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Non-geostationary satellite systems and networks

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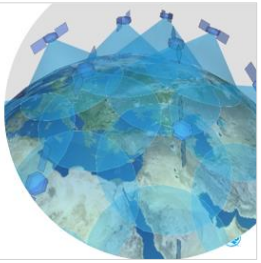
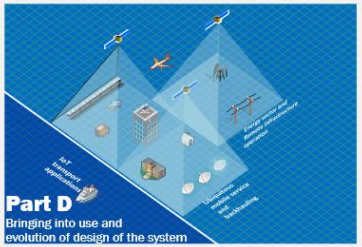
Part A
Overview of Non-GSO regulations

Part B
Short-duration mission regulations

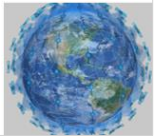
Part C
Coordination approach



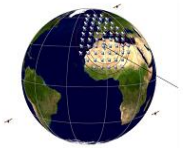


Part D
Bringing into use and evolution of design of the system

Part E
Non-GSO submission to ITU



Part F
EPFD concept



Part A

Overview of Non-GSO regulations

Non-GSO regulations

- **Coordination** – ensures protection of existing services on equitable access basis
  - Coordination between non-GSO and GSO in limited frequency bands
  - Coordination between non-GSO in limited frequency bands
- **Hard Limits** – Article 22 EPFD limits to protect GSO from non-GSO
- **Ultimate protection of GSO** – No. 22.2
  - Non-geostationary-satellite systems shall not cause unacceptable interference to and shall not claim protection from geostationary-satellite networks in the fixed-satellite service and the broadcasting-satellite service

Non-GSO applications and regulations

	API for short-duration mission	API	Coordination
Amateur satellite	✓	✓	
Science, Meteo, earth observation		✓	
Academia	✓	✓	
Global navigation			✓
End-user comms, data relay, IoT			✓

Part B

Short-duration mission regulations

SDM short-duration mission regulations

Conditions

- The maximum period of operation and validity is three years from the date of bringing into use, no suspension is possible
- Maximum number of satellites is 10
- Notification to be sent only after the launch of a satellite or first satellite
- No modification of characteristics of recorded assignments is possible
- ADM to provide commitment that if unacceptable interference caused by SDM is not resolved, the administration shall undertake steps to eliminate the interference or reduce it to an acceptable level

Improvements

- BR should publish its findings no more than four months from the date of receipt of complete information
- Expedited publication of comments to API on ITU website received under No. 9.3
- Automatic suppression after an expiry of the frequency assignments
- Additional Appendix 4 data easing technical analysis of API (support for sun-synchronous orbit) thus limiting unnecessary communications between administrations

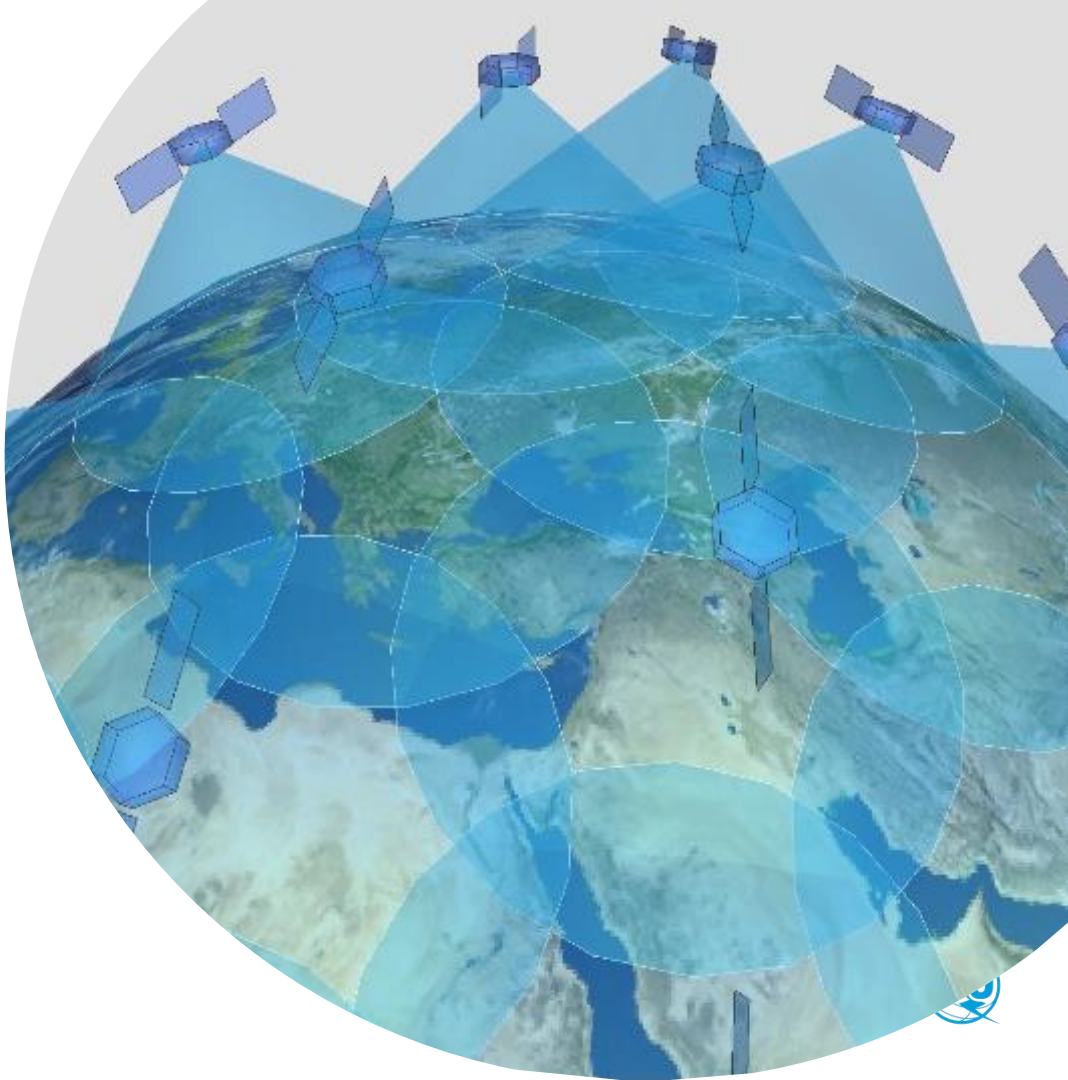
SDM short-duration mission regulations

Additional spectrum for Space operation service used by SDM

- **137.025 – 138 MHz Downlink**
  - Conditions are established in Resolution 660
  - PFD limit −140 dB(W/(m2 · 4 kHz))
- **148-149.9 MHz Uplink**
  - Conditions are established in No. 5.218A
  - PFD trigger for earth station for the application of 9.21
  - 9.17 and 9.18 apply

Part C

Coordination approach

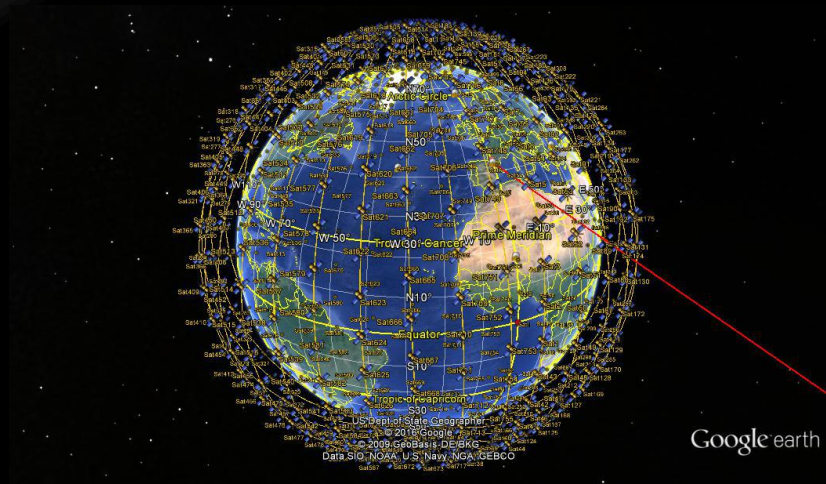


Coordination

between non-GSO and GSO (9.12A, 9.21/A) and between non-GSOs (9.12, 9.21/B)

—Only frequency overlap is used to trigger coordination

—Both co- and opposite direction of transmission



FSS frequency bands		No hard-limits for protection of GSO	Coordination between Non-GSO	Coordination between Non-GSO and GSO	Article 22 EPFD hard-limits are applicable
Earth-space	space-Earth				
	3400-4200 MHz	22.2			Yes (3700-4200)
5725-6700 MHz		22.2			Yes (5925-6700)
6700-7075 MHz		22.2	9.12		Yes (6700-6725)
7250-7750 MHz		22.2			
7900-8400 MHz		22.2			
	10.7-12.95 GHz	22.2	9.12		Yes
	11.2-11.45 GHz	22.2	9.12		Yes
	11.7-12.75 GHz	22.2	9.12		Yes
12.75-13.25 GHz		22.2	9.12		Yes
13.75-14.0 GHz		22.2	9.12		Yes
	17.8-18.6 GHz	22.2	9.12		Yes
	18.6-18.8 GHz	22.2			
	18.8-19.3 GHz		9.12	9.12A	
	19.3-19.7 GHz (MSS FL)		9.12	9.12A	
	19.3-19.7 GHz	22.2			
	19.7-20.2 GHz	22.2	9.12		Yes
	20.2-21.2 GHz	22.2			
27.5-28.6 GHz		22.2	9.12		Yes
28.6-29.1 GHz			9.12	9.12A	
29.5-30.0 GHz		22.2	9.12		Yes
V-band FSS	V-band FSS	22.2	9.12		Yes Single/Aggregate

Protection of GSO

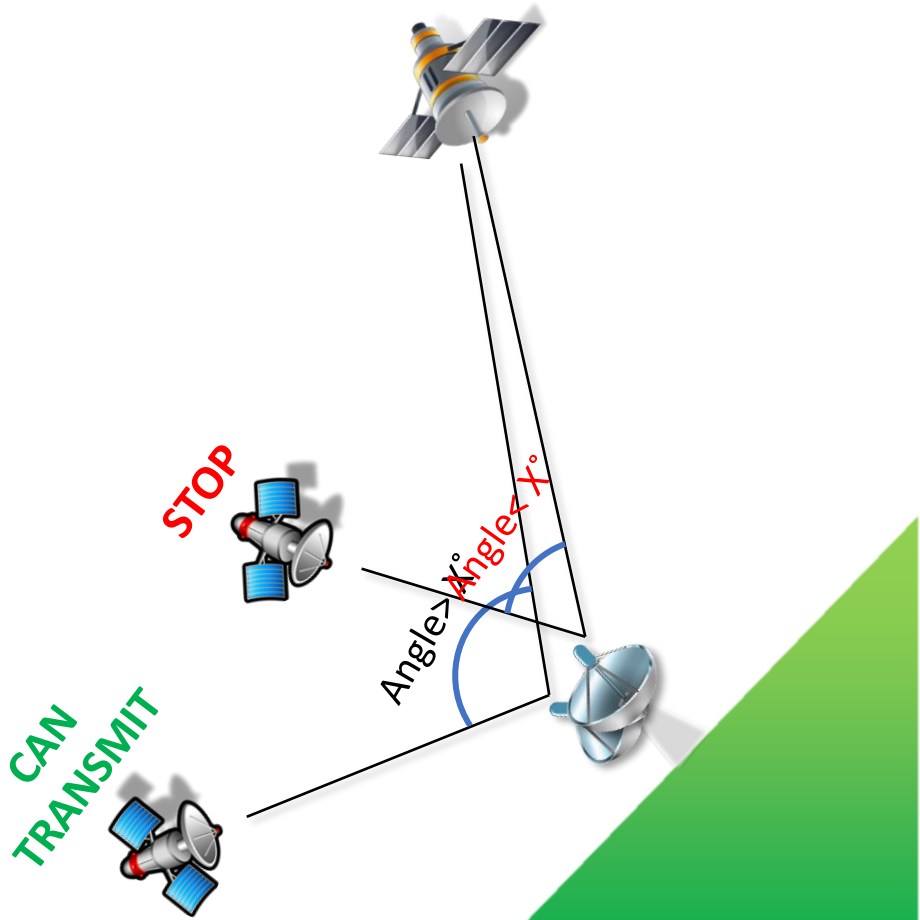
Two regulatory mechanisms

EPFD hard-limits

and

coordination

Technical solution for **non-GSO** is to avoid pointing antennas to **GSO** orbit or avoid operating satellite when there is insufficient separation angle between direction to **non-GSO satellite** and closest point on **GSO** when viewed from **non-GSO earth station**



Protection of terrestrial services

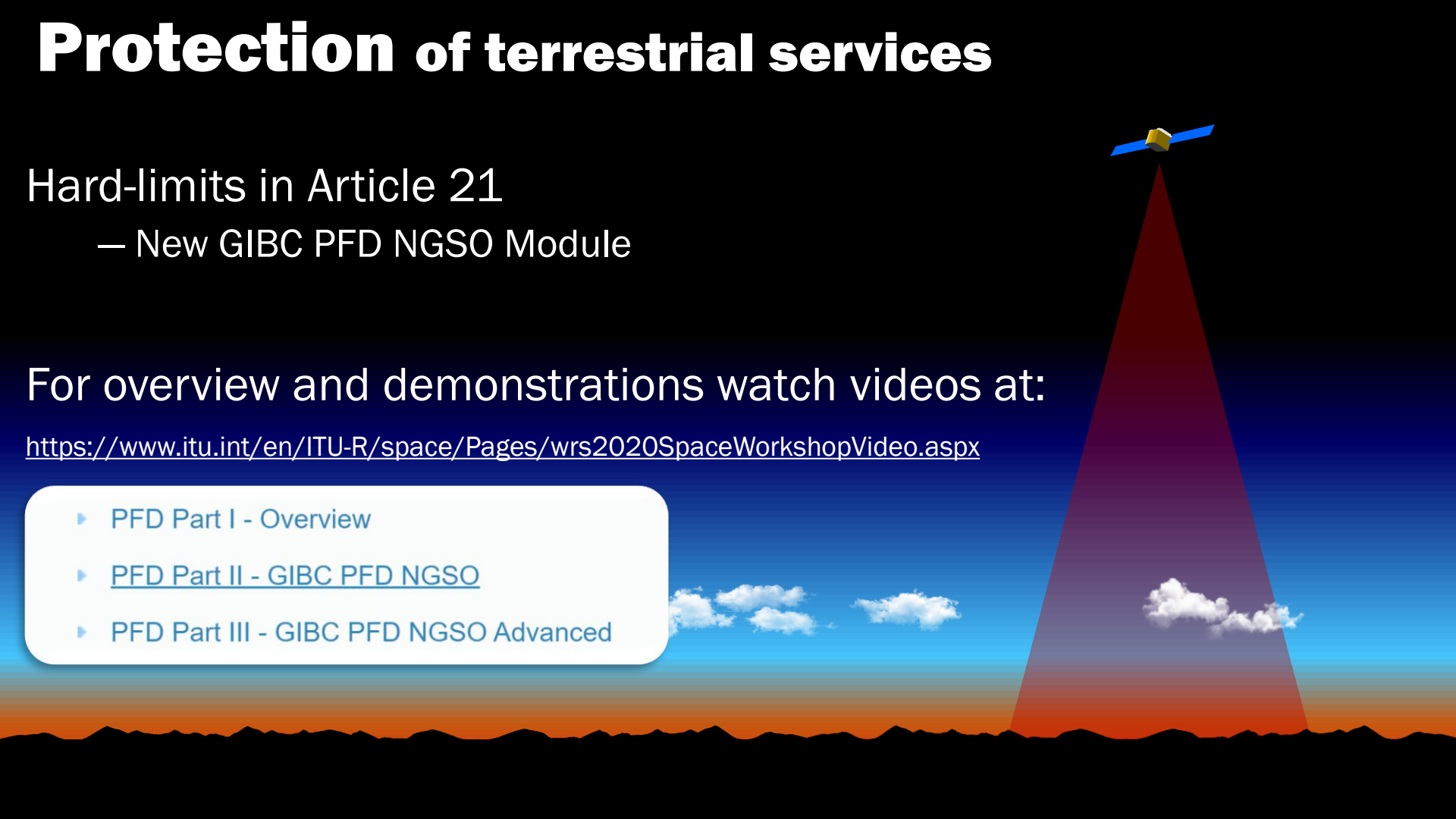
Hard-limits in Article 21

— New GIBC PFD NGSO Module

For overview and demonstrations watch videos at:

https://www.itu.int/en/ITU-R/space/Pages/wrs2020SpaceWorkshopVideo.aspx

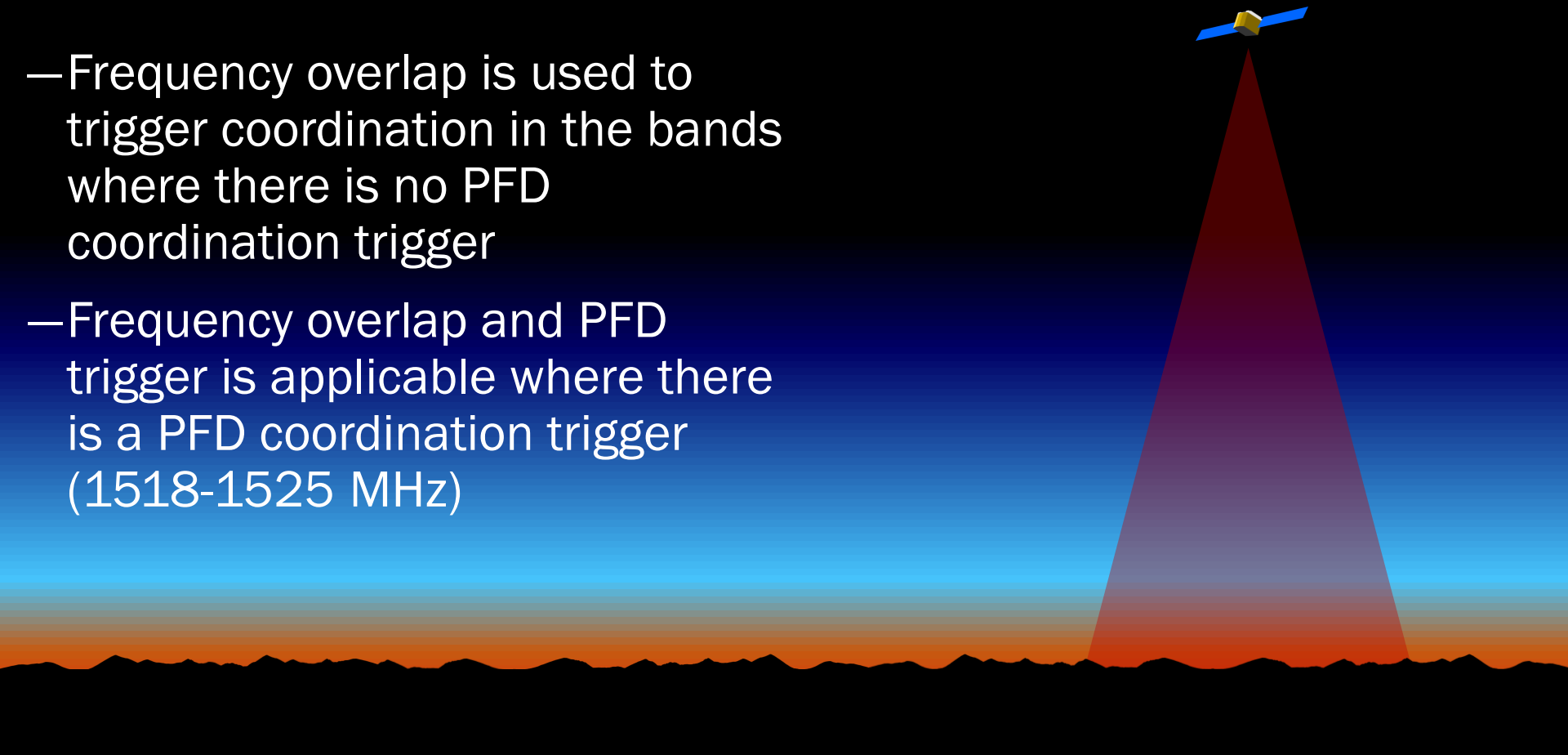
- PFD Part I - Overview
- PFD Part II - GIBC PFD NGSO
- PFD Part III - GIBC PFD NGSO Advanced

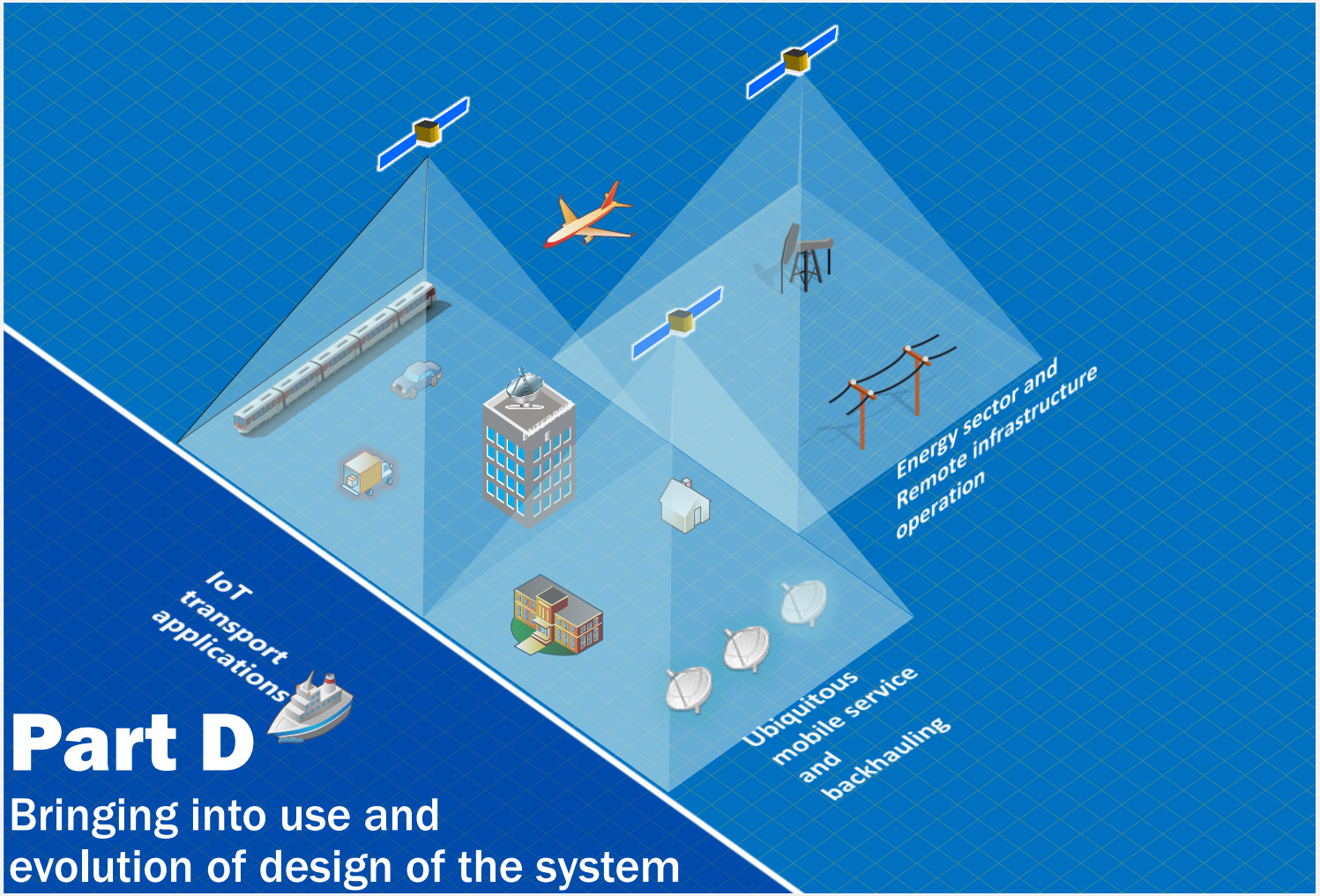


Coordination

between non-GSO and terrestrial services (9.14, 9.21/C)

- Frequency overlap is used to trigger coordination in the bands where there is no PFD coordination trigger
- Frequency overlap and PFD trigger is applicable where there is a PFD coordination trigger (1518-1525 MHz)





Part D

Bringing into use and evolution of design of the system

Further evolution of regulations

Bringing into use NGSO frequency assignments

Regulations on BIU are required to prevent warehousing orbit-spectrum and avoid paper satellites

What are the conditions of bringing into use?

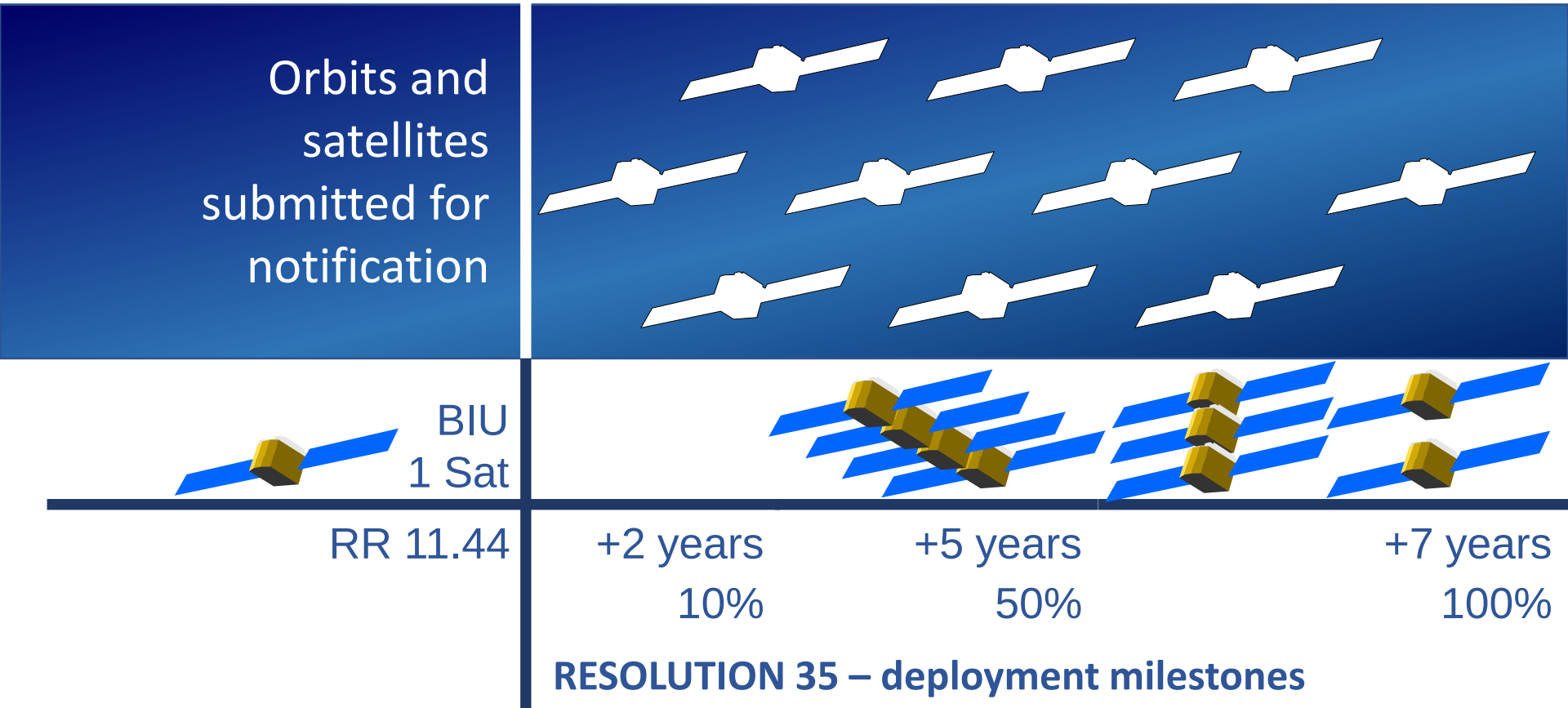
What are the tolerable changes in orbital parameters?

System design may not be final at the coordination stage

Regulatory schedule is tight for coordination and bringing into use

How modification of orbital parameters should be addressed/evaluated?

Milestone based approach adopted by WRC-19



Modification of NGSO

filing subject to coordination

The non-GSO operator submits MOD to:

- increase the number of satellites in their constellation with the same orbit altitude, inclination, eccentricity
- Decrease orbit altitude with the same inclination, eccentricity
- or with different orbit altitude, eccentricity, inclination?

How to maintain original date of receipt?

Modification of NGSO

filing subject to coordination

Guiding principle - RoP on No. 9.27

When the modified frequency assignments are subject to coordination, the conditions to keep the original date:

2.2 The guiding principles for dealing with modifications are:

– general obligation to effect coordination before notification (No. 9.6), and

– coordination is not required when the nature of the change is such as not to increase the interference to or from, as the case may be, the assignments of another administration

How to

measure increase of interference

Provision	Services	Measure
9.7	GSO vs GSO	Increase of dT/T
9.14 (PFD Trigger)	Non-GSO vs Terrestrial	?
9.14 (FO)	Non-GSO vs Terrestrial	?
9.7B	Non-GSO vs GSO earth stations	Increase of CDF EPFD curve
9.12/9.12A	Non-GSO vs Non-GSO and GSO	?

How to

measure increase of interference

Nos. 9.12, 9.12A, since no criteria exists except frequency overlap to identify affected systems,

the Bureau currently verifies whether or not modifications of the system increase the interference and applies paragraph 2.3.1 of the Rule as mentioned in **Section 6** of Radiocommunication Bureau Director's Report to Radio Regulations Board (Doc. **RRB17-2/3 rev.1**):

"in the absence of appropriate criteria or calculation methods to verify that there is no increase of interference or protection, the Bureau will thoroughly study the technical justifications provided by the notifying administration to make its finding and publish them to ensure the transparency of the process. Such justifications may be based on static and dynamic interference assessments. For the later one, calculation may be e.g. in the form of a cumulative distribution function of the interference level, expressed as an interference-to-noise (**I/N**) ratio for varying percentages of time and locations into the subsequently filed non-GSO FSS systems."

Submission
of multiple orbital configurations

For the submission of the advance publication information for a non-geostationary-satellite system representing a constellation or coordination request for non-geostationary-satellite systems:

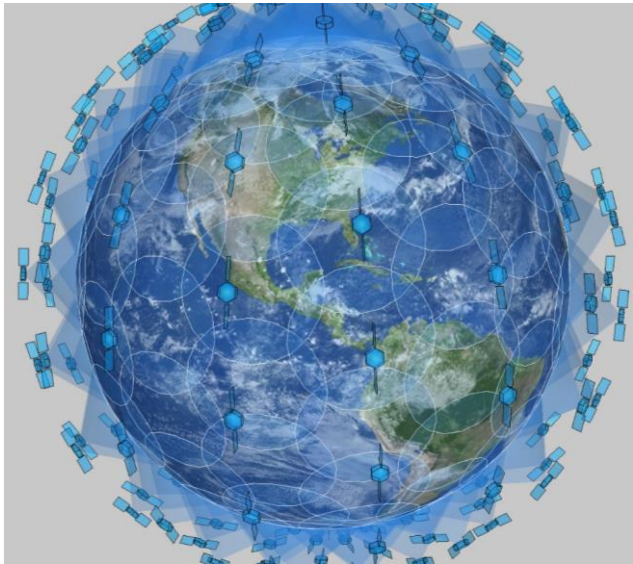
- WRC-19 added Appendix 4 data element A.4.b.1 an indicator of whether all the orbital planes describe:

  a) a single configuration where all frequency assignments to the satellite system will be in use or

  b) multiple configurations that are mutually exclusive where a sub-set of the frequency assignments to the satellite system will be in use on one of the sub-sets of orbital parameters to be determined at the notification and recording stage of the satellite system

Part E

Non-GSO submission to ITU



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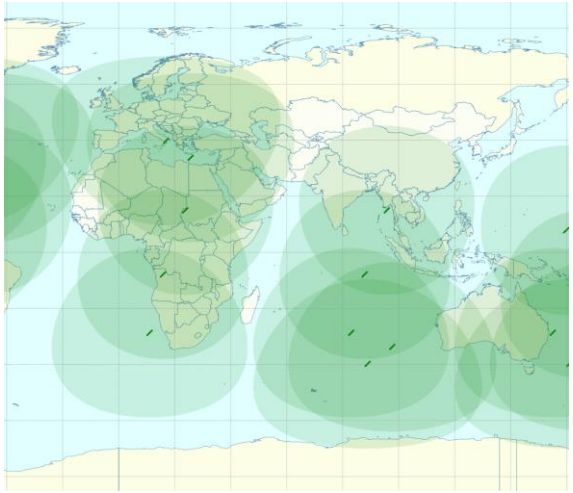
Kepler orbital elements

1. Inclination of orbit
2. Apogee/perigee, eccentricity
3. Right ascension of ascending node and/or longitude of ascending node
4. Phase angle of the satellite within its orbital plane (mean anomaly)
5. Argument of perigee

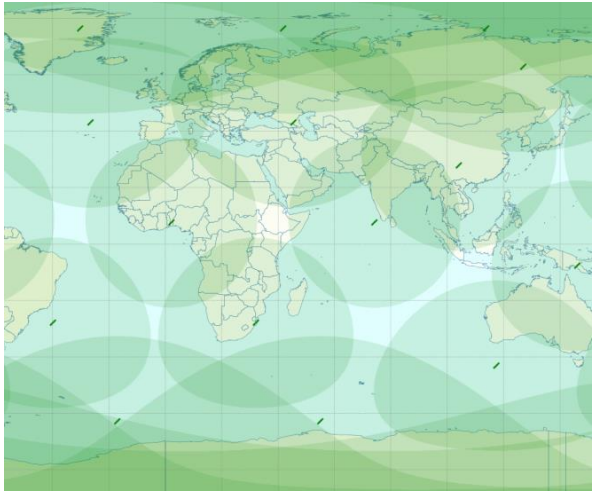
Orientation of orbit in space

A. Inclination of orbit

Inclination 40 degrees



Inclination 81 degrees



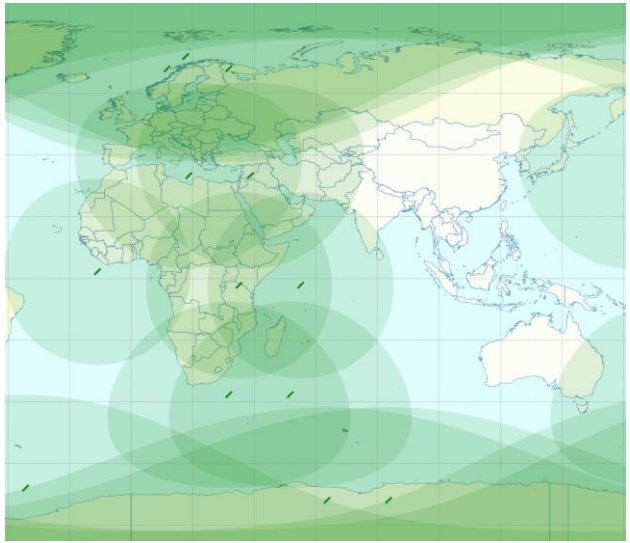
Orientation of orbit in space

B. Right ascension of ascending node and/or longitude of ascending node

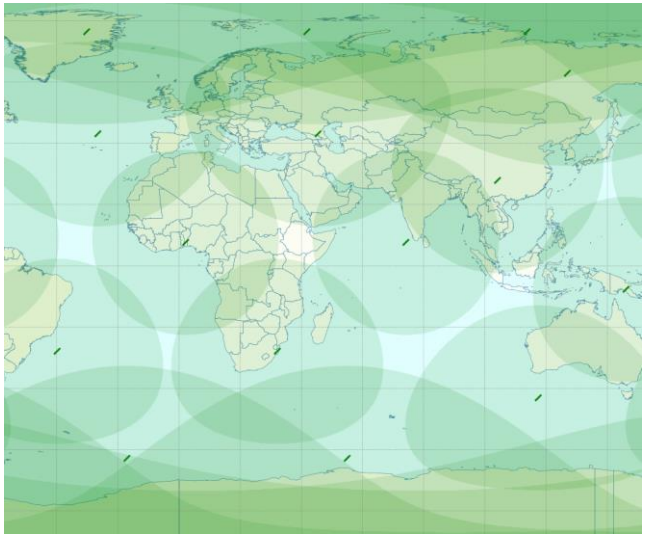
- RAAN is simply an angle (measured at the center of the Earth) between the point the Sun's orbit crosses Earth's equator in ascending direction, and the point where non-GSO orbit crosses equator
- Actual RAAN may change due to change in planned launching date
- Most importantly, in satellites systems with multiple orbital planes RAAN and LAN define inter-orbital spacing, e.g. orbits with 0, 30, 60, 90 RAAN have spacing of 30 degrees
- Changing RAAN would affect visibility statistics

Orientation of orbit in space

RAAN 10 degrees spacing



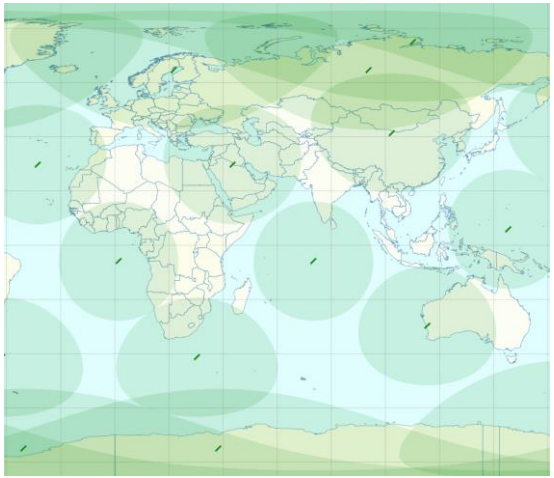
RAAN 36 degrees spacing



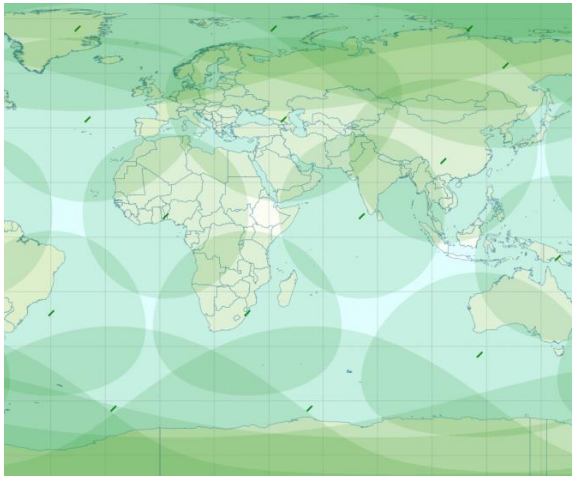
Semi-major axis

C.Apogee/perigee, minimum operating height

Orbit altitude 500 km



Orbit altitude 1000 km



Orientation of an ellipse in orbit

D. Argument of perigee (degrees)

- For elliptical orbit systems defines position of active arc – service area

Argument of perigee 90

(active arc in southern hemisphere)

Argument of perigee 270

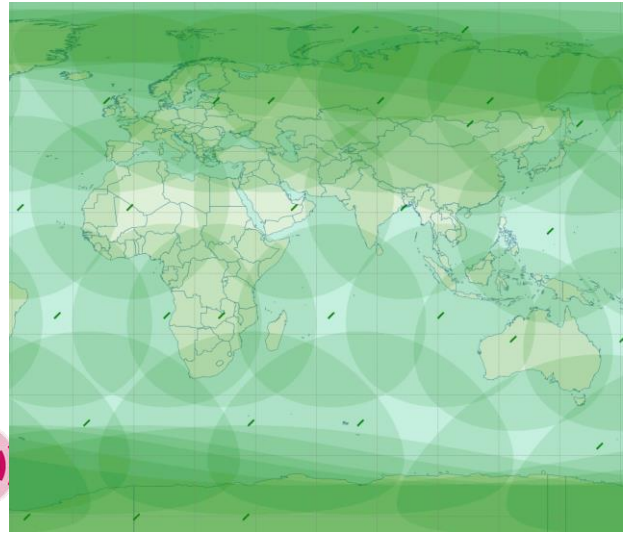
(active arc in northern hemisphere)

Position of satellites in orbit

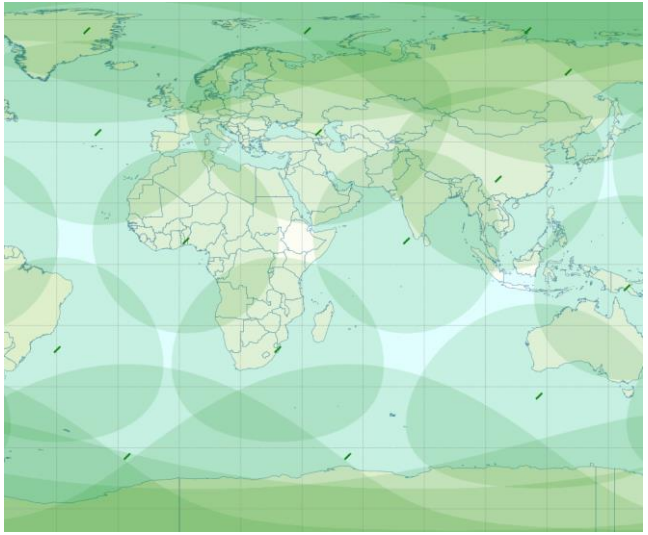
E. Phase angle, number of satellites, number of orbits

- Affects visibility statistics

10 orbits (50 sats)



5 orbits (25 sats)



Sun-synchronous orbit

For earth observation missions, WRC-19 introduced Appendix 4 data element A.4.b.4.m *an indicator of whether space station uses sun-synchronous orbit or not for not subject coordination*

Additional elements A.4.b.4.n and A.4.b.4.o to specify a local time of ascending or descending node

New elements are to enable technical analysis once API is published.

System flexibility – changing orbital parameters

Changing orbital parameters reviewed above except central body may require re-submission

Type of system	Requires new submission/modification	No need for new submission/modification
Subject to coordination	✔	
Not subject coordination but "constellation"		✔*
Not subject coordination		✔*
SDM		✔ - only new submission, no modification is possible

System flexibility – changing orbital parameters

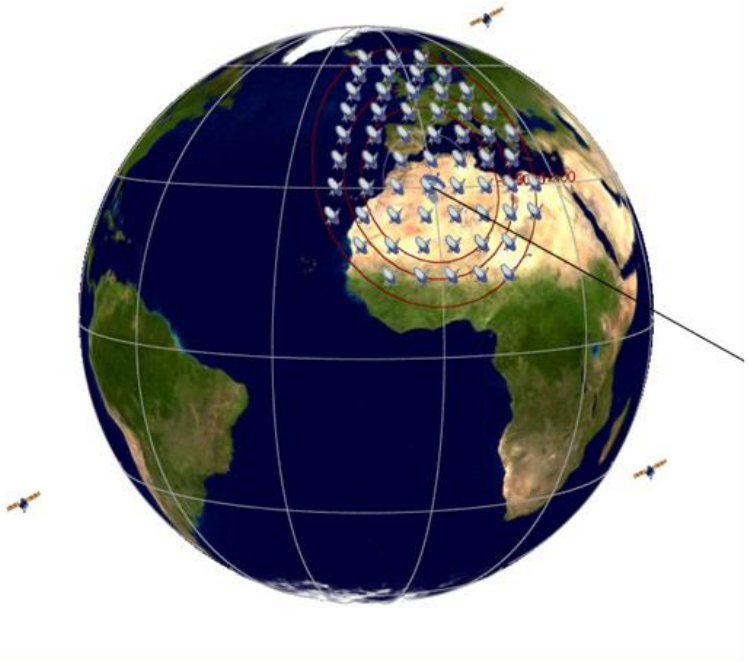
Changing orbital parameters reviewed above except central body may require re-submission

Type of system	Apogee/ perigee	Inclination	RAAN	LAN	Argument of perigee	Phase angle	Orbit period
Subject to coordination	R	R	R	-	R	R	N
Not subject coordination but "constellation"	A	A	-	A	A	A	N
Not subject coordination	A	A	-	A	-	-	N
SDM	A*	A*	-	A*	-	-	N

R – require modification of CR/C
N – do not require any modification
A - not require resubmission, but advisable to submit modification of API for interference-free operation
A* – For SDM no modification is possible, it is advisable to submit new API under new name if changes are significant

Part F

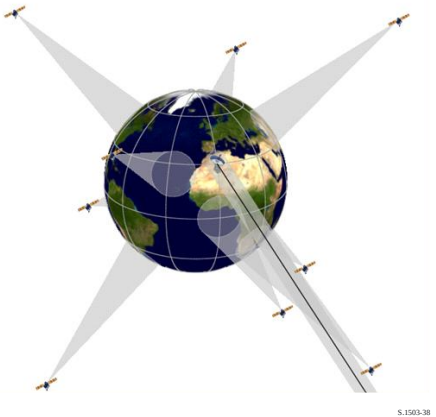
EPFD concept



S.1503-39

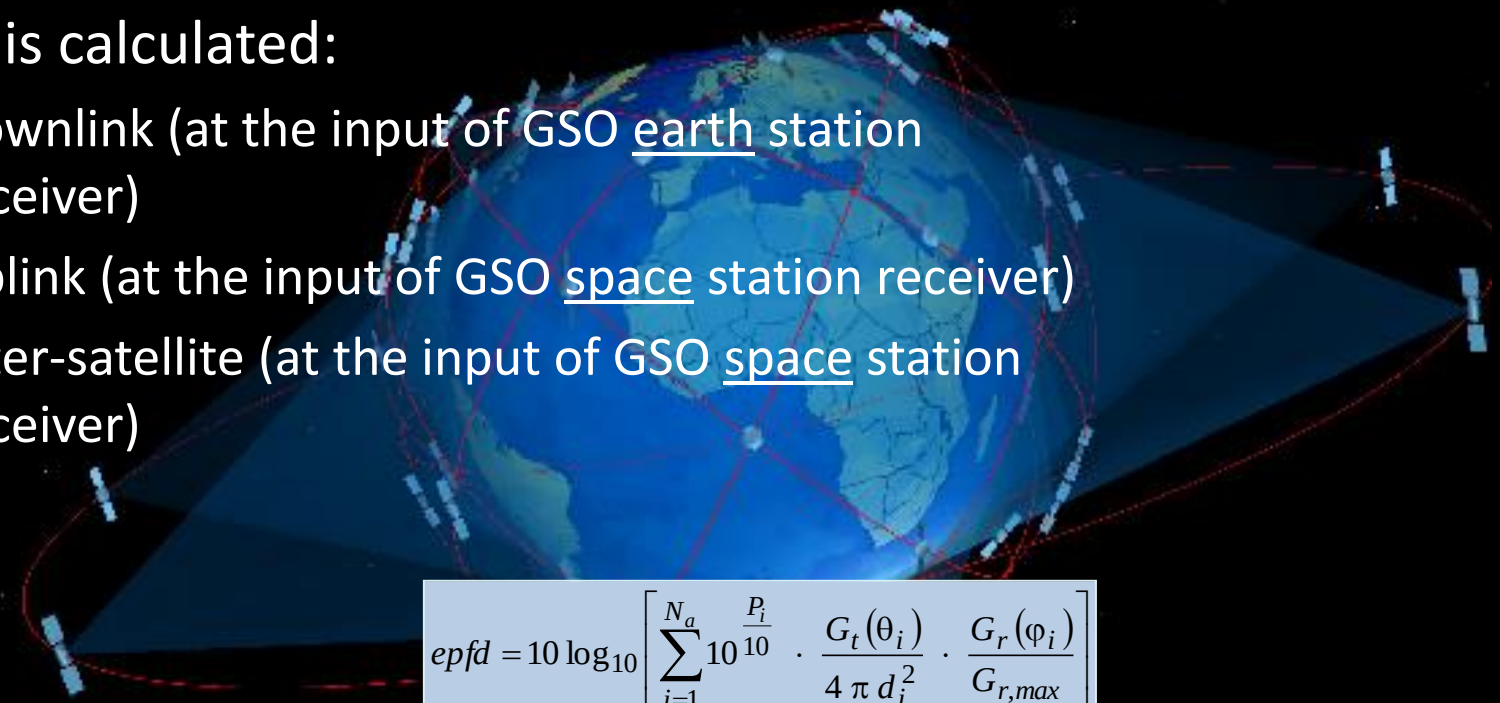
EPFD

- **Equivalent power-flux density** (EPFD) takes into account the aggregate of the emissions from all non-GSO satellites in the direction of any GSO earth station, taking into account the GSO antenna directivity
- EPFD considers pointing of a victim receiving antenna with respect to any source of interference
- Complex calculation methodology considers an interference varying in time and space



What is EPFD?

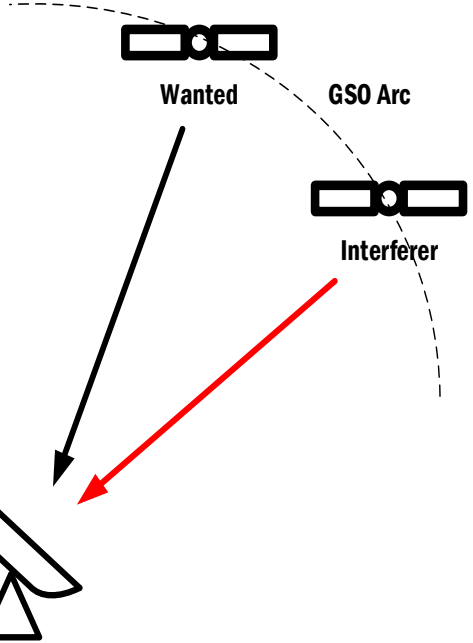
- EPFD is calculated:
  - Downlink (at the input of GSO earth station receiver)
  - Uplink (at the input of GSO space station receiver)
  - Inter-satellite (at the input of GSO space station receiver)



$$epfd = 10 \log_{10} \left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4 \pi d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,max}} \right]$$

Why EPFD?

GSO to GSO



Wanted/interferer geometry is fixed

Criteria ΔT/T, C/I

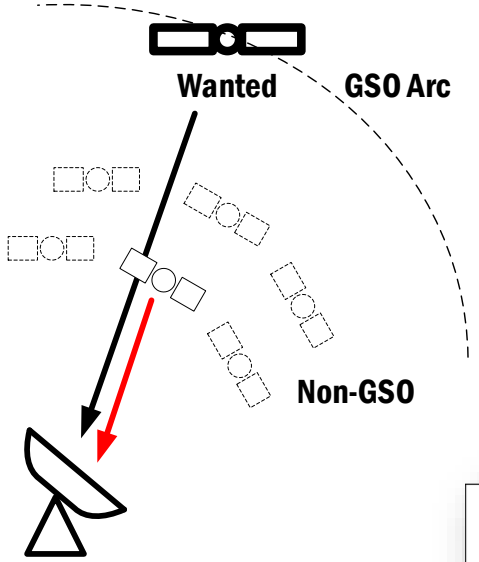
Interfering signal path loss

≈

Wanted signal path loss

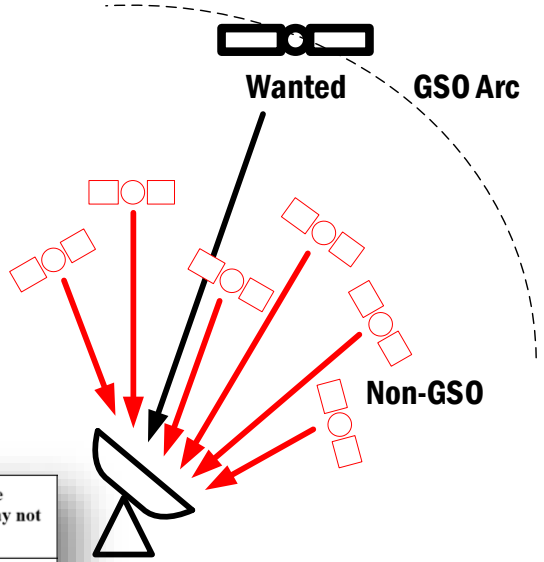
Why EPFD?

Non-GSO to GSO



Constantly changing wanted vs interferer geometry

epfd↓ (dB(W/m²))	Percentage of time during which epfd↓ may not be exceeded
−175.4	0
−174	90
−170.8	99
−165.3	99.73
−160.4	99.991
−160	99.997
−160	100



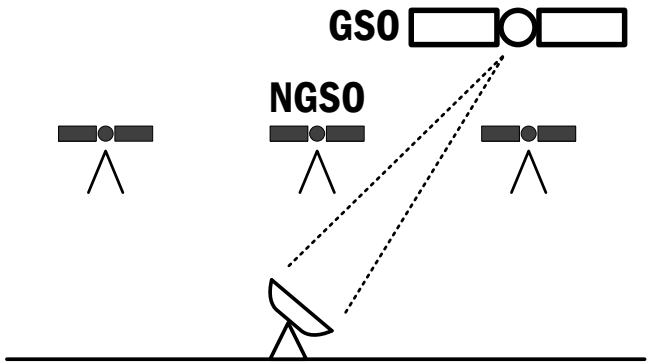
Aggregate effect of interference from several sources

Regulatory Framework

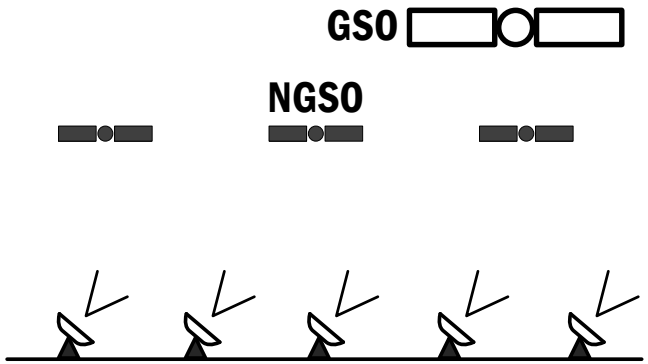
- Article **22 – Hard Limits to protect GSO from Non-GSO**
  - Hard EPFD limits enable non-GSO FSS systems to share frequencies with and protect GSO systems without requiring individual coordinations with all the systems worldwide
  - FSS non-GSO satellite systems shall comply with the EPFD limits contained in Tables **22-1A**, **22-1B, 22-1C, 22-1D, 22-1E, 22-2 and 22-3** of RR Article **22**
    - ✓ Article 22 contains reference parameters of GSO stations to be protected

Frequency band (GHz)	epfd↓ (dB(W/m²))	Percentage of time during which epfd↓ may not be exceeded	Reference bandwidth (kHz)	Reference antenna diameter and reference radiation pattern[7]
10.7-11.7 in all Regions; 11.7-12.2 in Region 2; 12.2-12.5 in Region 3 and 12.5-12.75 in Regions 1 and 3	−175.4 −174 −170.8 −165.3 −160.4 −160 −160	0 90 99 99.73 99.991 99.997 100	40	60 cm Recommendation ITU-R S.1428-1

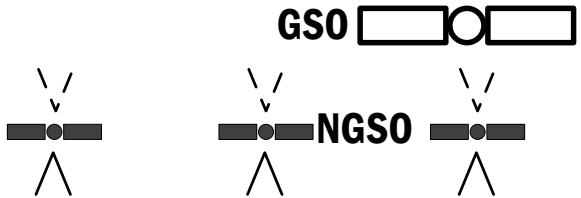
EPFD on downlink



EPFD on uplink



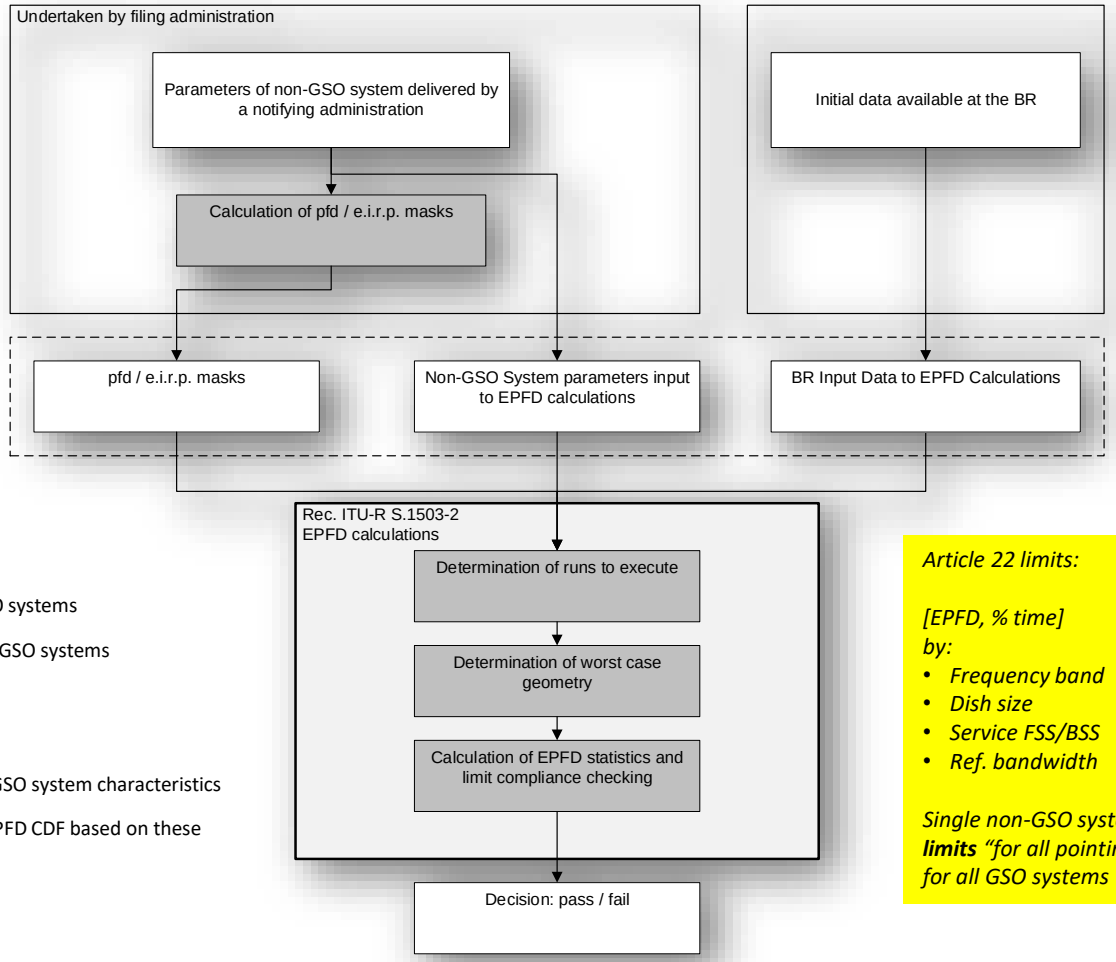
EPFD on inter-satellite path



EPFD Limits Validation Tools

- Validation Software is developed in accordance with methodology in Recommendation ITU-R S.1503-2
- Resolution 85 (WRC-03) establishes intermediate arrangements until required software is developed
- “Qualified favourable” finding was given before availability of the software based on the commitment by notifying administration to fulfill Article 22 limits
- Findings under review

App.4 "for space stations operating in a frequency band subject to Nos. 22.5C, 22.5D or 22.5F…"



Objectives:

- Protection for GSO systems
- Flexibility for non-GSO systems

Approach:

- Measurable non-GSO system characteristics
- Computation of EPFD CDF based on these parameters

Article 22 limits:

[EPFD, % time]
by:
- *Frequency band*
- *Dish size*
- *Service FSS/BSS*
- *Ref. bandwidth*

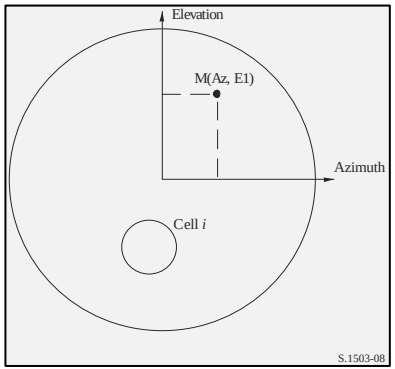
*Single non-GSO system **verification limits** "for all pointing directions" for all GSO systems*

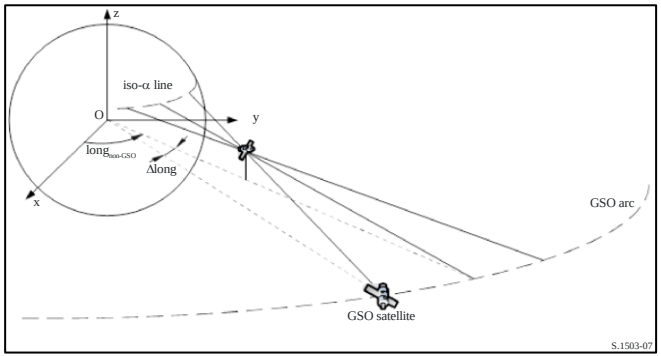
Steps required to prepare the data for Article 22 Examination

- Get familiar with ITU-R Recommendations S. 1503-2/3
  - PART A – Assumptions
  - PART B – Input parameters
  - PART C – Generation of pfd/e.i.r.p. masks
  - PART D – General description of software algorithms

Steps required to prepare the data for Article 22 Examination - Masks

- Defines non-GSO station transmission “footprint”
  - For transmitting non-GSO earth station in form of eirp and off-axis eirp mask
  - For transmitting non-GSO satellite in form of pfd-mask given either in azimuth-elevation plane or relative to GSO exclusion zone
  - For transmitting non-GSO satellite in bi-directional frequency bands in form of eirp and off-axis eirp mask
- Masks are presented in XML-format and embedded in MS Access .MDB container
  - https://www.itu.int/ITU-R/go/space-mask-XMLfile/en
- Not included in BR IFIC SRS database
- Are published once examination of non-GSO satellite system is completed





Steps required to prepare the data for Article 22 Examination - Masks

- PFD Mask is a powerful instrument, its definition is based on consideration:
  - Mitigation techniques used towards GSO receiving stations
  - Variation of transmission per sub-satellite latitude
- Provided for each frequency band subject to EPFD
- Can have several different PFD-masks assigned to specific orbital planes or even satellites

Steps required to prepare the data for Article 22 Examination - Masks

PFD Mask can take a form of:

PFD as a function of

– azimuth and elevation angles from a non-GSO space station towards a point on the Earth

or

PFD as a function of

– the separation angle α between a non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth

– the difference Δ L in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the α angle is minimized

Steps required to prepare the data for Article 22 Examination – SNS Data

Some other important parameters used:

- For Uplink,
  - The average distance on the Earth's surface between co-frequency beams (*d*) from the non-GSO system (km) and density of co-frequency non-GSO ES *(Density)*
  - Used to derive the number of earth stations operating within GSO footprint defined at -15 dB level. Number of ES within co-frequency beam:

$$NUM\_ES = d * d * Density$$

  - EIRP of representative ES:

$$REP\_e.i.r.p. = ES\_e.i.r.p. + 10log10\ (NUM\_ES)$$

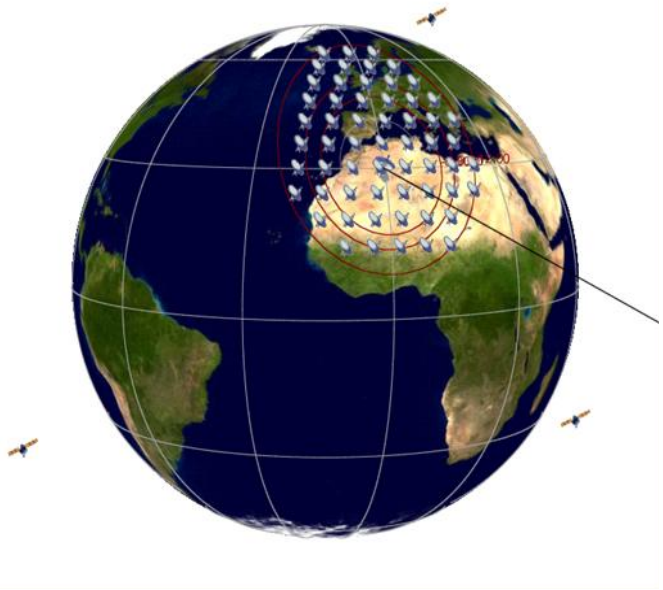
Defined in **non_geo** table, fields **avg_dist** and **density**

Steps required to prepare the data for Article 22 Examination

- Representative ES are then populated within GSO beam footprint with separation in longitude and latitude:

$$\Delta lat = \frac{d}{R_e}$$

$$\Delta long = \frac{d}{R_e \cos lat}$$



Steps required to prepare the data for Article 22 Examination

- For uplink and downlink
  - Minimum elevation angle the non-GSO earth station when it is receiving or transmitting

Defined in **grp** table, field **elev_min**

- For Uplink,
  - Maximum number of co-frequency tracked non-geostationary satellites receiving simultaneously

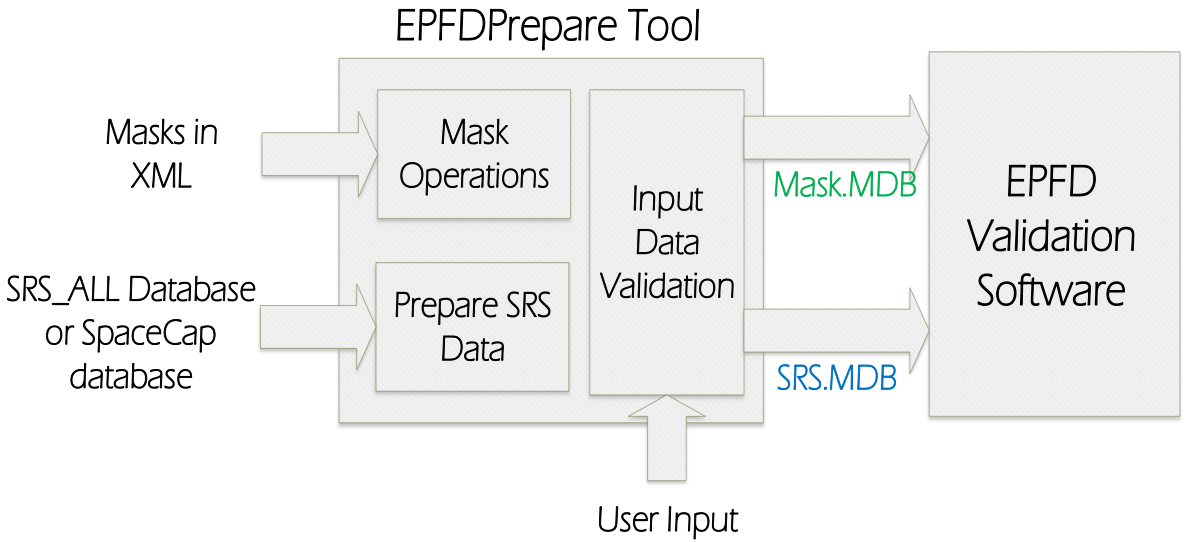
Defined in **non_geo** table, field **nbr_sat_td**

- For Downlink,
  - Maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location within the latitude range

Defined in **sat_oper** table, fields **lat_fr**, **lat_to**, **nbr_opr_sat**

Compiling Data Set

- Masks in XML format are stored in MDB file
- All other parameters are contained in SRS Database.
- To facilitate calculation it is advisable to extract a notice to a separate database only including 1 frequency assignment per each frequency band subject to Article 22, 9.7A, 9.7B examination.
- All data is compiled using EPFDPrepare Tool



Resources

ITU-R Recommendation S.1503-2

Functional description to be used in developing software tools for determining conformity of non-geostationary-satellite orbit fixed- satellite system networks with limits contained in Article 22 of the Radio Regulations

EPFD software web-page

http://www.itu.int/ITU-R/go/space-epfd/en

EPFD Support Forum

http://groups.itu.int/epfd/en-us/epfdforum.aspx - **undergoing upgrade!**

epfd-support@itu.int

Demonstration and exercise

1. **Download exercise file:**

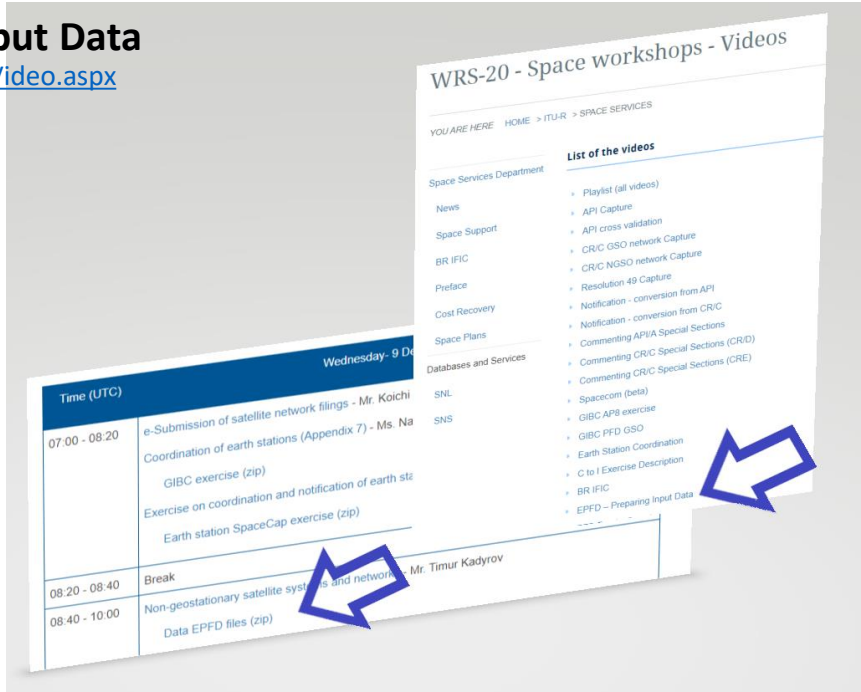
   Data EPFD files (zip)

   https://www.itu.int/en/ITU-R/space/WRS20space/28%20Non-geostationary%20satellite%20systems%20and%20networks.zip

2. **Unzip it somewhere on local drive**

3. **Follow demonstration in video EPFD – Preparing Input Data**

   https://www.itu.int/en/ITU-R/space/Pages/wrs2020SpaceWorkshopVideo.aspx



Thank you!

ITU – Radiocommunication Bureau

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