EPFD Verification Software Status and Perspective

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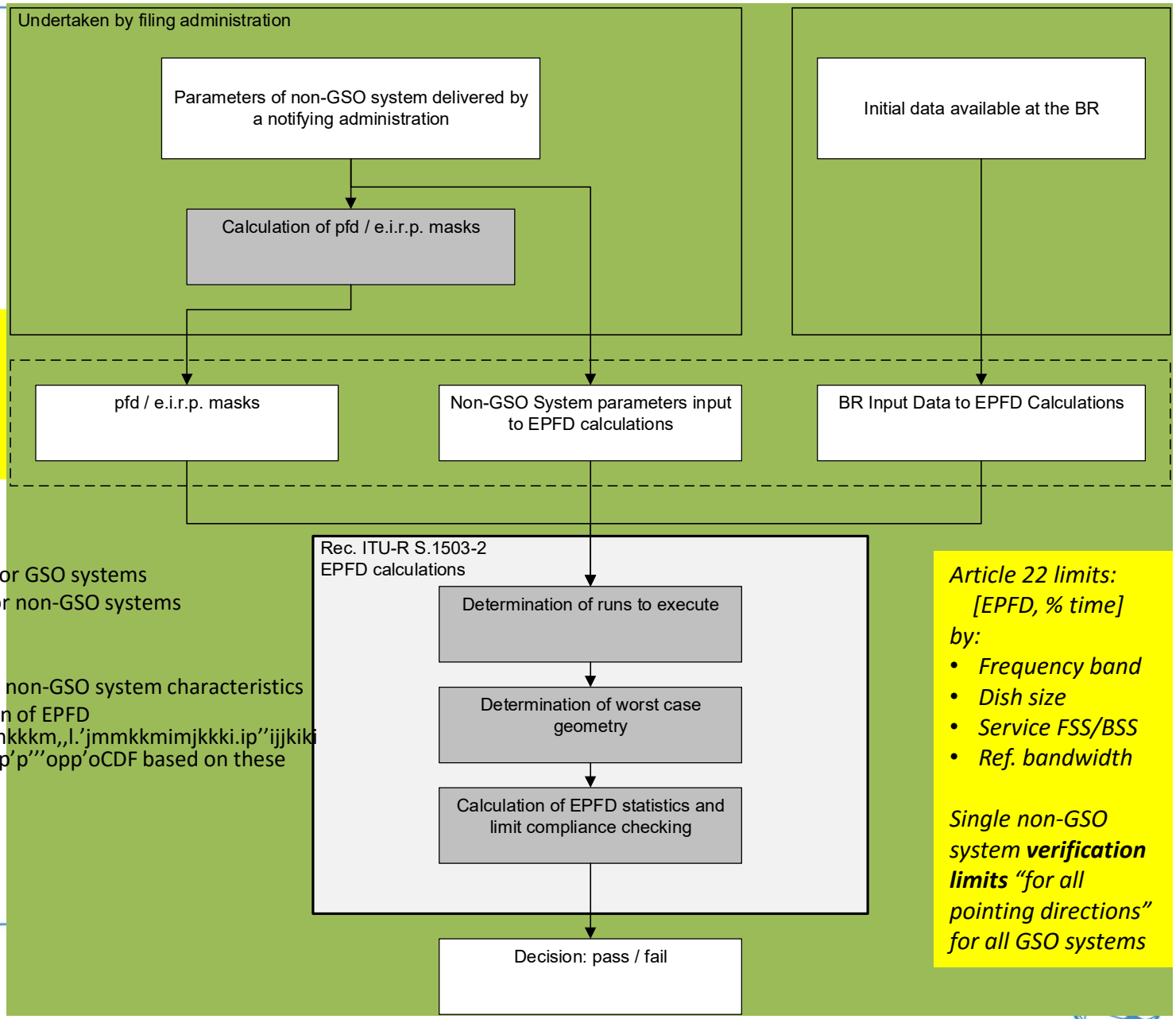
Rec. ITU-R S.1503-2 Overview

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 jlkkkjkjjjjmmkkkm,,l.'jmmkkmimjkkki.ip''ijjkiki p'p'oiiiikloop'p'''opp'oCDF 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*

EPFD calculation for EPFD(down/up)

EPFD(down): for each time step:

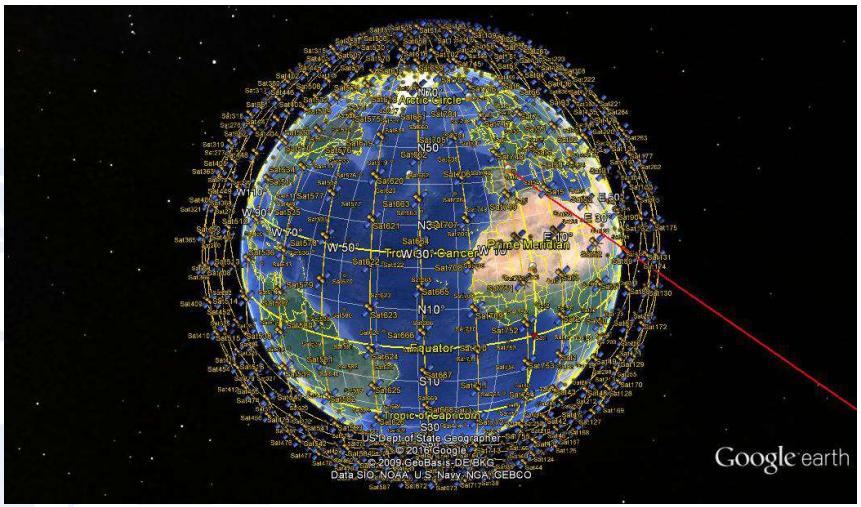
- Identify those non-GSO satellites that meet the ε_0 and α_0 criteria at the GSO ES location
- For each satellite, calculate $EPFD_i$ at the GSO ES:

$$\mathbf{EPFD_i = PFD_i(az,el) + G_{rel,\,i}(\theta)}$$

Or:

$$\mathbf{EPFD_i = PFD_i(\alpha,\Delta long) + G_{rel,\,i}(\theta)}$$

- Select the N_{co}[lat] largest entries as assumed to be serving the GSO ES location plus those in the exclusion zone (assumed to be serving other locations)
- Update EPFD histogram with this aggregate EPFD

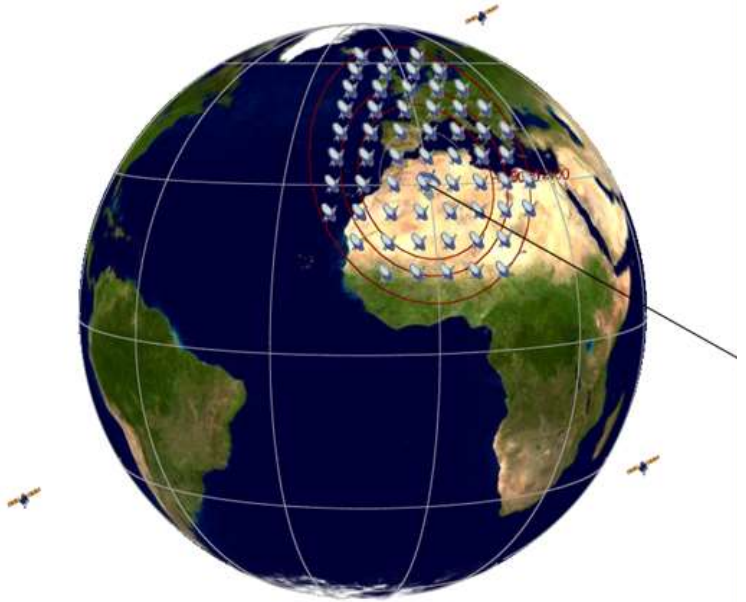


EPFD(up): deploy representative non-GSO ES across GSO beam down to -15 dBi taking into account access method and frequency re-use. Then for each time step:

- For each non-GSO ES, identify those non-GSO satellites that meet the ε_0 and α_0 criteria
- For each non-GSO ES, calculate $EPFD_i$ at the GSO satellite:

$$\mathbf{EPFD_i = EIRP(\theta) + L_s + G_{rel,\,i}(\phi)}$$

- Select the N_{co} largest entries assumed to be serving the non-GSO ES location
- Update EPFD histogram with this aggregate EPFD



EPFD Software Project

- Two parallel developments:
  - Transfinite Systems Ltd, developed in C++
  - Agenium, developed in C#
- Reasons for two developments:
  - Confidence in results: useful for BR and admins to be able to check the result of more than one tool
  - Independent viewpoint on algorithm in Recommendation
  - Assists in testing stage of development
- Working since July 2015, building on previous phases
- Software to be provided to the BR by end of this month (April 2016)
- BR to run their own tests, then to be made generally available part of the SRS space applications, run from GIBC
- Automatic process: no user input required as takes as input the filing database and associated mask database
- Also 9.7A and 9.7B analysis

EPFD Software Status

1. The software being readied for delivery to the BR
2. The algorithm in Rec. ITU-R S.1503-2 was found to meet requirements and achieves objectives:
   - No fundamental flaw or omission found in any component (worst case geometry, time step calculation, EPFD calculation etc.)
   - Editorials and clarifications on S.1503 have been documented and will be provided to the BR
   - Some large constellations require significant computational resources – weeks or even months of CPU
3. Testing has been very comprehensive: testing between two implementations for all test networks completed with better than 0.1 dB match between the tools (often 1e-5 dB)
4. Run with 14 test systems based on the orbit characteristics of real systems designed to flex various components of the algorithm
5. Plus 9.7A and 9.7B cases

Test Case	Timestep	WCG	Results
Skybridge	AGREE	AGREE	AGREE
Boeing	AGREE	AGREE	AGREE
O3B-A	AGREE	AGREE	AGREE
O3B-B	AGREE	AGREE	AGREE
USCSID	AGREE	AGREE	AGREE
CANPOL-POLAR	AGREE	AGREE	AGREE
CANPOL-LEO	AGREE	AGREE	15/17
ASK-1 TAP	AGREE	AGREE	AGREE
ASK-1 MOLNIYA N1	AGREE	AGREE	AGREE
ASK-1 MOLNIYA N3	AGREE	AGREE	AGREE
ASK-1 MOLNIYA N4	AGREE	AGREE	AGREE
ASK-1 MOLNIYA N5	AGREE	AGREE	AGREE
SPECIFIC - Non-Repeating	AGREE	AGREE	AGREE
SPECIFIC - Repeating	AGREE	AGREE	AGREE
9.7A	AGREE	-	AGREE
9.7B	AGREE	-	AGREE

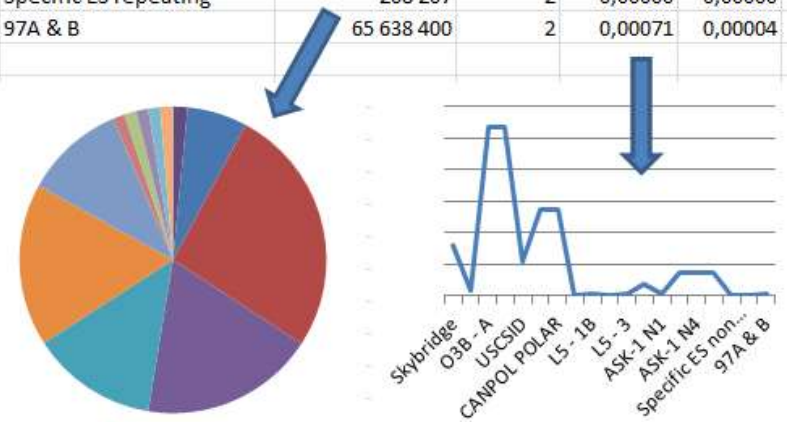
NOTE: To be concluded - testing is on-going in BR to verify all results are matching

Validation metrics

- **224 billion time steps tested**
- **339 runs computed**
- **Max delta observed : 0.053dB**

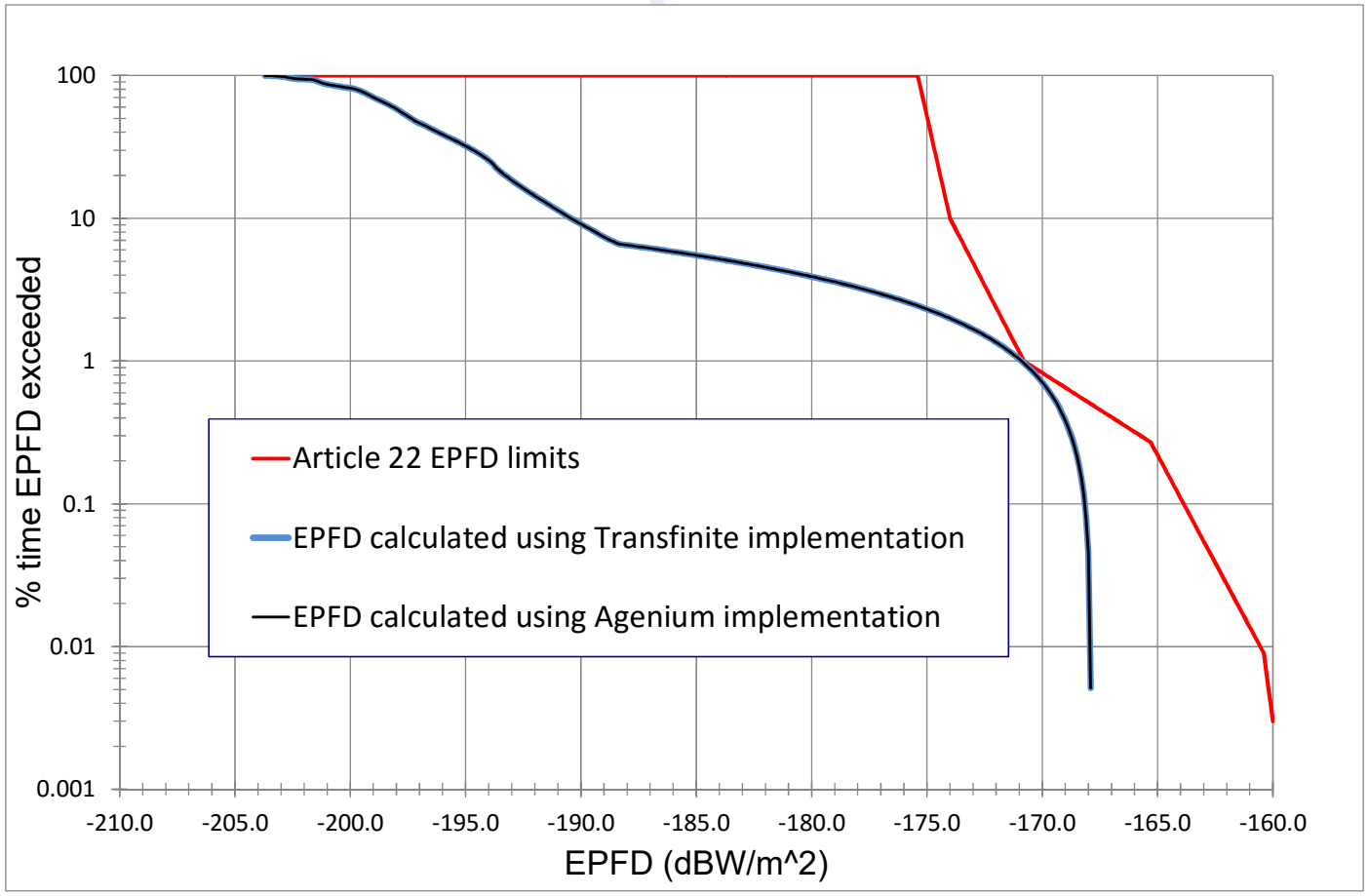
- Data compared:
  - Runs parameters:
    - EPFD type
    - Frequencies
    - Antenna diameters
    - Time step size and number of steps
    - Worst Case Geometry
  - Non-GSO Earth Stations generated
  - CDF generated
  - Orbits positions

NGSO system	nb timesteps	nb runs	max delta	min delta
Skybridge	119 995 487	32	0,01598	0,00000
Boeing	3 301 641 801	32	0,00179	0,00002
O3B - A	1 156 065	8	0,05349	0,00000
O3B - B	8 892 590	17	0,05357	0,00000
USCSID	14 202 902 796	15	0,01111	0,00002
CANPOL LEO	58 936 841 330	17	0,02724	0,00001
CANPOL POLAR	10 642 986	17	0,02724	0,00033
L5 - 1A	41 123 873 015	6	0,00048	0,00000
L5 - 1B	29 780 723 221	6	0,00085	0,00000
L5 - 2	38 419 232 539	14	0,00020	0,00000
L5 - 3	23 602 459 446	14	0,00080	0,00000
ASK-1 TAP	2 861 119 619	31	0,00388	0,00002
ASK-1 N1	2 835 669 203	31	0,00095	0,00000
ASK-1 N3	2 835 669 203	31	0,00728	0,00004
ASK-1 N4	2 835 669 203	31	0,00728	0,00004
ASK-1 N5	2 835 669 203	31	0,00728	0,00004
Specific ES non repeating	66 998 025	2	0,00017	0,00003
Specific ES repeating	208 207	2	0,00000	0,00000
97A & B	65 638 400	2	0,00071	0,00004



Example Test Results: SkyBridge

Run 5: EPFD(down) FSS D=0.6m Ku band



Run	Max Delta (dB)
Run 1	0.00006
Run 2	0.00001
Run 3	0.00002
Run 4	0.00002
Run 5	0.00031
Run 6	0.01598
Run 7	0.00008
Run 8	0.00003
Run 9	0.00090
Run 10	0.00004
Run 11	0.00237
Run 12	0.00006
Run 13	0.00010
Run 14	0.00017
Run 15	0.00088
Run 16	0.00096
Run 17	0.00006
Run 18	0.00016
Run 19	0.00006
Run 20	0.00006
Run 21	0.00029
Run 22	0.00017
Run 23	0.00036
Run 24	0.00023
Run 25	0.00014
Run 26	0.00006
Run 27	0.00035
Run 28	0.00084
Run 29	0.00045
Run 30	0.00132
Run 31	0.00000
Run 32	0.00000

Issues with the input data

- S.1503 specific parameters in Appendix 4 mapped to SRS fields and XML format PFD/EIRP masks used by the software tools
- Have observed syntax and presentation errors:
  - XML format not complete
  - Exclusion zone method
  - Earth Station distribution parameters (density and average distance between co-frequency cells)
  - EIRP masks for different antenna diameters – only one antenna diameter is used to populate earth stations
- Specific system having more than 2000 PFD-masks (per satellite, one for ascending and for descending nodes)
  - Masks volume ~ 1 TB
  - How to store, handle and run?
- BR can assist in clarifying how to specify parameters required by S.1503-2

EPFD Software - Summary

1. The software will be ready for delivery to BR by the end of the month
2. The algorithm in Rec. ITU-R S.1503-2 is sound and no fundamental errors were identified
3. The testing of the two implementations gives extremely close results

Further actions

- Complete the testing of the software with the test-cases identified for Rec. 1503-2 implementation
- Complete new system trials for:
  - L5, MCSAT LEO, STEAM-1
- Publish evaluation-package on ITU-R Web Site
- BR provides to notifying administrations a test-data used during the tests
- To provide a software package as part of BR Examination Software (Q3/Q4 2016).
- BR informs administrations on the implementation of Resolution 85 and requests notifying administrations to submit the data required for EPFD-examination

Mods to non-GSO and the EPFD software

- What should happen when/if:
  a) Rec. ITU-R S.1503 is updated with improved methodology (as discussed at WRC and 4A)?
  b) The non-GSO operator submits mod to increase the number of satellites in their constellation with the same {a, e, i}?
     Note that S.1503-2 categorises non-GSO systems using {a, e, i}
  c) …Or with different {a, e ,i}?
  d) The non-GSO operator reconfigures their system leading to a different Article 22 related parameters e.g. PFD/EIRP masks?

- General principles:
  – Non-GSO systems should be encouraged to be examined and not be penalised for submitting masks so hence retain flexibility
  – The examination is of the whole constellation including all satellites whenever filed
  – The examination process is a binary pass/fail: it does not matter if the EPFD levels increase as long as the thresholds are met
  – EPFD verification is different from non-GSO to non-GSO coordination