements known at the time of that conference;

b) that the passive service spectrum requirements above 71 GHz are based on physical phenomena and therefore are well known, and are reflected in the changes made to the Table of Frequency Allocations by that conference;

c) that several frequency bands above 71 GHz are already used by the Earth exploration-satellite service (EESS) (passive) and space research service (passive) because they are unique bands for the measurement of specific atmospheric parameters;

d) that frequency bands in the frequency range 275-1 000 GHz are identified for use by administrations for passive service applications in No. **5.565**, without precluding the use of this frequency range by active service applications, and urging administrations to take all practicable steps to protect the passive service applications from harmful interference;

e) that there is currently only limited knowledge of requirements and implementation plans for the active services that will operate in frequency bands above 71 GHz;

f) that, in the past, technological developments have led to viable communication systems operating at increasingly higher frequencies, and that this can be expected to continue so as to make communication technology available in the future in the frequency bands above 71 GHz;

g) that, in the future, alternative spectrum needs for the active and passive services should be accommodated when the new technologies become available;

h) that, following the revisions to the Table of Frequency Allocations by WRC-2000, sharing studies may still be required for services in some frequency bands above 71 GHz;

i) that interference criteria for passive sensors have been developed and are given in Recommendation ITU-R RS.2017;

j) that protection criteria for radio astronomy have been developed and are given in Recommendations ITU-R RA.769 and ITU-R RA.1513 and Report ITU-R RA.2189;

k) that several satellite downlink allocations have been made in frequency bands adjacent to those allocated to the radio astronomy service;

l) that sharing criteria for active and passive services in frequency bands above 71 GHz have not yet been fully developed within the ITU Radiocommunication Sector (ITU-R),

Interference Criteria for Passive Satellites

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- Maximum interference level according to Rec. ITU-R RS.2017 for different frequency bands between 95 – 275 GHz and the lowest satellite at each band (space.oscar.wmo.int)

Frequency band [GHz]	Maximum Interference Level [dBW]	Scan mode [N, C, L]	Lowest Satellite Altitude [km]	
115.25 – 122.25	–166/–189	N, L	705	Aura (NASA)
148.5 – 151.5	–159/–189	N, L	705	Aqua (NASA)
155.5 – 158.5	–163	N, C	817	MetOp (EUMETSAT)
164 – 167	–163/–189	N, C, L	407	GPM Core Observatory (NASA/JAXA)
174.8 – 191.8	–163/–189	N, C, L	407	GPM Core Observatory (NASA/JAXA)
226 – 231.5	–160/–194	N, L	705	Aura (NASA)
235 – 238	–194	L	705	Aura (NASA)

- **N**: Nadir
- **L**: Limb
- **C**: Conical

“The Chart”: Show available bandwidths with and without sharing with passive service

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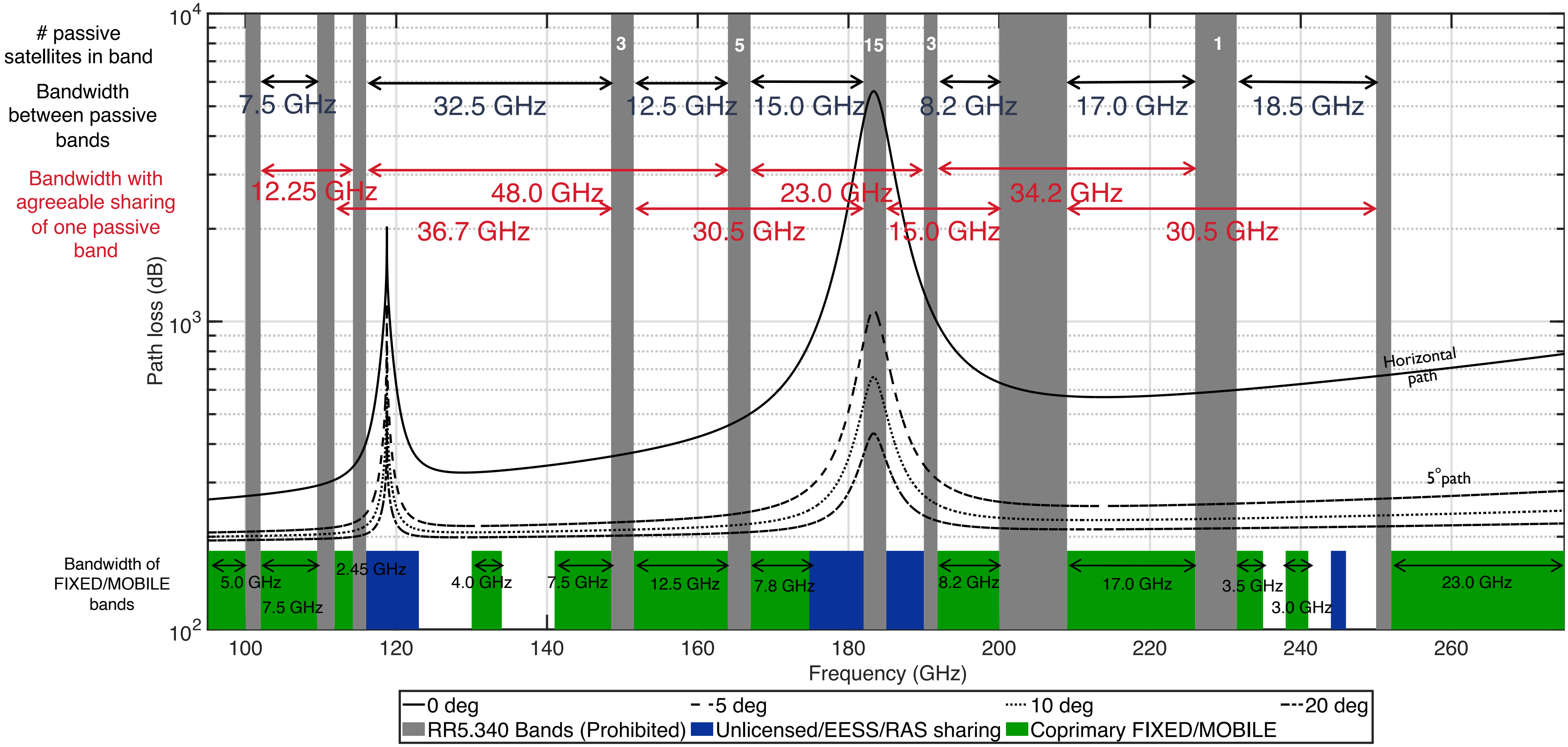

Terahertz Time-Domain Spectroscopy

https://en.wikipedia.org/wiki/Terahertz_time-domain_spectroscopy

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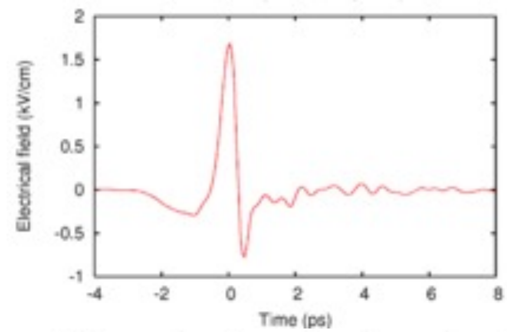
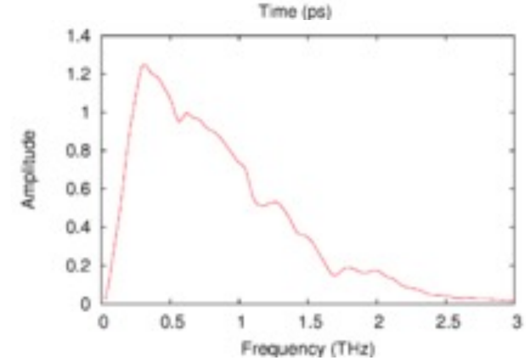
- Developed in the 1990 this short range (~1m) radar-like technology uses picosecond pulses to probe materials' composition
  - Used for safety-critical nondestructive testing in NASA Space Shuttle Program
  - Used in military testing of RAM on aircraft & ships
  - Used in manufacturing operations for real time quality control and process correction
- Continuous spectrum that spans 5.340 bands creates regulatory ambiguity and uncertainty for developers
  - But products are now manufactured in several countries





Possible sharing concepts for Fixed Service use

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- Greater than normal suppression of high elevation angle sidelobes
- Methods based on (Az, El) location of above horizon passive satellites
  - Mesh network with dynamic routing
  - Use orbit information to following satellite overhead path with a null formed by a MIMO-like antenna

Greater than normal suppression of high elevation angle sidelobes

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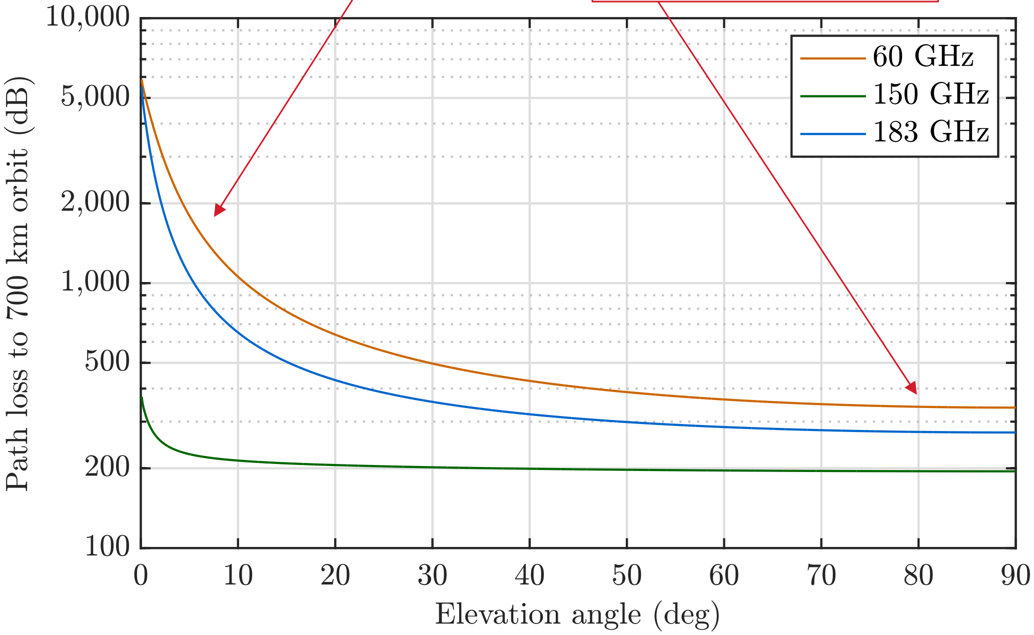
- Typical dish antennas have sidelobes in the -25 dBi range which is capable to exceeding RS.2019 protection levels at high elevation angles
  - Thus, main beam power is not an interference threat in general
- Higher than normal sidelobe suppression is needed at high elevation angles
  - Facilitated by small λ
  - Techniques are known in radar and radio astronomy literature

Atmosphere is essentially opaque at main beam low elevation angles typical in telecom

But similar to lower bands at high angles



Methods based on (Az, El) location of above horizon passive satellites

Null tracking

- While MIMO antenna are normally designed to maximize T->R throughput or SNR, their math permits more than 1 objective
  - Add a 2nd objective to be minimized, in this case the power at the (Az,El) of a passive satellite
  - "Track" the satellite with a null while it passes at high elevation angles

Methods based on (Az, El) location of above horizon passive satellites

Mesh network with dynamic routing

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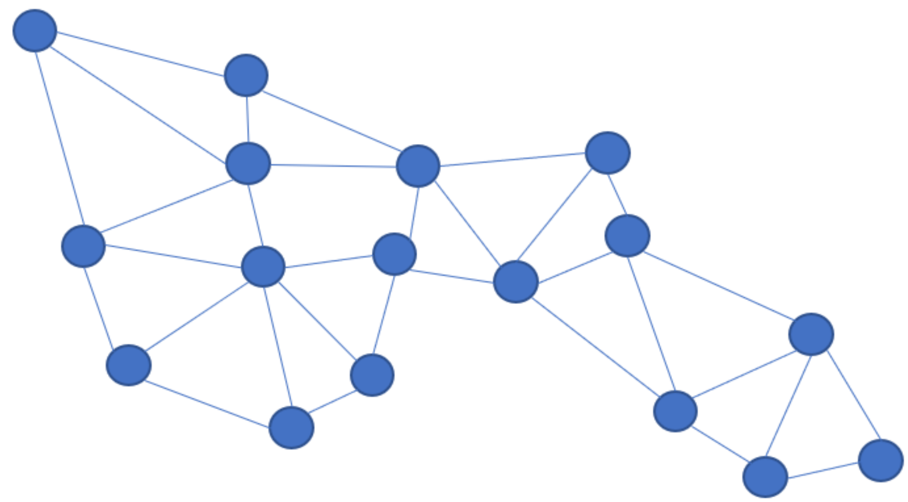
- NORAD TLE database gives orbit elements to predict (Az,El)
  - Unlike 5G MIMO, passive satellites do not have a signal to permit direct nulling
- Predict impact of antenna sidelobes from each possible path on passive satellite and pick routing that assures RS.2019 criteria is met as satellite passes overhead



Methods based on (Az, El) location of above horizon passive satellites – A possible issue

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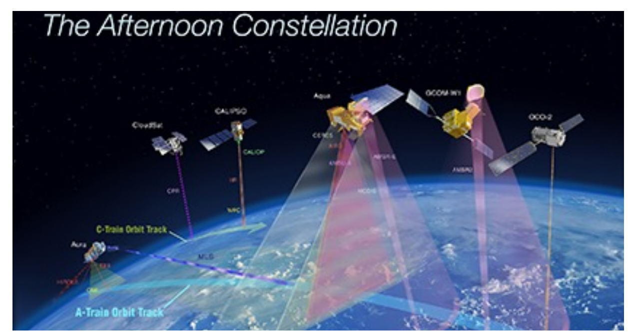
- There is presently no explicit limit of the number of passive satellites in a band that might be in view at a given location and time
  - What if it exceeds reasonable capabilities on these 2 approaches?
- Possible approach - Res. 731 states:

> *recognizing*
>
> that, to the extent practicable, the burden of sharing among active and passive services should be equitably distributed among the services to which allocations are made,

- "Equitably distributed" "burden of sharing" might include *either*
  - limits on passive satellite orbits to preclude more than *x* satellites visible at a time *or*
  - might require some to fly in groups "in formation"



https://atrain.nasa.gov/

How *you* can get involved in ITU-R deliberations on Res. 731 issues

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- **In USA** - contact chair of USWP's involved and ask to participate:
  - USWP5C (Fixed)
    - shaskins@ntia.gov
  - USWP5D (Mobile)
    - dante.ibarra@fcc.gov
  - USWP7C (Passive satellites)
    - david.franc@noaa.gov
  - USWP7D (Radio astronomy)
    - bevander@nsf.gov

- **Outside USA**
  - Ask your national spectrum regulator,

    or
  - Participate through a nongovernmental ITU-R member
    - https://www.itu.int/online/mm/scripts/gensel11?_memb=SAU&_sect=R

- In both cases participation gives one a password for current document drafts being considered on ITU website

Conclusions

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- The sharing of passive bands >100 GHz is a **high payoff difficult technical challenge**
  - Sharing is necessary to access more than 12.5 GHz contiguous spectrum
  - ITU rules clearly state sharing must meet specific cumulative protection levels at both passive satellites and radio astronomy facilities
  - Opening these bands to controlled sharing will enable new technology for spectrum-based alternatives to fiber optics in special circumstances where fiber is not viable due to installation issues/costs
  - Will also enable use of Terahertz time domain spectroscopy for nondestructive testing and enhancing manufacturing productivity
- Let's get the passive and active communities to cooperate with each other in good faith to pursue this challenge under the ITU's guidelines in Res. 731

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Thank you very much for your attention

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