国家无线电监测中心
The State Radio Monitoring Center

Practice of Spectrum Engineering

Dr. Tan WANG
State Radio Monitoring Center of China
Spectrum Management Research Division

Content

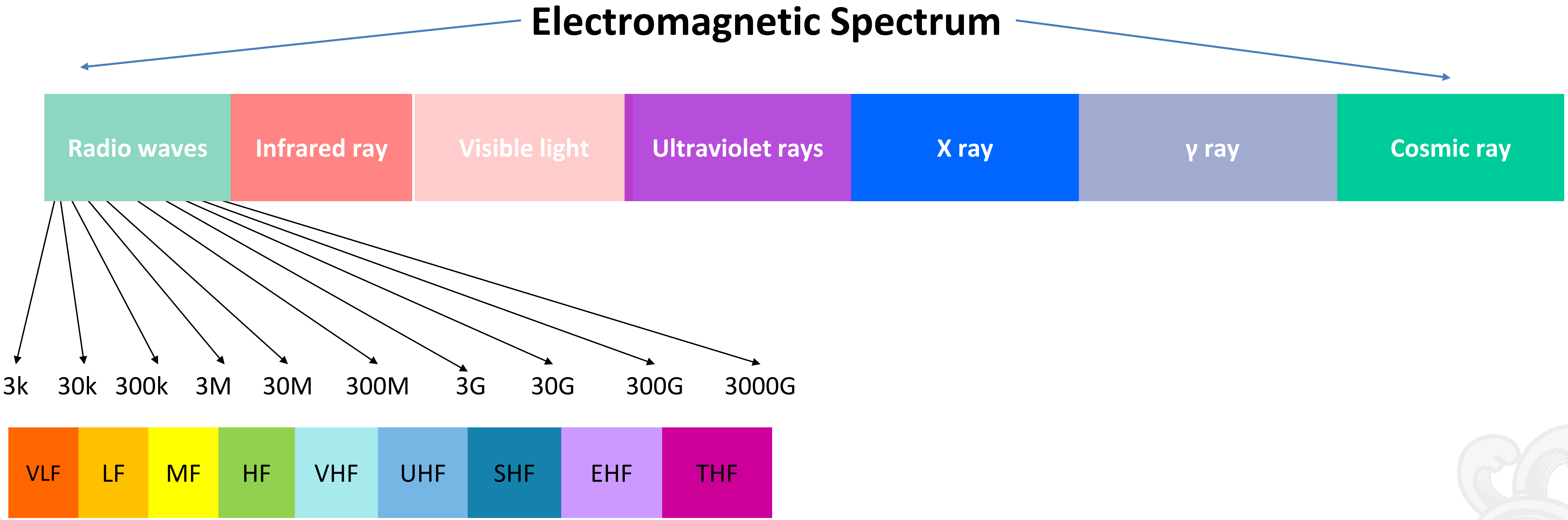
Principles

国家无线电监测中心
The State Radio Monitoring Center

Principles

Radio waves

- Electromagnetic waves of frequencies arbitrarily lower than 3000 GHz, propagated in space without artificial guide.



Principles

Widely use of radio spectrum

- **Home**（Wi-Fi）
- **Regional** (Mobile communication)
- **Overseas**（HF communication）
- **Global**（Satellite）
- **Outer space**（Radio astronomy）

Principles

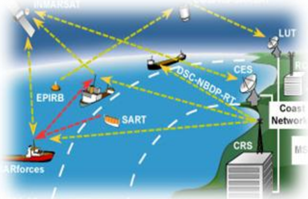
Use of radio spectrum

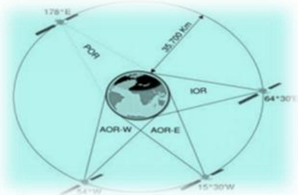
- **To realize information transmission by utilizing the radio propagation**

  - Two-way communication: point to multipoint

    public mobile, intercom, GMDS, Aeronautical HF/VHF, INMARSAT



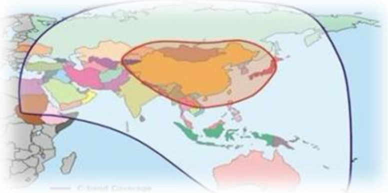




  - Two-way communication: point to point

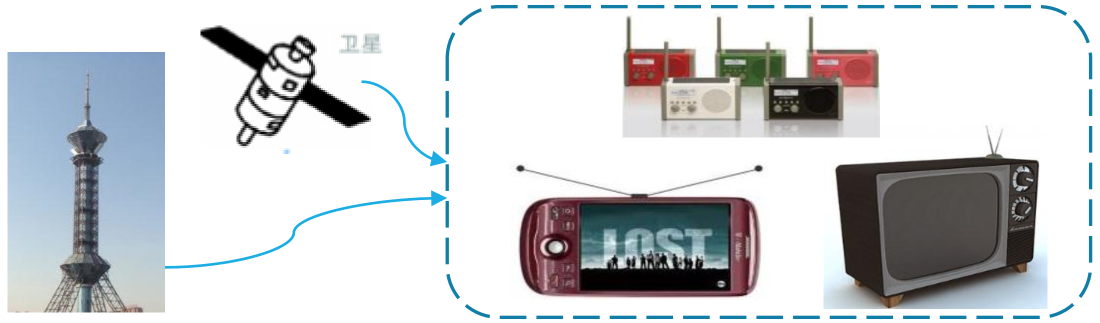
    HF、Microwave relay、Asia-Pacific 7





  - One-way communication: broadcasting

    Audio, TV, multimedia broadcasting

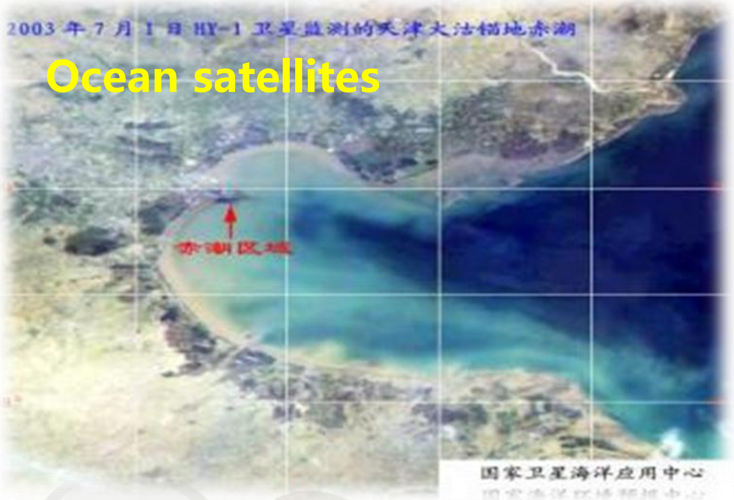


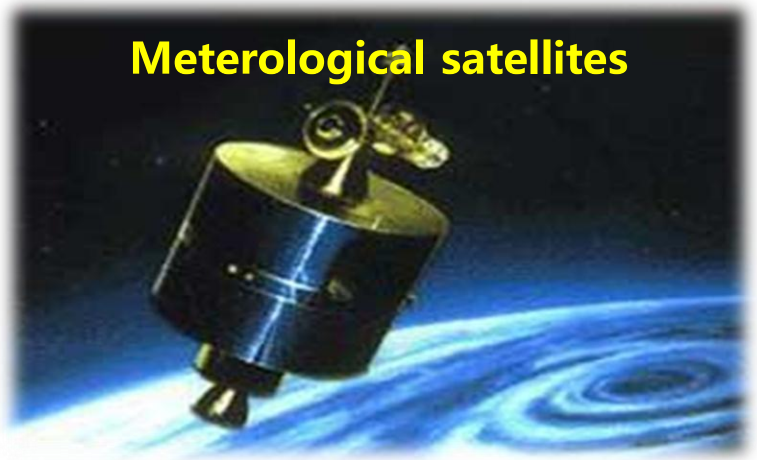
Principles

Use of radio spectrum

- To realize target detection by **reflection**
  - Radiolocation

  - Exploring information from the nature





Principles

Use of radio spectrum

- To generate heat by radio electromagnetic characteristics

  - In a microwave oven, microwave penetrates the food with oscillation frequency of 2450MHz. When the microwave is absorbed by food, polar molecules in food (such as water, fat, protein, sugar, etc.) are attracted to rapid oscillations, the food is heated.

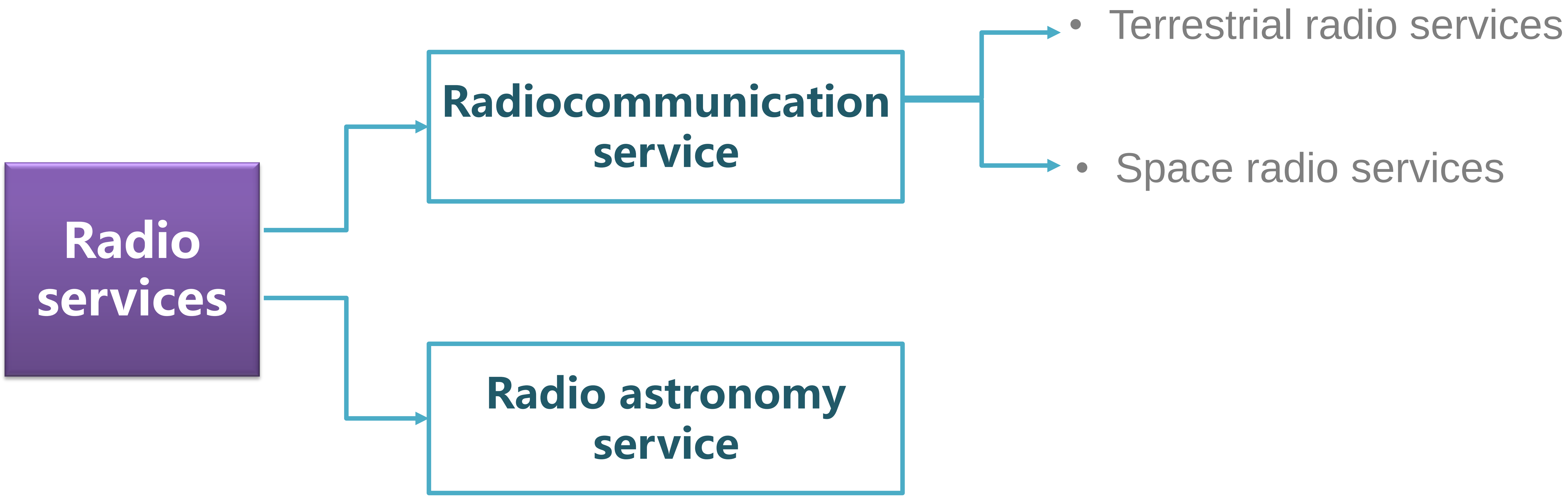
Principles

Use of radio spectrum

- **To explore the universe and study the origins of human beings.**
  - Radio astronomy is a subfield of astronomy that studies celestial objects celestial objects at radio frequencies.

Principles

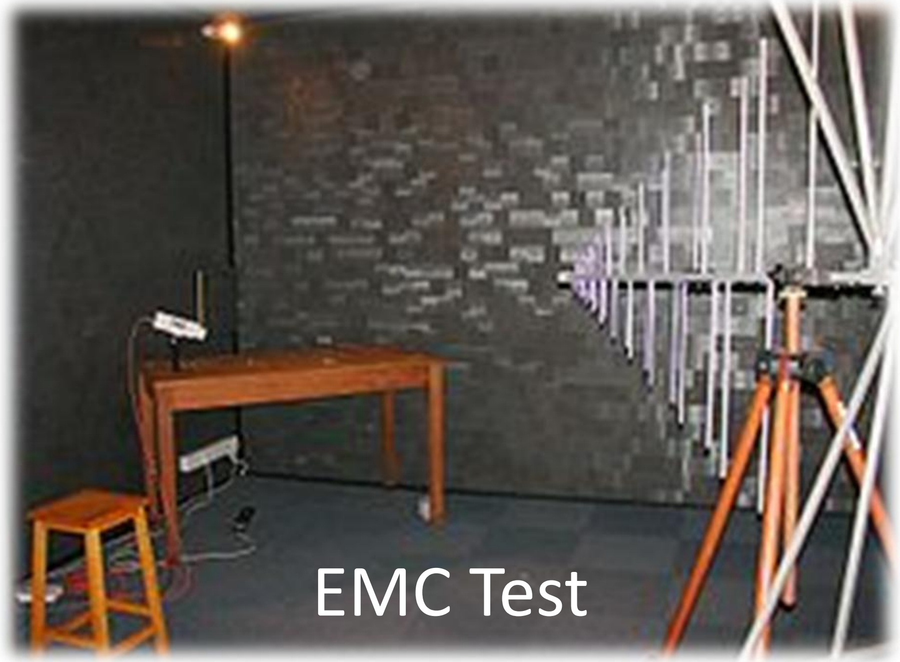
Radio Regulations **of ITU has defined 42 radio services**



Principles

Electromagnetic compatibility (EMC)

- Before frequencies are allocated for a new radio application, compatibility with existing radio systems and with non-radio devices must be ensured, which is referred as EMC*.
- Purely theoretical radio compatibility studies are often not adequate. The monitoring service may be called to assist with the necessary practical studies.


EMC Test

* Source: ITU-R. Handbook on National Spectrum Management. Editon of 2015.

Principles

Technical parameters

- Carrier frequencies
- Transmitter power
- Bandwidth
- Unwanted emission
- Intermodulation products
- Sensitivity of radio receivers

Principles

Interference analysis

- The wanted signal at the receiver is mainly degraded by four interference types:

Co-channel interference

Adjacent channel interference

Receiver desensitization

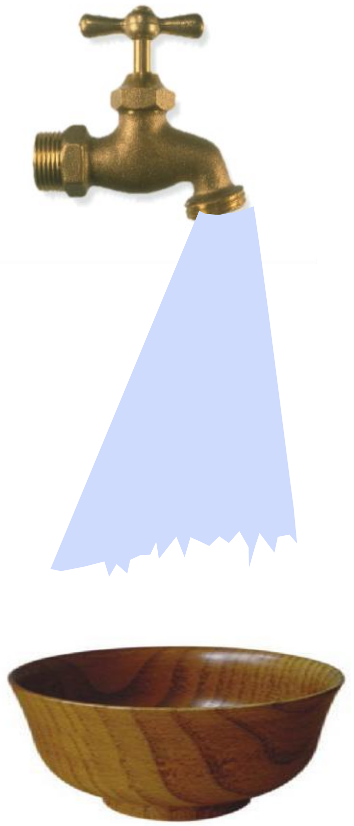
Intermodulation interference

Principles

Interference types

Co-channel interference

- Caused by the presence of desired and interfering signals operating in the same channel within the bandwidth of the intermediate frequency (IF) amplifier
- Both the desired and interfering signals overlap, the interfering signal cannot be filtered out by normal means
- The main reason for co-channel interference is the same frequency reused for radio stations, and stations operating at same frequency without coordination, such as illegal stations, stations in the border areas with neighboring country

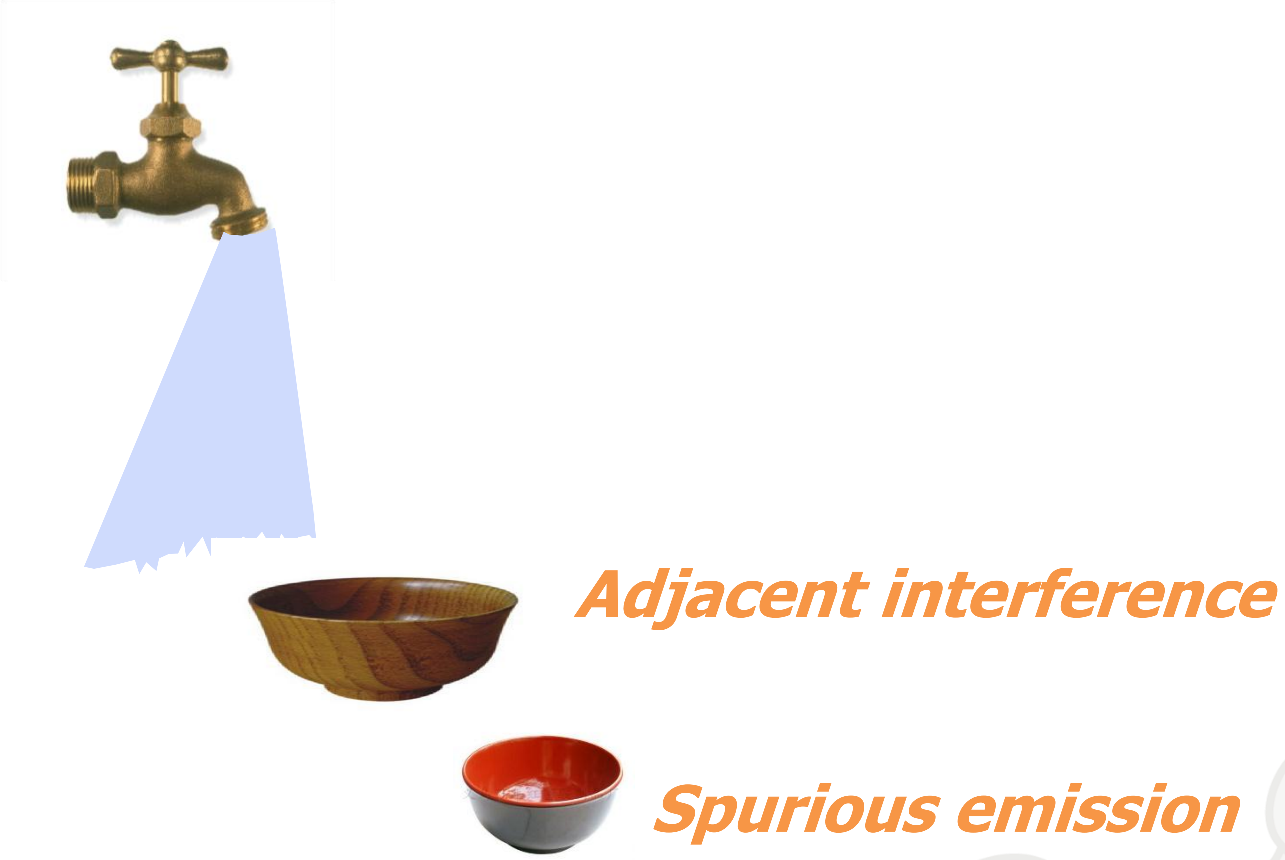


Principles

Interference types

Adjacent channel interference

- May occur due to an interfering signal operating in the adjacent channel or transmitter spurious emissions
- The level of adjacent-channel interference is dependent on the radio-frequency rejection characteristics of the receiver, which refers to the filtering effect of the receiver's front-end filter and the intermediate frequency filter

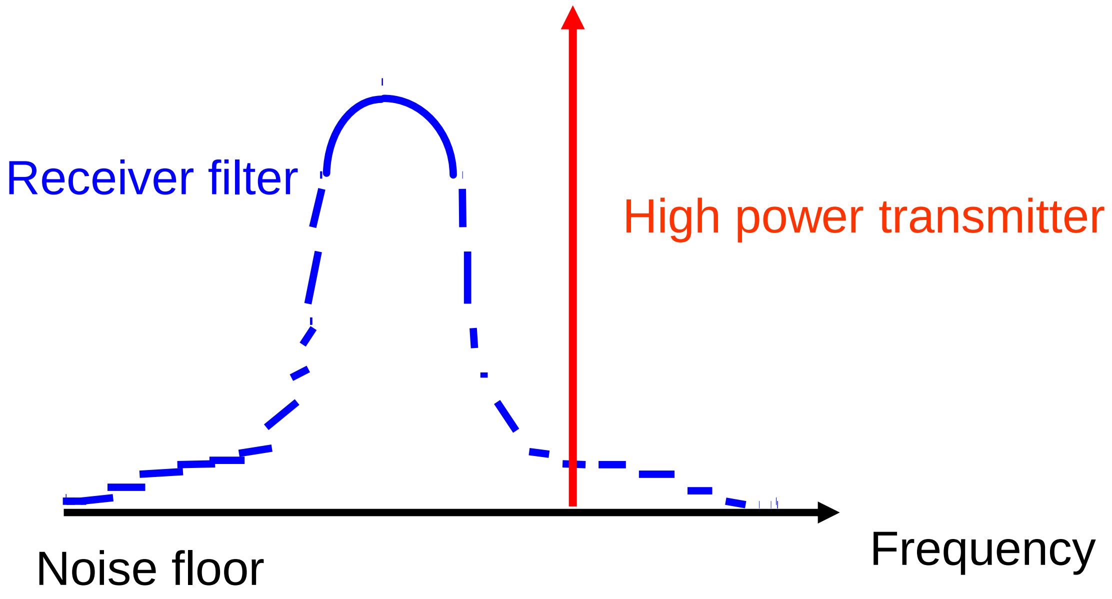


Principles

Interference types

Receiver desensitization

- Desensitization may occur when an interfering transmitter operates at close proximity to a receiver. If the interfering signal is sufficiently strong the receiver may be driven to saturation
- **Blocking interference** means that when strong interfering signals are added to the receiver at the same time as the wanted signal, strong interference will saturate the nonlinear components of the receiver link and produce non-linear distortion

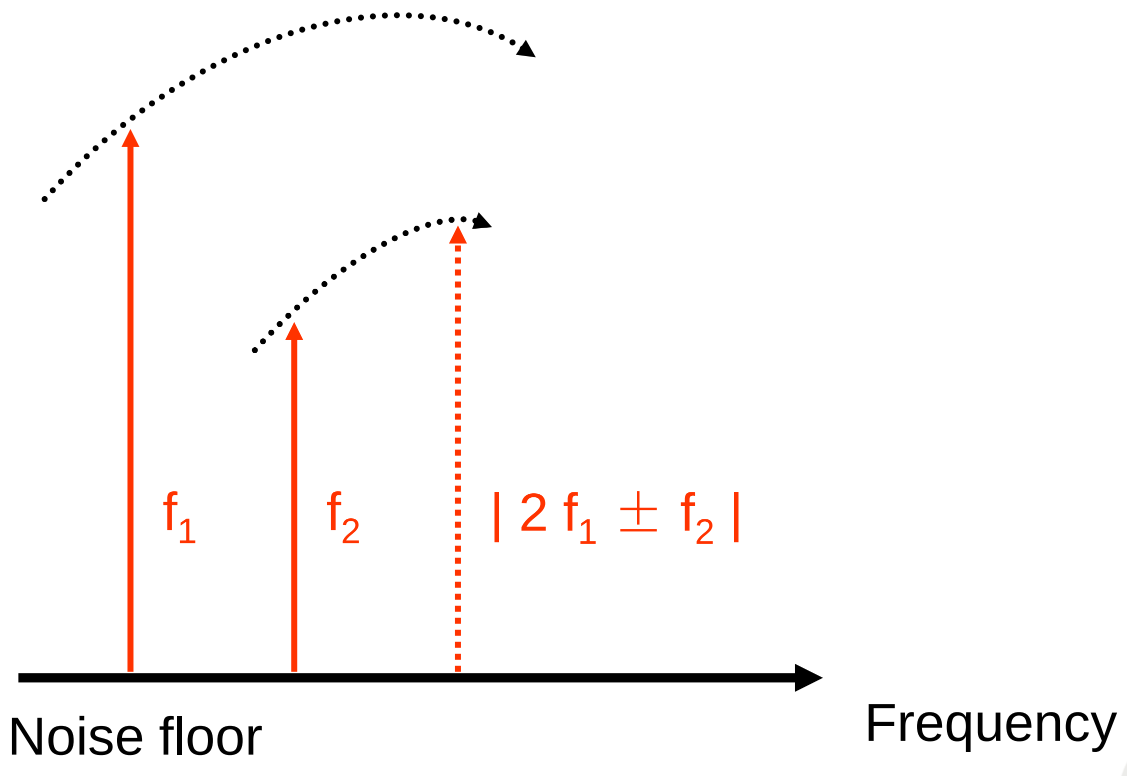


Principles

Interference types

Intermodulation interference

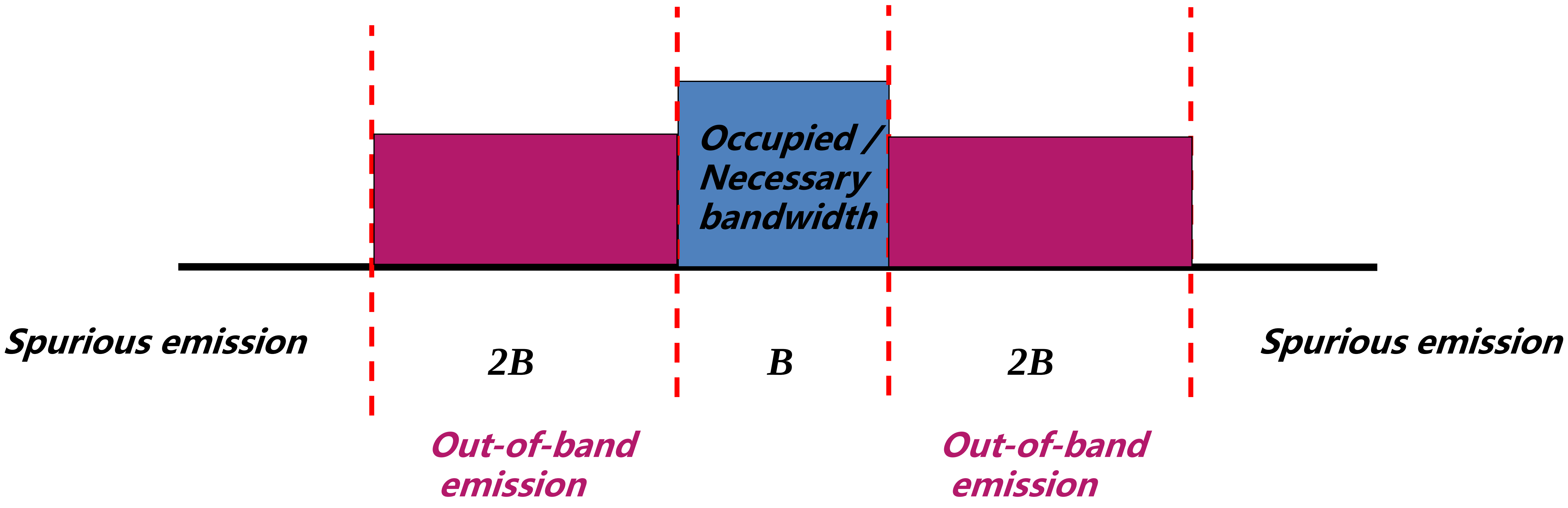
- Caused by the non-linearities in a transmission circuit.
- When two or more different frequency signals are input to the non-linear circuit, many harmonic and combined frequency components are generated.
- The combined frequency components which close to the desired signal frequency will be successfully through the receiver to become interference, this interference is called intermodulation interference.
- The third order intermodulation products cause the most serious impact.



Principles

Technical parameters

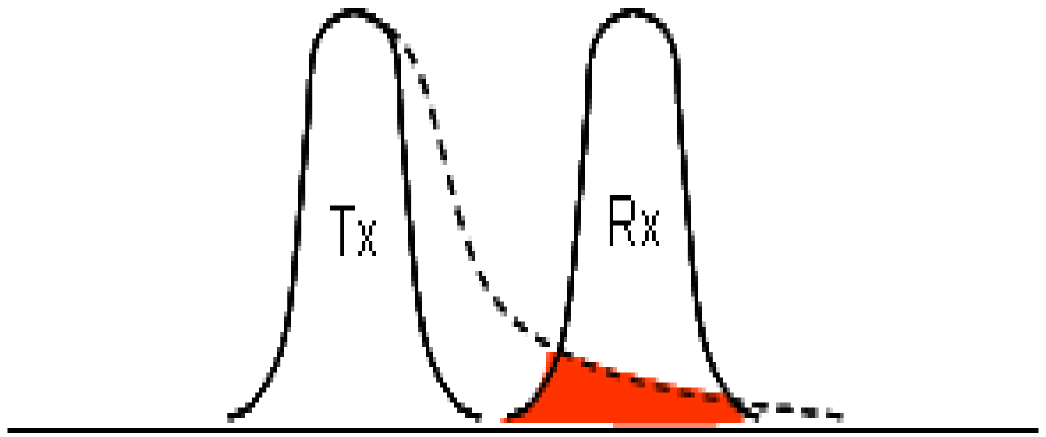
- Unwanted emission:
  includes out-of-band emission and spurious emission



Principles

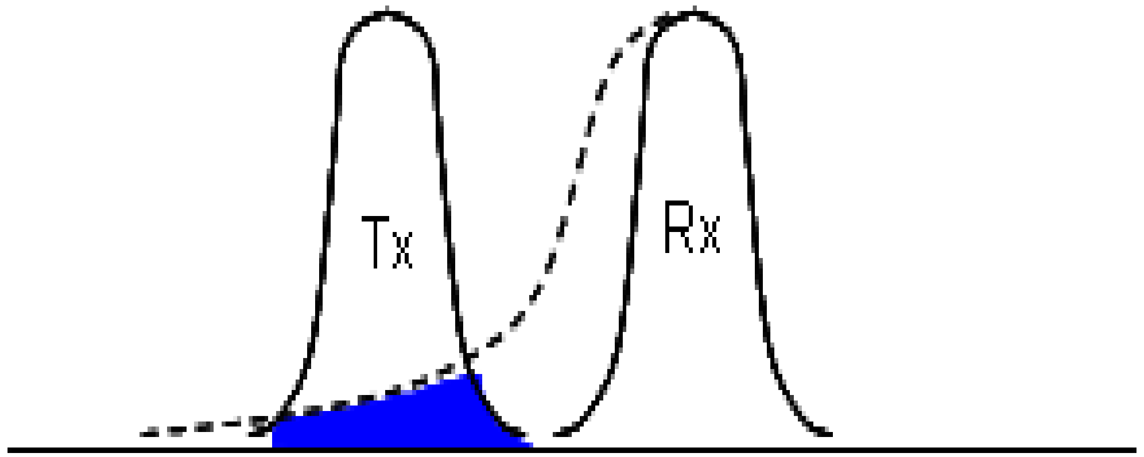
Adjacent channel interference

ACLR



$$\frac{1}{ACIR} = \frac{1}{ACLR} + \frac{1}{ACS}$$

ACS



Principles

Interference calculation

- Interference level for co-channel, adjacent channel and desensitization:

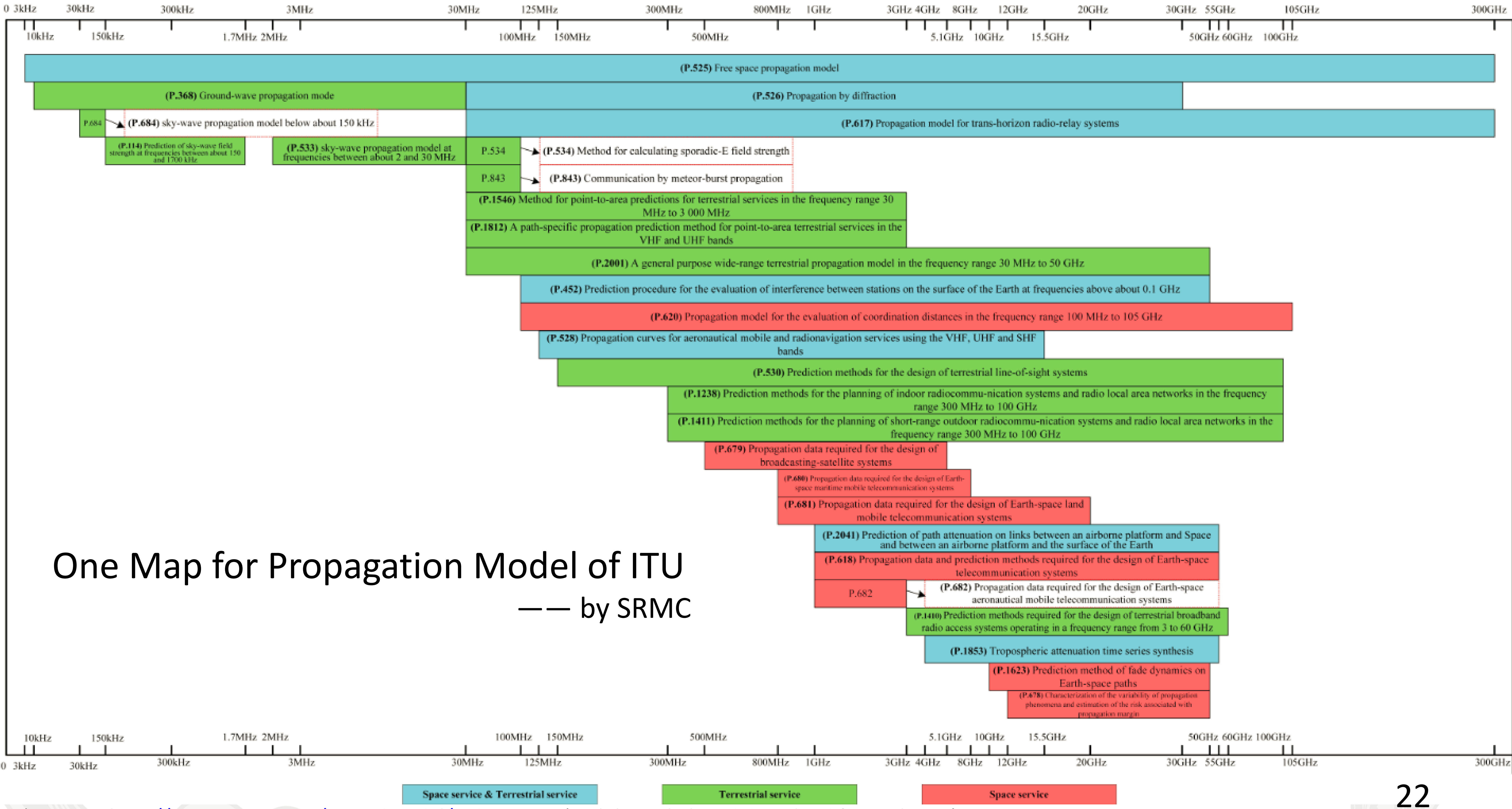
$$I = P_t + G_t + G_r - L_b(d) - FDR(\Delta f)$$

- P_t, the interfere transmitter power,
- G_t, the gain of the interfere antenna in the direction of the receiver (dBi)
- G_r, the gain of the interfere antenna in the direction of the interferer(dBi)
- $L_b(d)$, the basic loss for a separation distance d between the receiver and the interferer,
- $FDR(\Delta f)$, the frequency dependent rejection depending on f.

Principles

Model of propagation

- Core factors of spectrum engineering in EMC link budget calculation
- ITU-R Recommendation P. series
    - Terrestrial/Space
- ITU-R Study Group 3
- Other models
    - 3GPP Technical Report, e.g. TR 36.873 Study on 3D channel model for LTE
    - Intra-system/Inter-system



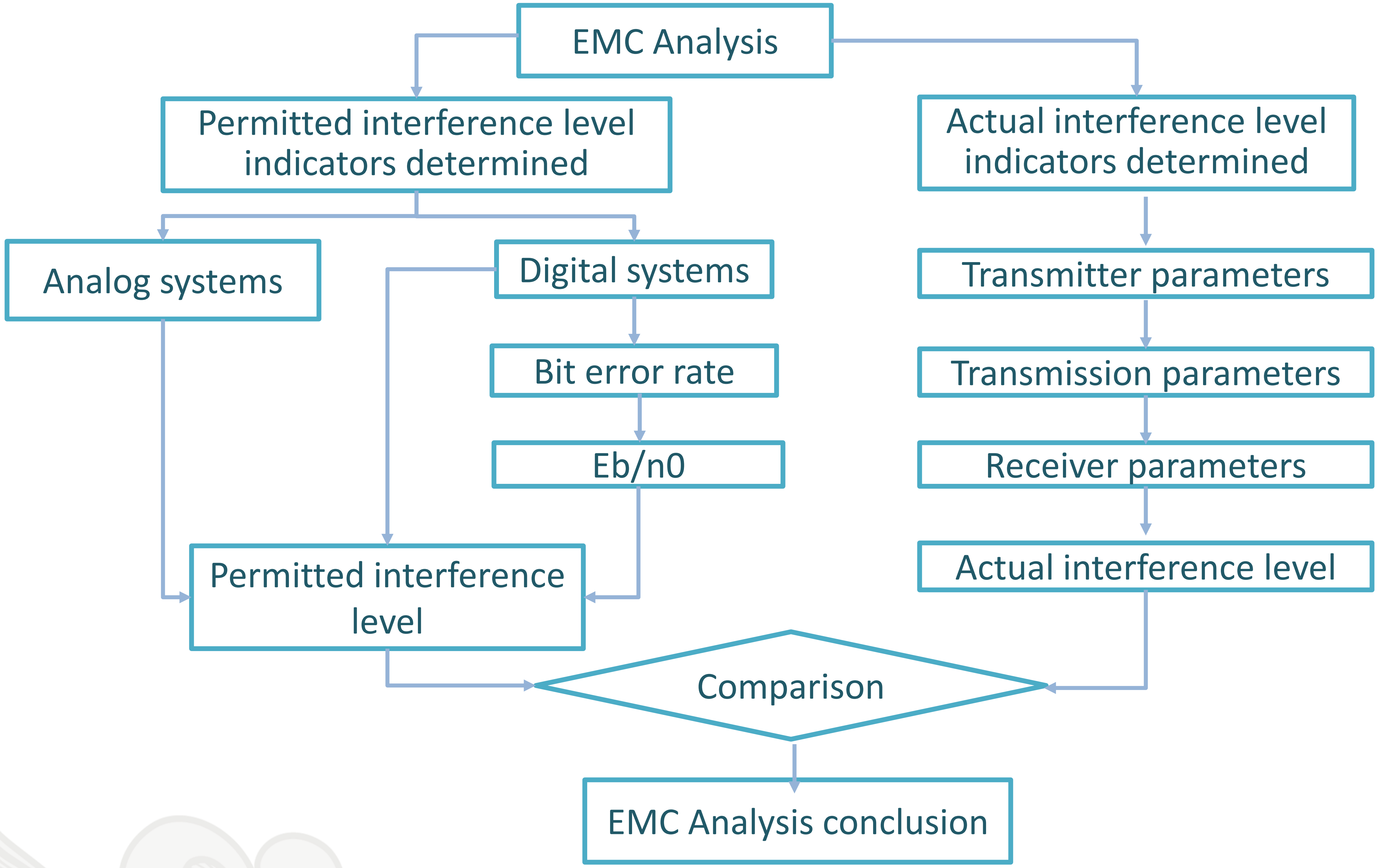
One Map for Propagation Model of ITU

—— by SRMC

* Source: http://www.srrc.org.cn/spreadmodel/Index.aspx (with hyperlink and download for each REC)

Principles

EMC Analysis Methodology



Methodology

- Deterministic calculation
- Simulation
- Test

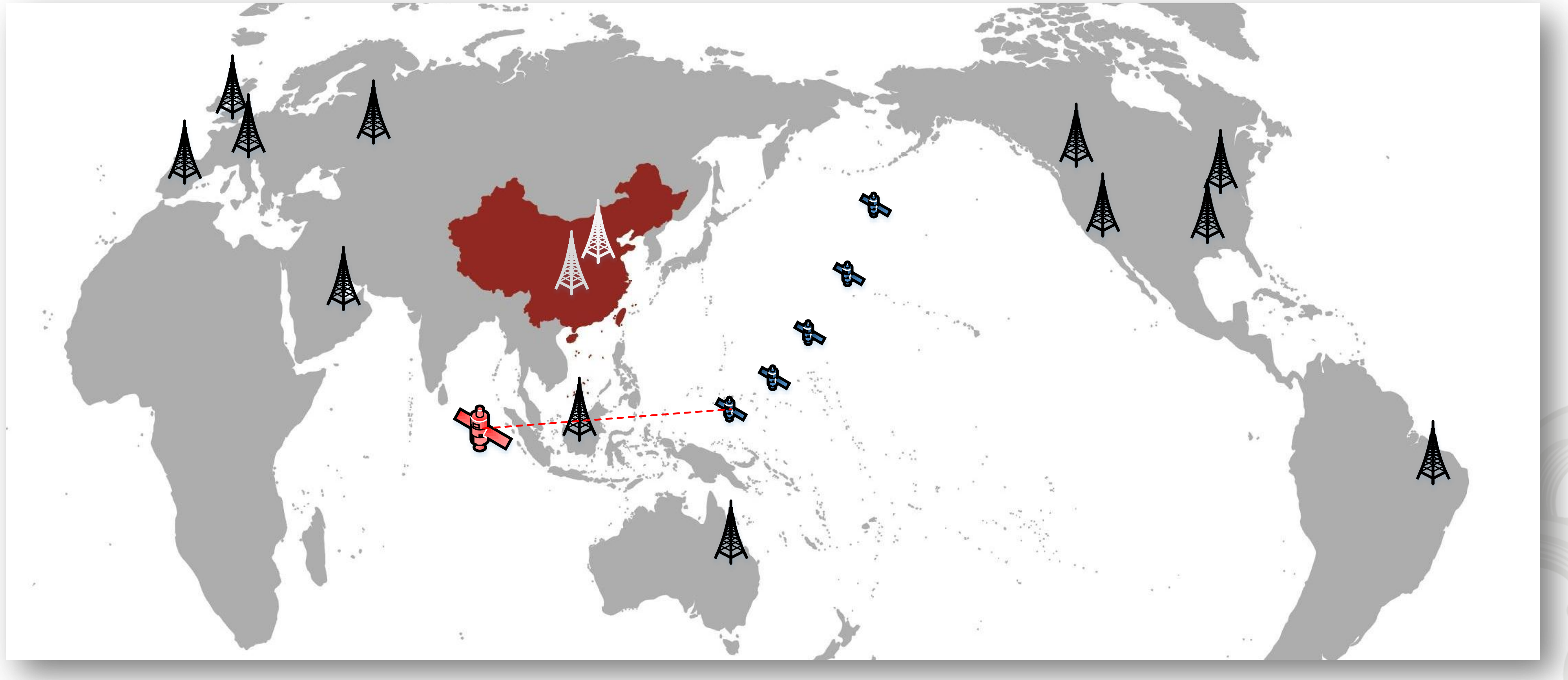
Case study:

5G and ISS @26GHz

国家无线电监测中心
The State Radio Monitoring Center

Case study: 5G and ISS @26GHz

- **Sharing and compatibility between IMT-2020 (5G) system and inter satellite service in the frequency range 25.25-27.5GHz**
  - A very typical, complicated, challenging and interesting case study
  - A sharing and compatibility between terrestrial and space radio services
  - A global size issue, not a country size



Case study: 5G and ISS @26GHz

1. Background

- **WRC-19 Agenda Item 1.13**
  - Resolution 238 (WRC-15) calls for studies to determine **the spectrum needs** for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz, as well as **sharing and compatibility studies**, taking into account the protection of services to which the band is allocated on a primary basis, for the frequency bands:
    – **24.25-27.5 GHz , 37-40.5 GHz, 42.5-43.5 GHz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4 52.6 GHz, 66-76 GHz and 81-86 GHz**, which have allocations to the mobile service on a primary basis; and
    – **31.8-33.4 GHz, 40.5-42.5 GHz and 47-47.2 GHz**, which may require additional allocations to the mobile service on a primary basis.

Case study: 5G and ISS @26GHz

1. Background

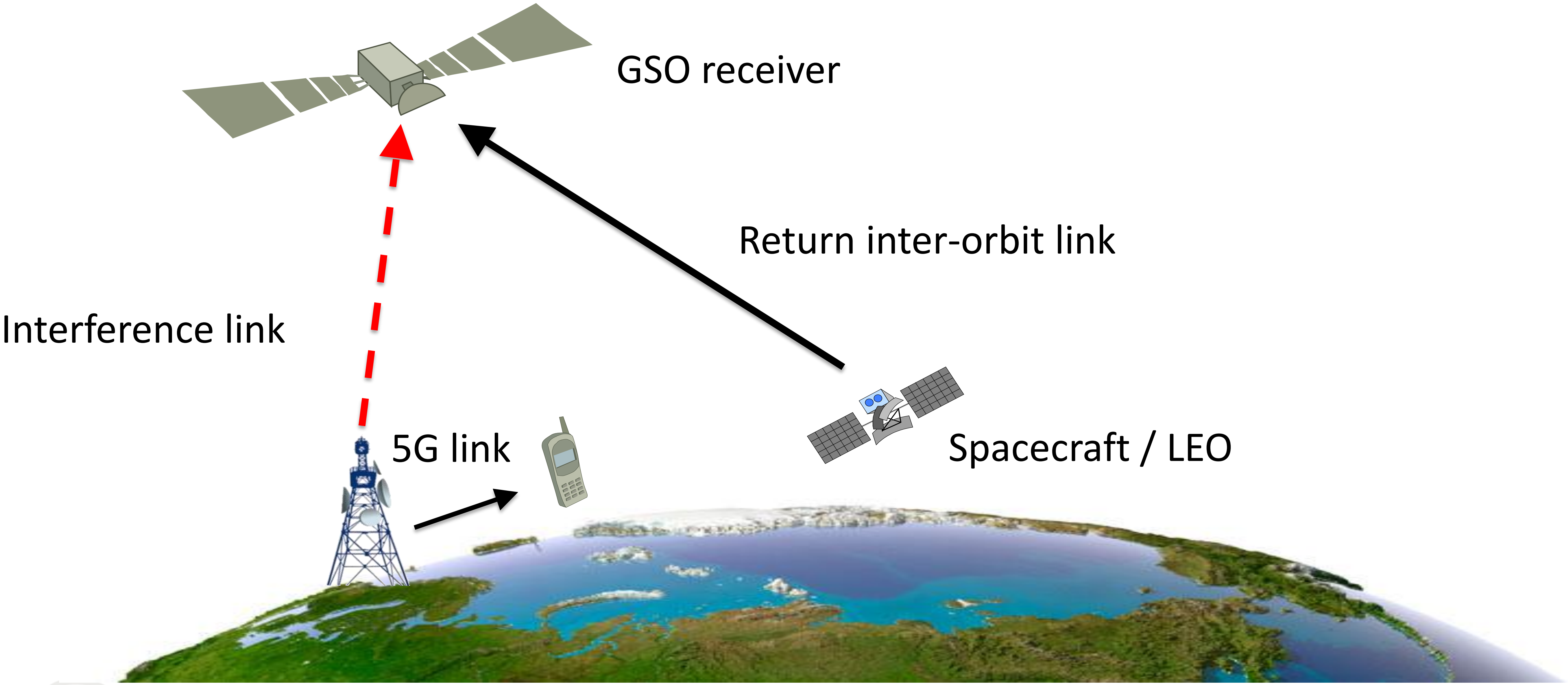
- **Frequency allocations in the 25.25-27.5 GHz frequency range**

Allocation to services		
Region 1	Region 2	Region 3
25.25-25.5 FIXED INTER-SATELLITE 5.536 MOBILE Standard frequency and time signal-satellite (Earth-to-space)		
25.5-27 EARTH EXPLORATION-SATELLITE (space-to Earth) 5.536B FIXED INTER-SATELLITE 5.536 MOBILE SPACE RESEARCH (space-to-Earth) 5.536C Standard frequency and time signal-satellite (Earth-to-space) 5.536A		
27-27.5 FIXED INTER-SATELLITE 5.536 MOBILE	27-27.5 FIXED FIXED-SATELLITE (Earth-to-space) INTER-SATELLITE 5.536 5.537 MOBILE	

Case study: 5G and ISS @26GHz

2. Scenario for study

- According to ITU-R REC. SA.1414, ISS in this frequency band is reverse link (low -> high)



Case study: 5G and ISS @26GHz

3. Key technical and operational characteristics

- inter-satellite service operating in 25.25-27.5GHz - transmitting

Network	Europe	Japan	United States of America	China	Russian Federation
Orbital locations	Mainly low-Earth orbit				
Transmission rate	≤ 300 Mbit/s	≤ 300 Mbit/s	≤ 800 Mbit/s	≤ 600 Mbit/s	≤ 600 Mbit/s
Modulation	OQPSK	PSK	PSK	PSK	MPSK
Polarization	Circular				
Antenna size (m)	(3)	≤ 1.9	≤ 1.5	≤ 0.8	≤ 1
Tx antenna gain (dBi)	≤ 50	≤ 49.7	≤ 47	≤ 44.5	≤ 46.1
Tx antenna radiation pattern	Rec. ITU-R S.672				
Necessary bandwidth (MHz)	≤ 405 per channel	≤ 300	≤ 650	≤ 600	≤ 300
Maximum power spectral density (dB(W/Hz))	-58.5	–58.8	–67.5	–50	-68.3
Maximum e.i.r.p. spectral density (dB(W/Hz))	-8.5	–9.1	–20.5	–5.5	-22.2

Case study: 5G and ISS @26GHz

3. Key technical and operational characteristics

- inter-satellite service operating in 25.25-27.5GHz - receiving

Network	Europe	Japan	United States of America	China	Russian Federation
Orbital locations	Rec. ITU-R SA.1275 or Rec. ITU-R SA.1276				
Antenna size (m)	1.3	3.6	4.9	4.2	4
Rx antenna gain (dBi)	49.0	58.8	55.9	57.5	57.4
Rx antenna radiation pattern	Rec. ITU-R S.672				
System noise temperature (K)	800	475	870	1 000	550
Link reliability (%)	99.6		99.9	99.9	99.9
Interference criterion	Rec. ITU-R SA.1155				

recommends

1 that receivers onboard DRS that operate in the 25.25-27.5 GHz band which should be protected in accordance with Recommendation ITU-R F.1249 are located at the following geostationary orbital positions (given in the East direction): 10.6°, 16.4°, 16.8°, 21.5°, 47°, 59°, 77°, 80°, 85°, 89°, 90.75°, 95°, 113°, 121°, 133°, 160°, 167°, 171°, 176.8°, 177.5°, 186°, 189°, 190°, 192.5°, 195.8°, 200°, 221°, 298°, 311°, 314°, 316°, 319°, 328°, 344°, 348°.

TABLE 1

Protection criteria

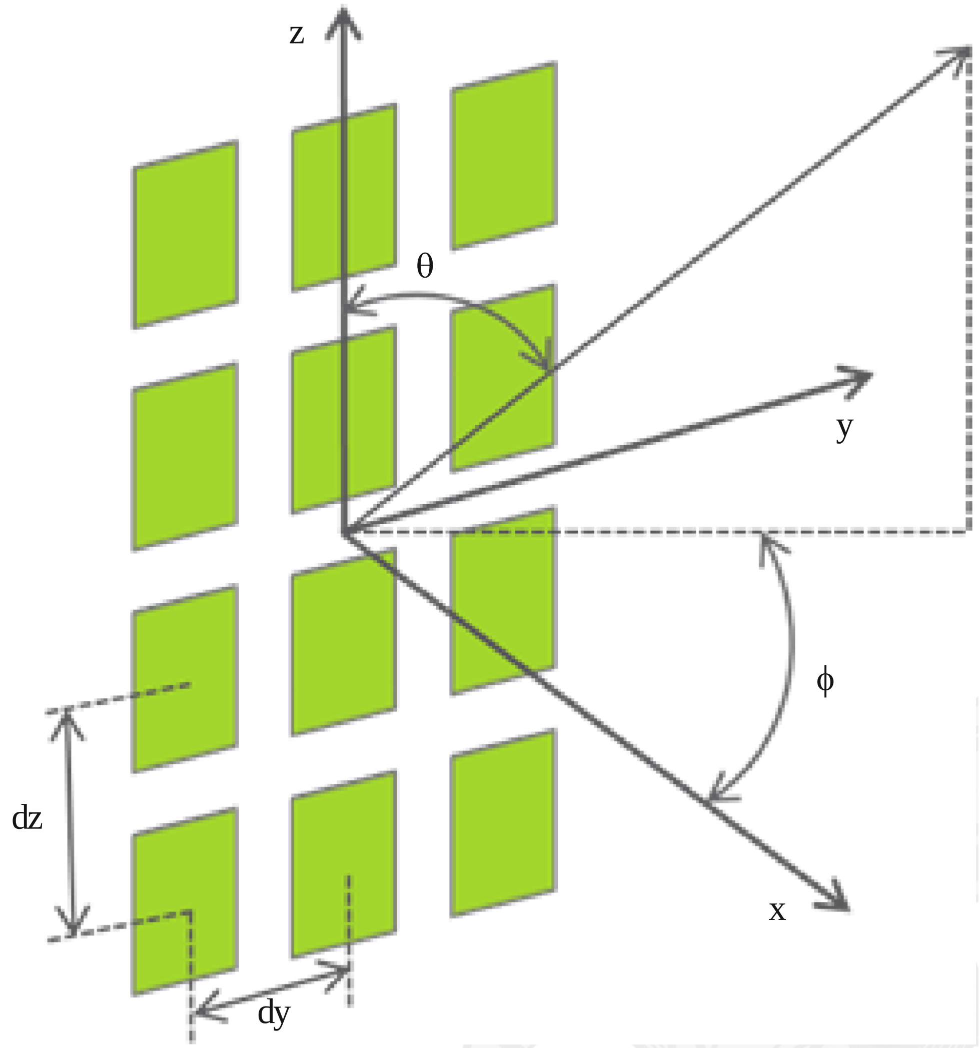
Data relay satellite link	**Receiver location**	**I_0/N_0 (dB)**
Forward inter-orbit link 2 025-2 110 MHz 13.4-14.3 GHz 22.55-23.55 GHz	User spacecraft	−10
Return inter-orbit link 2 200-2 290 MHz 14.5-15.35 GHz 25.25-27.5 GHz	Data relay satellite	−10

Case study: 5G and ISS @26GHz

3. Key technical and operational characteristics

- IMT systems - Outdoor urban hotspot - Base station characteristics/Cell structure

Channel bandwidth (MHz)		200 MHz
Duplex method		TDD
Network topology and characteristics		30 BSs/km^2
Frequency reuse		1
Antenna height (radiation centre)		6 m (above ground level)
Sectorization		Single sector
Downtilt		10 degrees
Antenna deployment		Below roof top
Network loading factor (Average base station activity)		20%, 50%
BS TDD activity factor		80%
1	Antenna Characteristics	
1.1	Antenna pattern	Rec ITU-R M.2101
1.2	Element gain (dBi)	5
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	65º for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	30 for both H/V
1.5	Antenna polarization	Linear ±45º
1.6	Antenna array configuration (Row × Column)	8×8 elements
1.7	Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V
1.8	Array ohmic loss (dB)	3
1.9	Conducted power (before ohmic loss) per antenna element (dBm/200 MHz)	10
1.10	Base station maximum coverage angle in the horizontal plane (degrees)	120



M.2101 -10

国家无线电监测中心
The State Radio Monitoring Center

Case study: 5G and ISS @26GHz

3. Key technical and operational characteristics

- **IMT systems - Outdoor urban hotspot - Deployment consideration in a relatively large area**

The deployment density values for large area (*Dl*) to be used in a sharing study is therefore calculated according to the following formula:

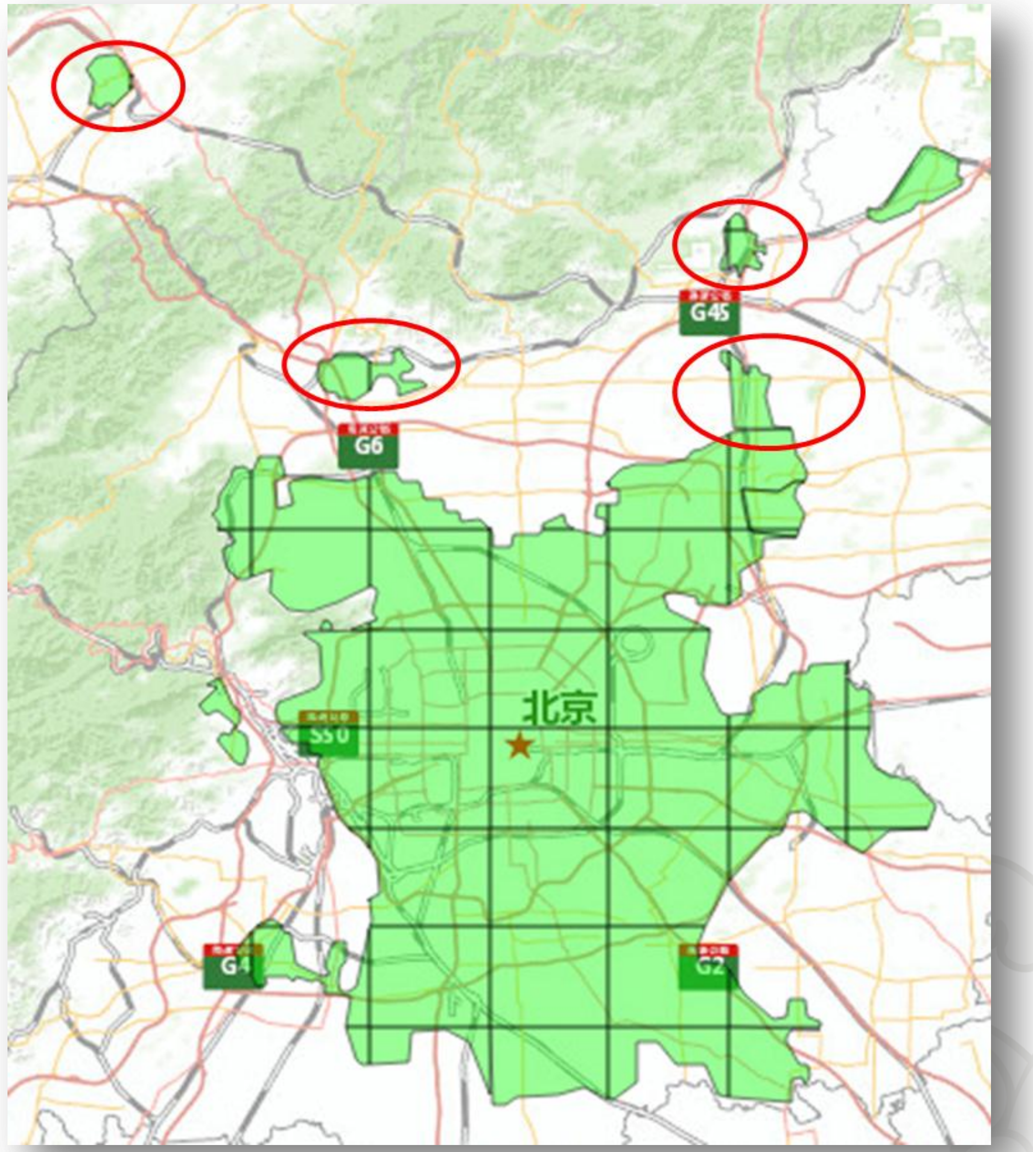
$$Dl = Ds * Ra * Rb$$

where:

Ds = Density value in Tables 10-13 for outdoor hotspot area, i.e. density of simultaneously transmitting UEs or number of BS per km^2 (see the "Network topology and characteristics" rows in the relevant Tables);

Ra (%) = ratio of hotspot areas to areas of cities/built areas/districts;

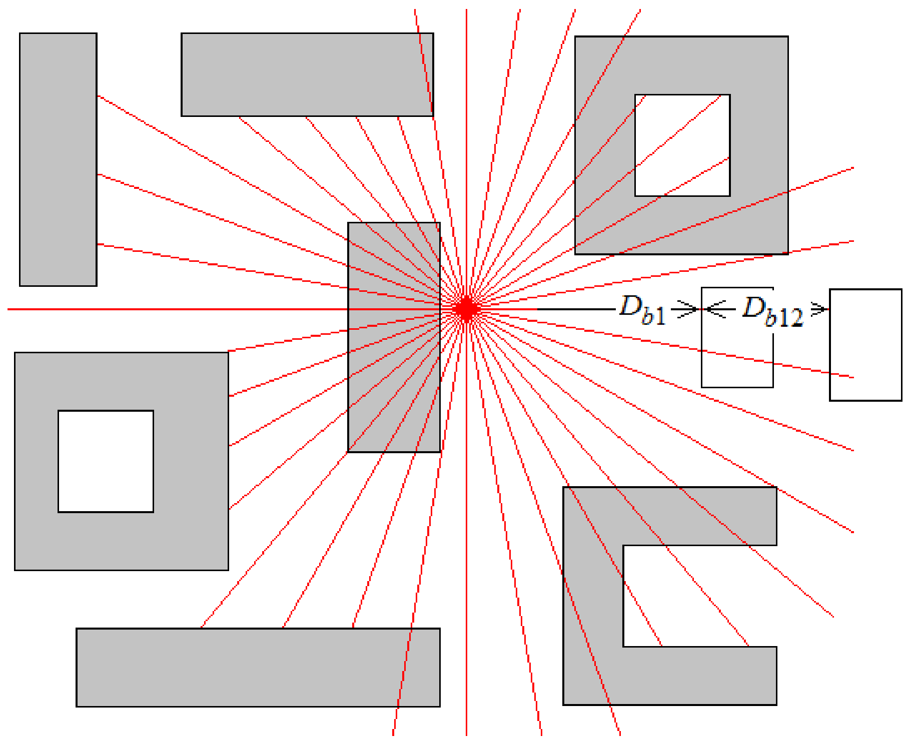
Rb (%) = ratio of built areas to total area of region in study.

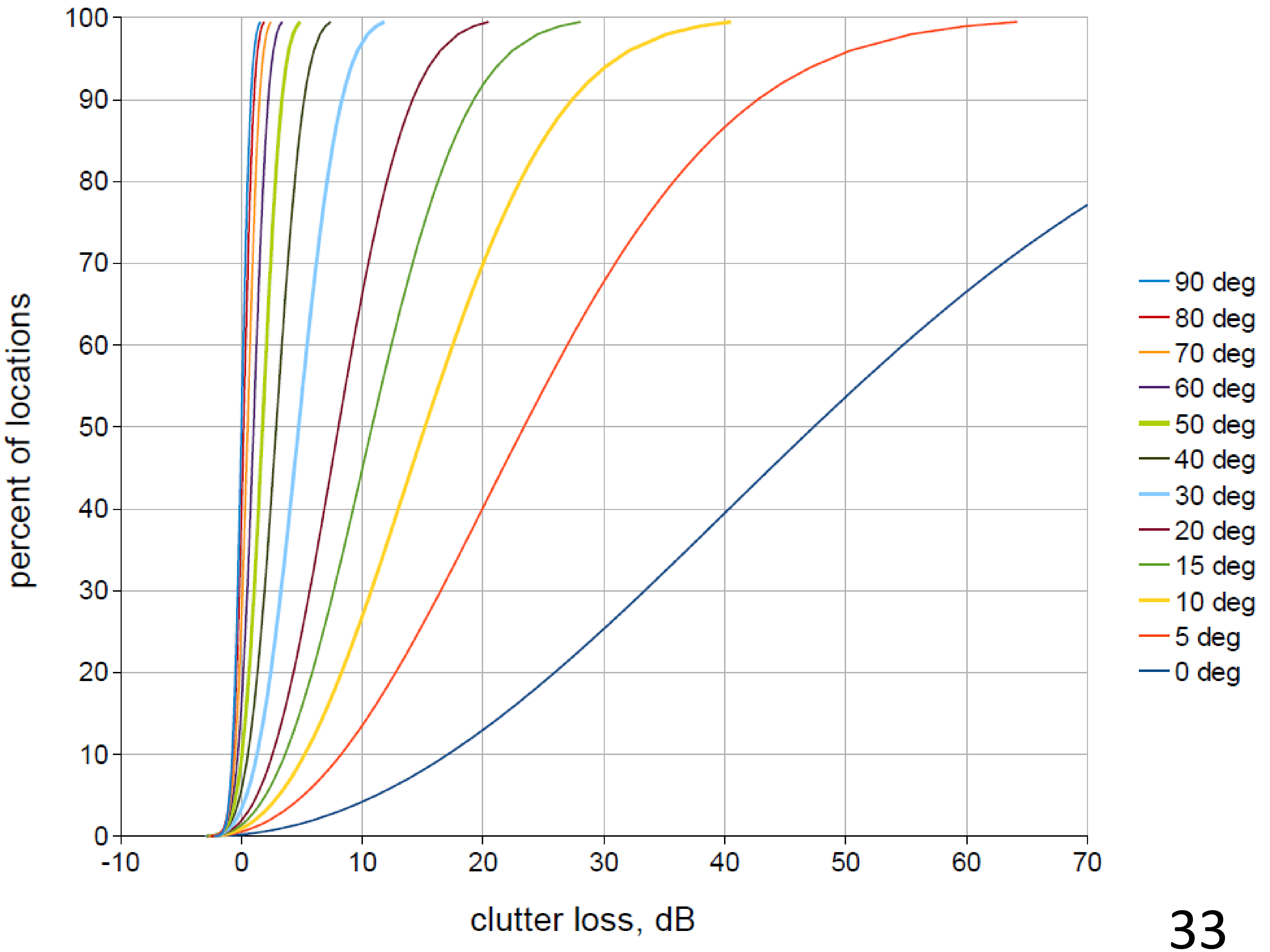


Case study: 5G and ISS @26GHz

3. Key technical and operational characteristics

- **Propagation models**
  - Freespace pathloss
  - Atmospheric loss
  - Clutter loss (BEL loss for indoor)

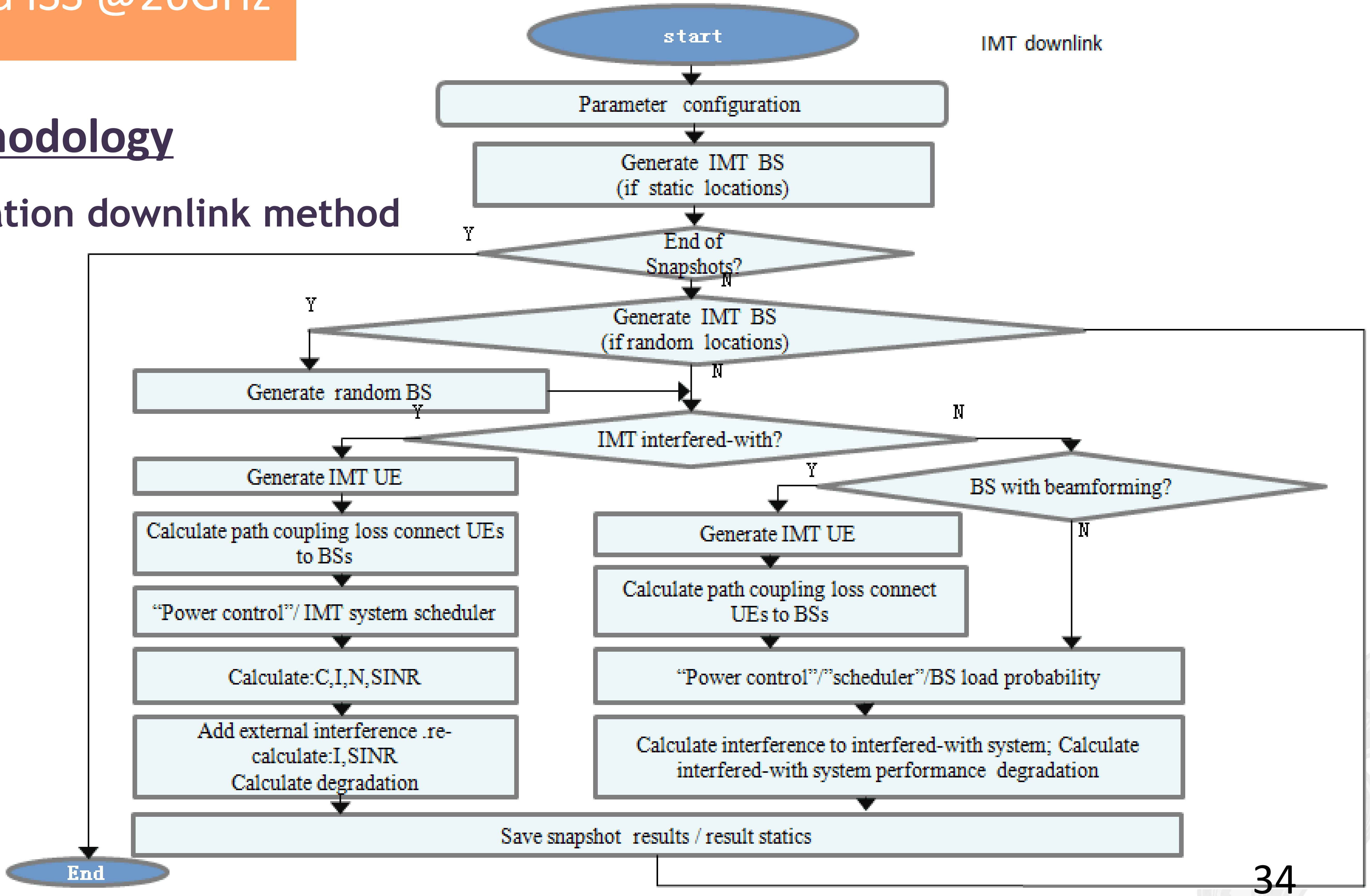




Case study: 5G and ISS @26GHz

4. Simulation methodology

- Flowchart of simulation downlink method

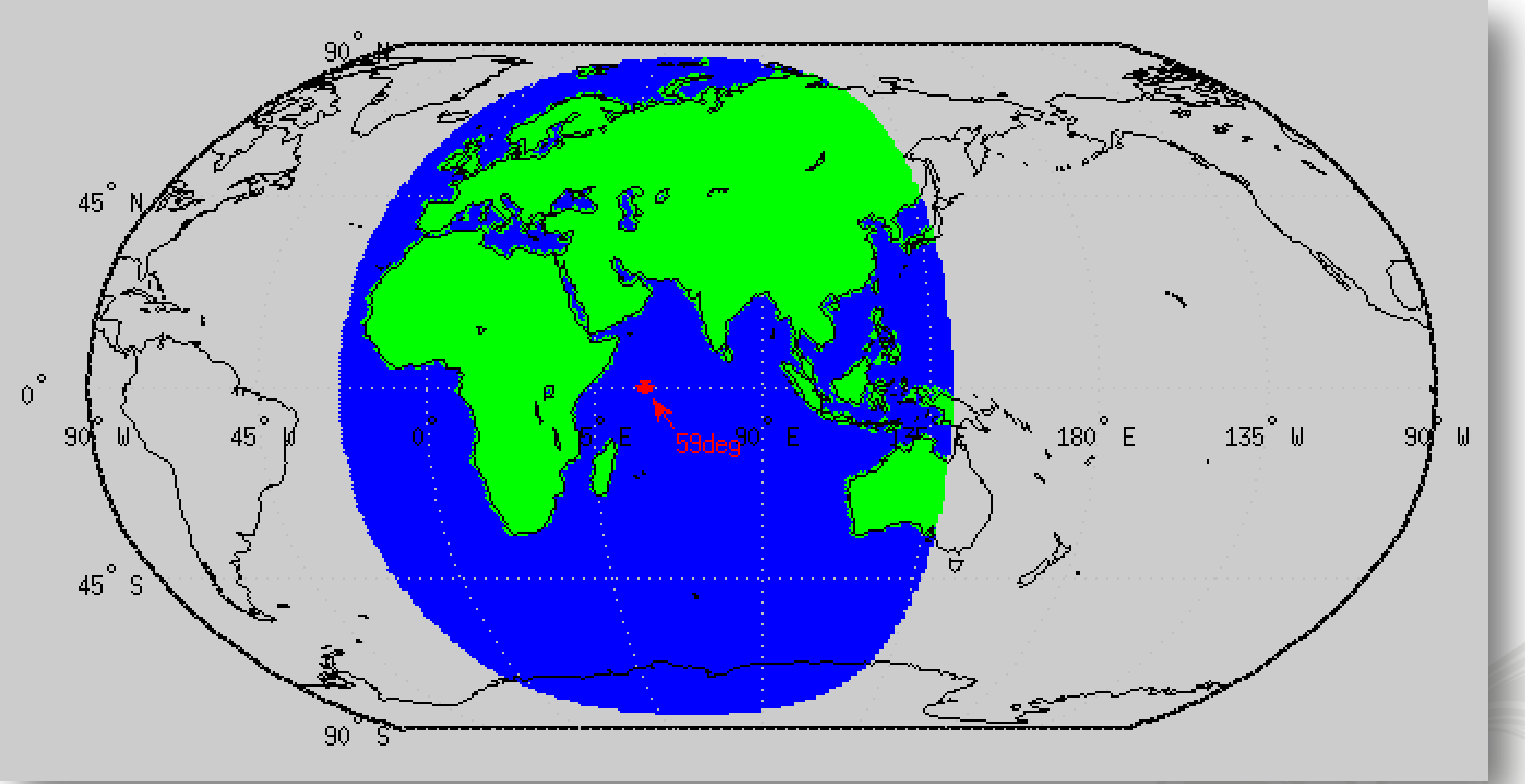


* Source: ITU-R Rec. M.2101

Case study: 5G and ISS @26GHz

4. Simulation methodology

- **Key problems:**
  - How to model the large amount of IMT base stations in a GSO visible area*, considering the individual beam-forming feature?
  - How to evaluate the protection criterion?
  - How to model NGSO-GSO tracking?



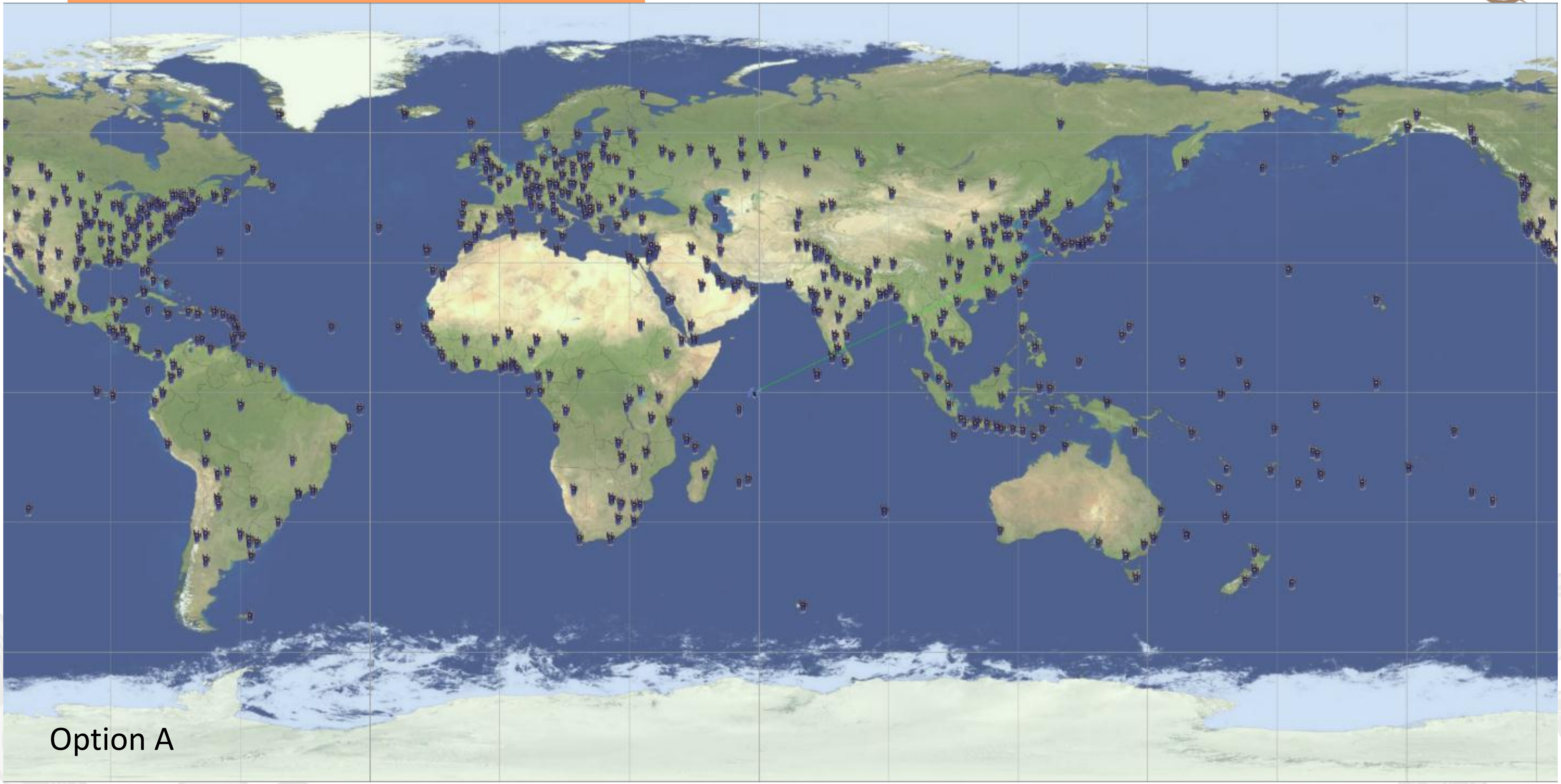
* Source: IMT-2020 (5G) Promotion Group Study Report

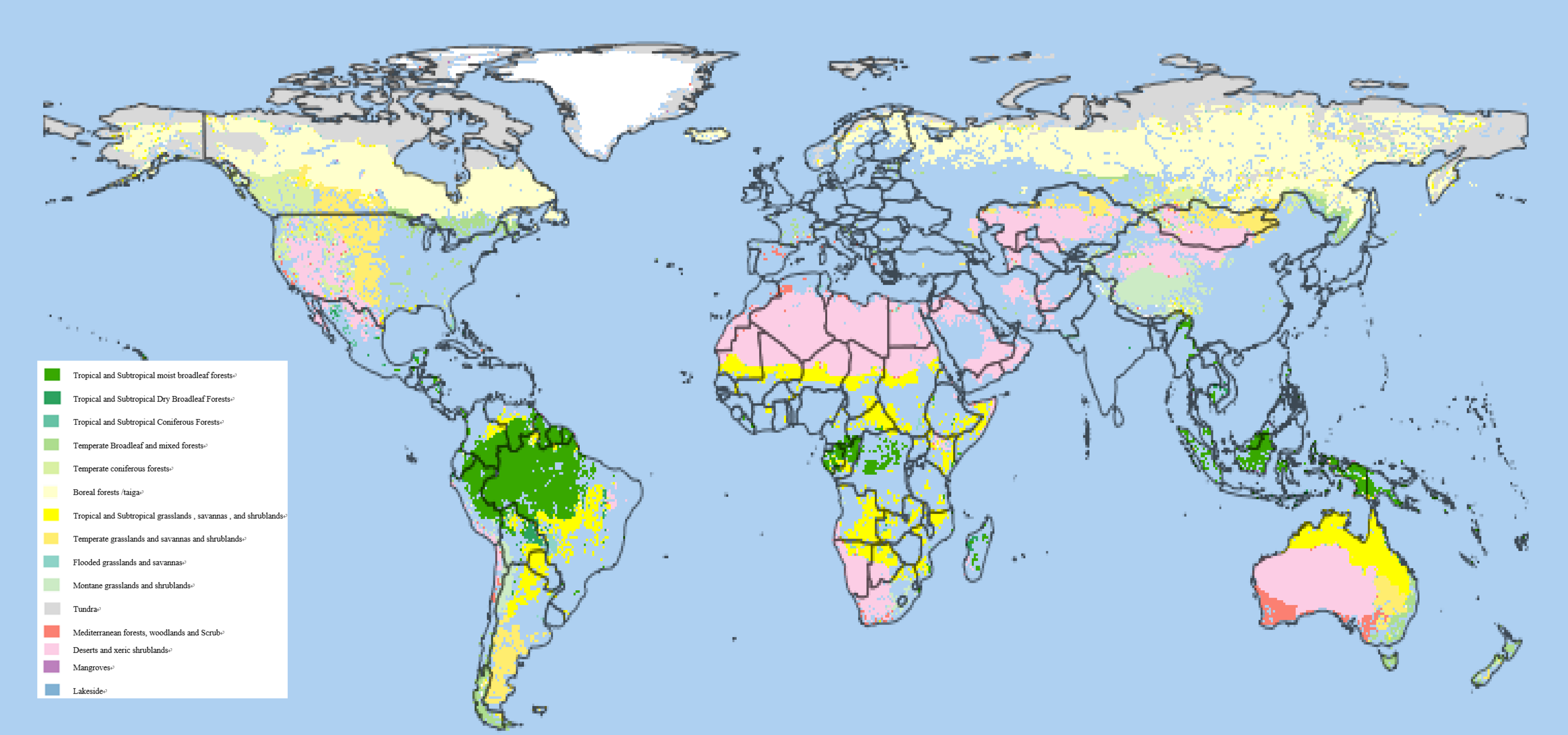
Case study: 5G and ISS @26GHz

4. Simulation methodology

- **Two options to model the large amount of IMT base stations**
  - Cluster by cluster* —— to define the central base stations (CBS), each CBS located in a specific city represents a number of base stations, i.e. the total transmission power is combine. And How many BSs that one CBS represents is according to the population or GDP or area of that city.
  - One by one —— to model the base stations in the global land area. For the unpopulated areas, e.g. deserts, forests, mountain regions etc. such areas/regions could be excluded.

*Source: Recommendation ITU-R F.1509-3 (09/2015), Technical and operational requirements that facilitate sharing between point-to-multipoint systems in the fixed service and the inter-satellite service in the band 25.25-27.5 GHz


Option A



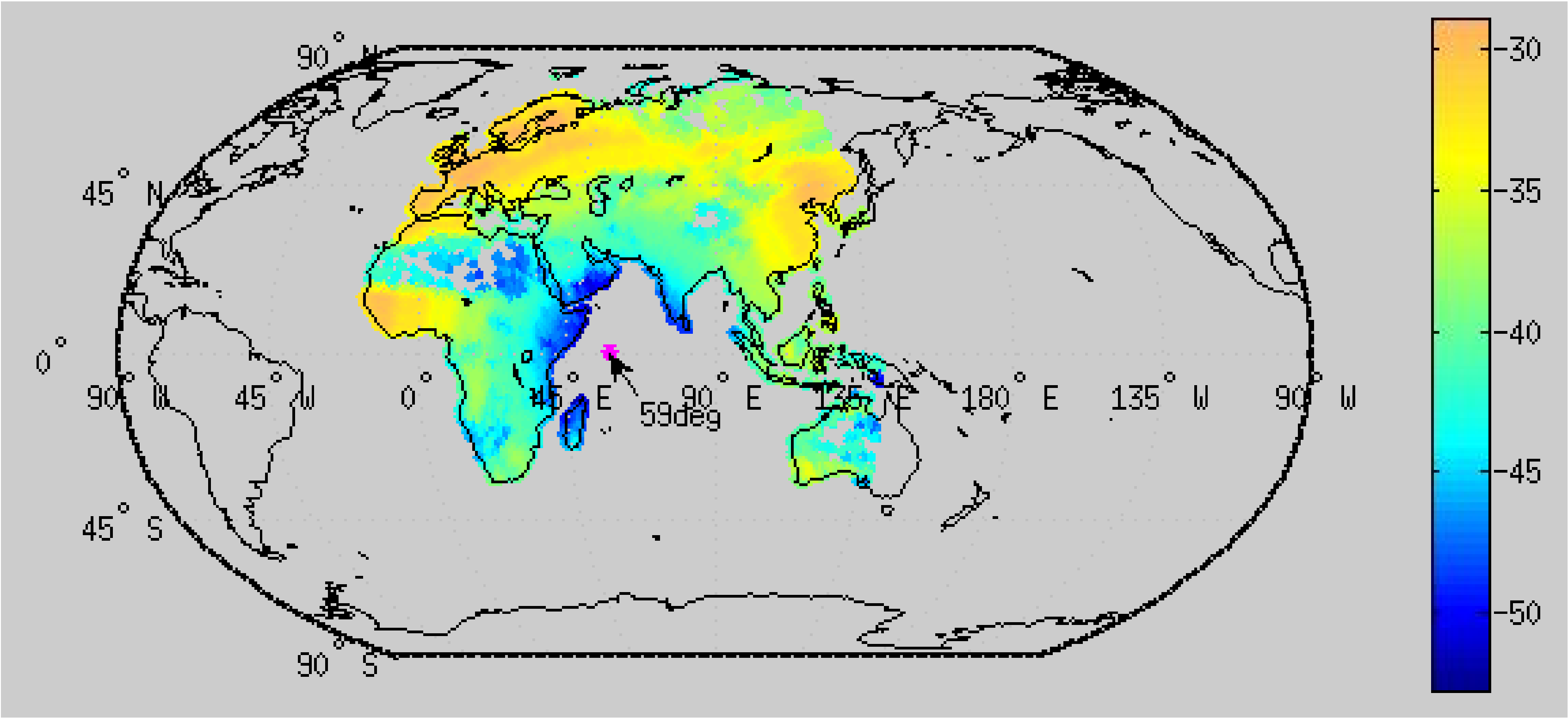
Option B*

*Source: IMT-2020 (5G) Promotion Group Study Report

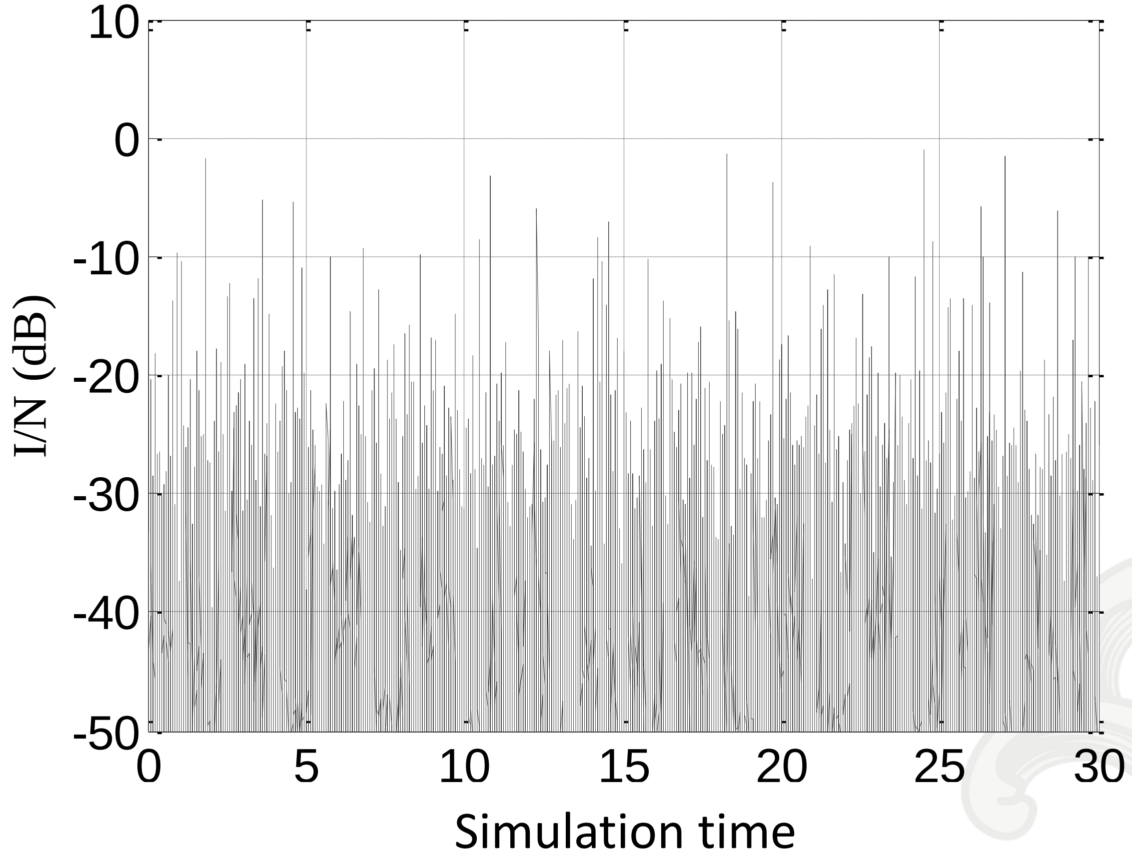
Case study: 5G and ISS @26GHz

4. Simulation methodology

- **How to evaluate the protection criterion**
  - Spatial analysis, the receiving antenna of the GSO scans the whole visible area
  - Temporal analysis, the receiving antenna of the GSO is assumed to be tracking a NGSO



* Source: IMT-2020 (5G) Promotion Group Study Report, a preliminary result



Case study: 5G and ISS @26GHz

4. Simulation methodology

- **How to model NGSO-GSO tracking**
  - ITU BR IFIC: to obtain specific satellite material from database

    GSO： name/orbit position/antenna characteristic/…

    NGSO： name/system/height/incline/antenna characteristic/…
  - Use Visualyse/STK software to model the track of running NGSO

    Simulation time step by several seconds/minutes…

    When there is a NGSO system, set a appropriate tracking strategy (nearest/specific/…)

Spectrum inventory and utilization evaluation

Spectrum inventory and utilization evaluation

Background

- Challenges of emerging ICT trends

Industry 4.0

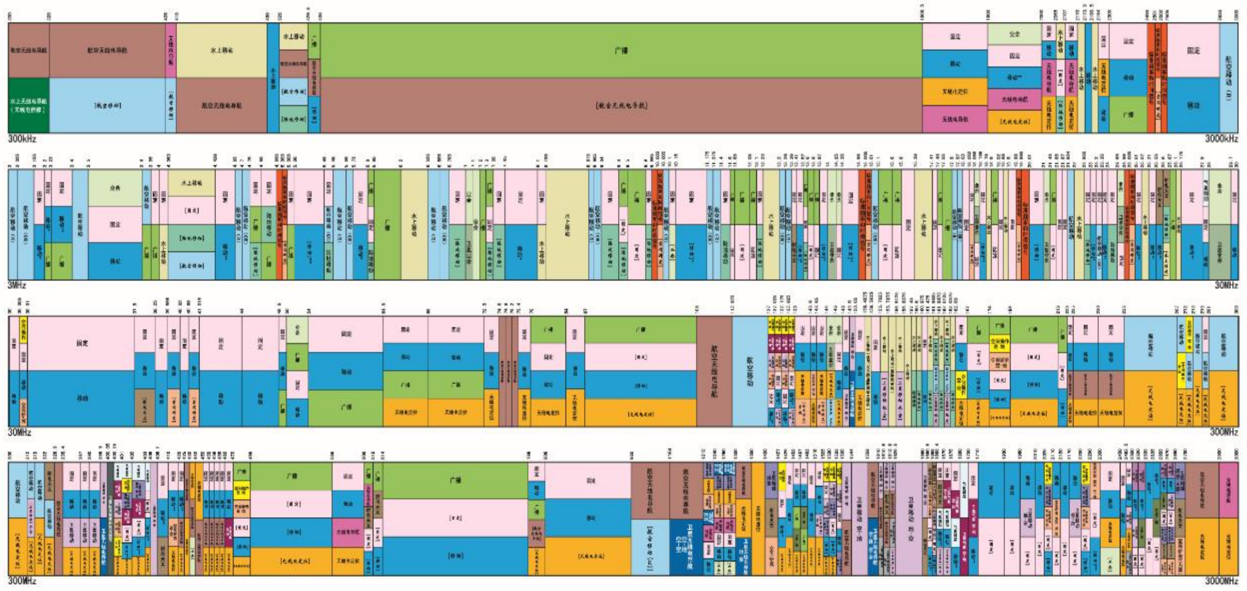
IMT-2020 (5G)

Internet of things

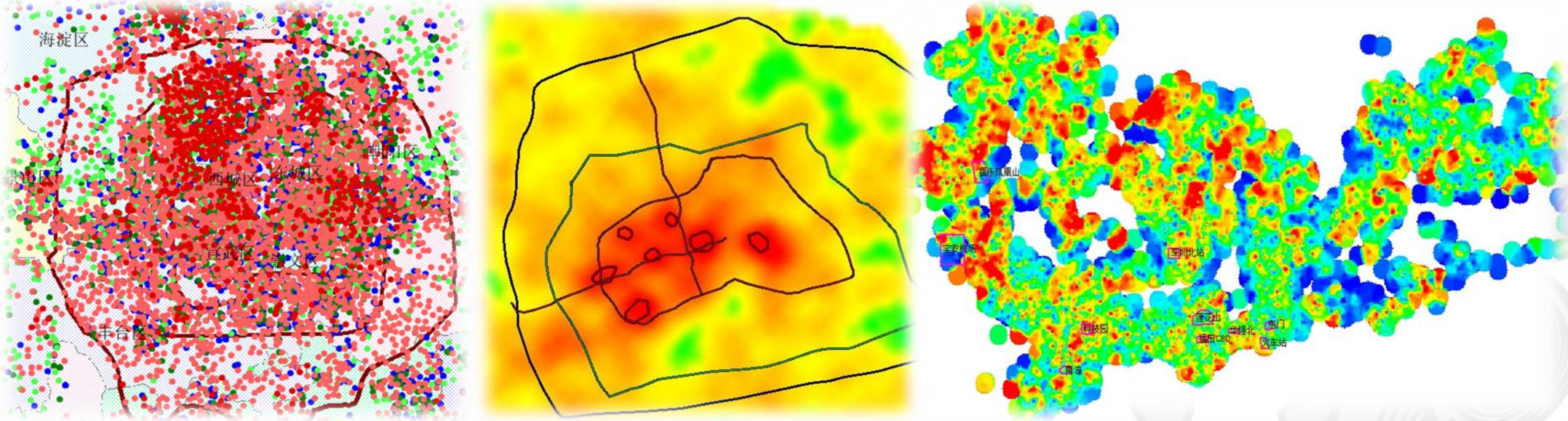
Internet of cars

Wireless big data

- The spectrum demand is structural, i.e., different in time, space and frequency domain.



Frequency allocation table



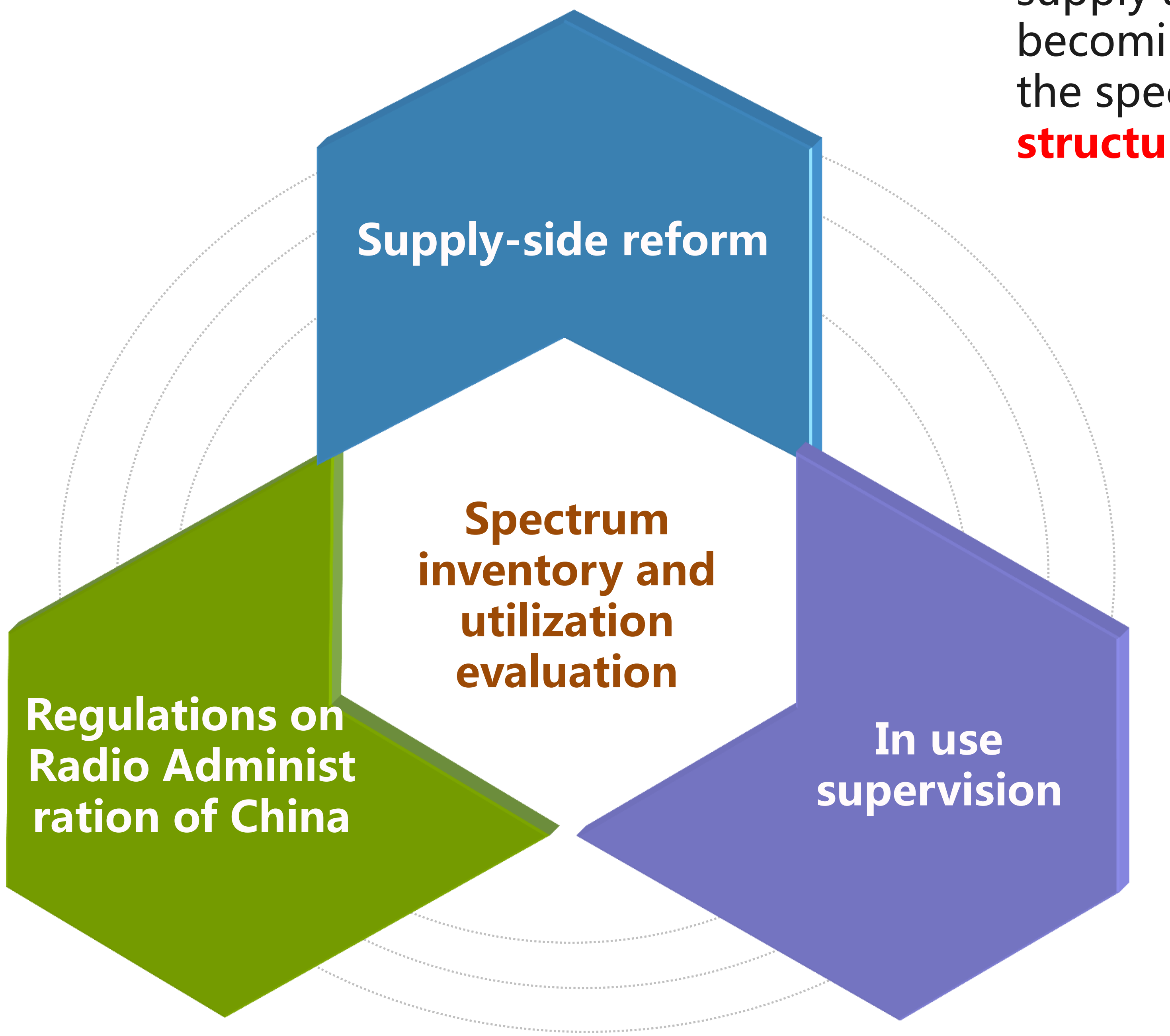
Mobile Base Station and traffic distributions

Spectrum inventory and utilization evaluation

Background

《Regulations on Radio Administration of China》

- Article 56: responsibility of radio management institutions to carrying out spectrum inventory and utilization evaluation
- Article 16/26: new requirements for spectrum utilization efficiency



Supply-side reform

- Currently, the contradiction between supply and demand of spectrum is becoming more and more prominent, and the spectrum demand has obvious **structural characteristics**

Strengthen the supervision to the spectrum in use

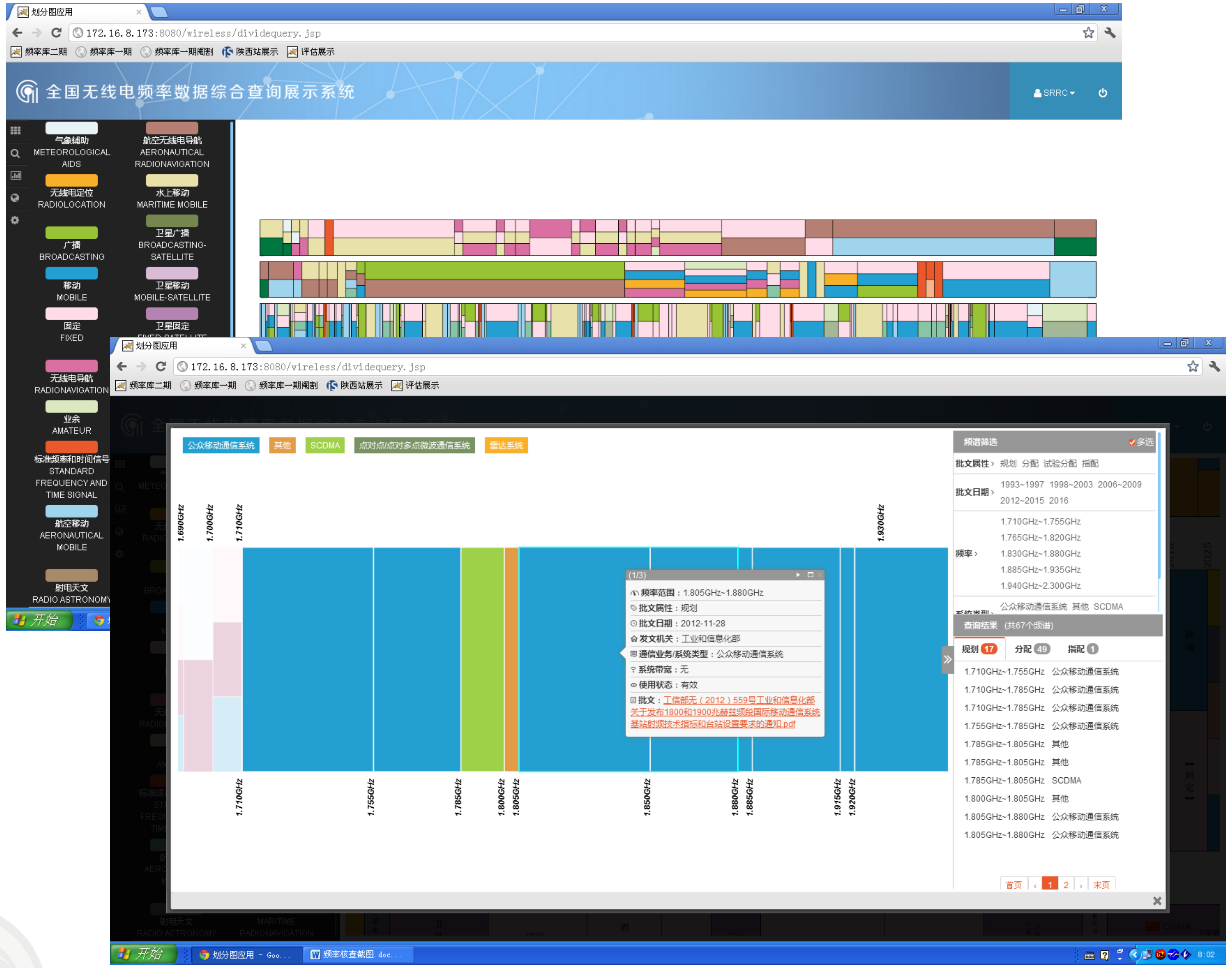
- Traditional spectrum management focuses on the ex ante part, and lacks a total life cycle management

Spectrum inventory in 2015

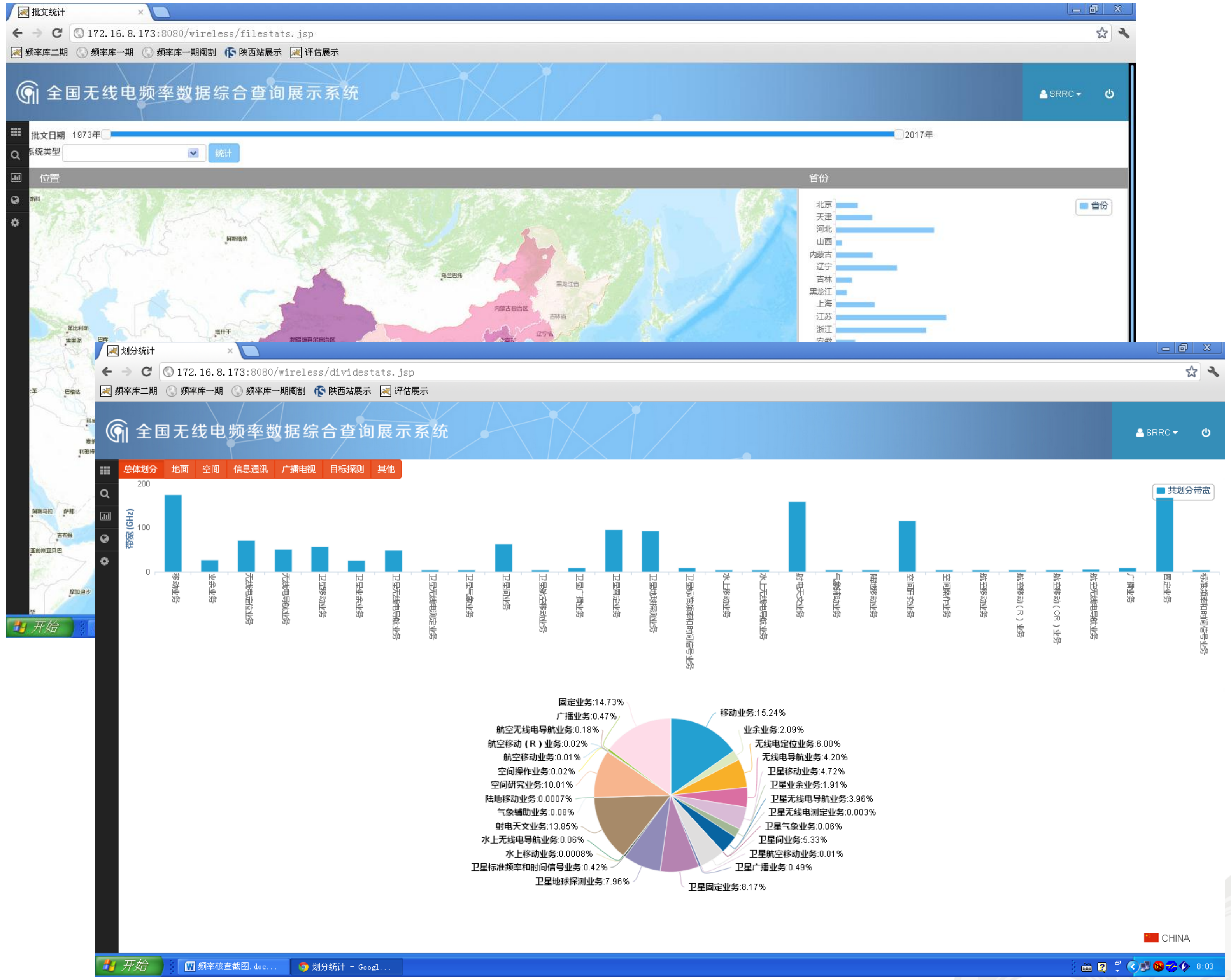
- **Objective**
  - ✓ To sort out all kinds of historical frequency planning, allotment and assignment files issued by government
  - ✓ To rebuild the frequency database and information system
- **Achievements**
  - ✓ 28250 files re-scanning
  - ✓ 168965 data items re-filled in and re-checked

Spectrum inventory in 2015

- **Frequency database and information system**



Frequency data query

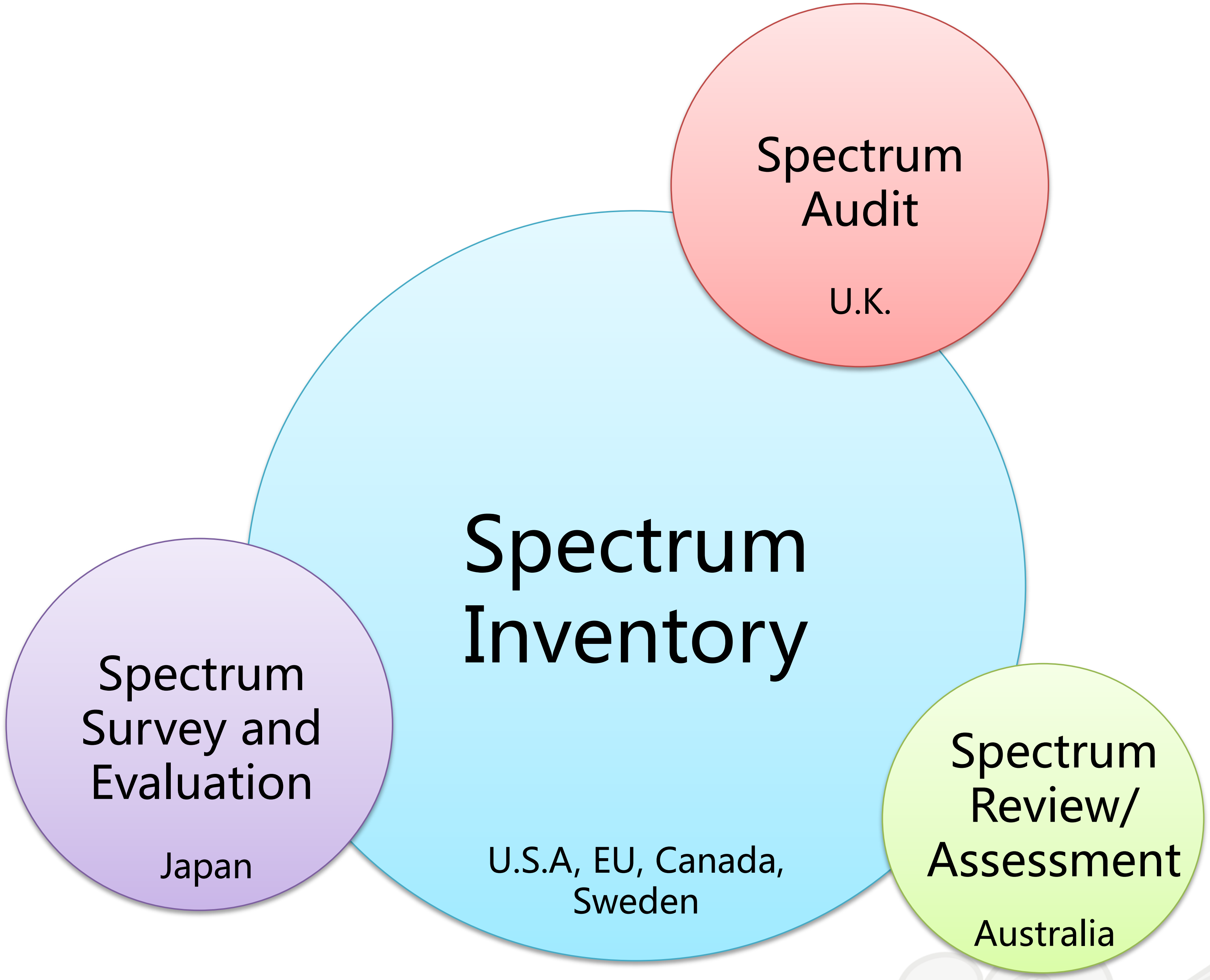


Related statistics

Spectrum utilization evaluation in 2016

Background

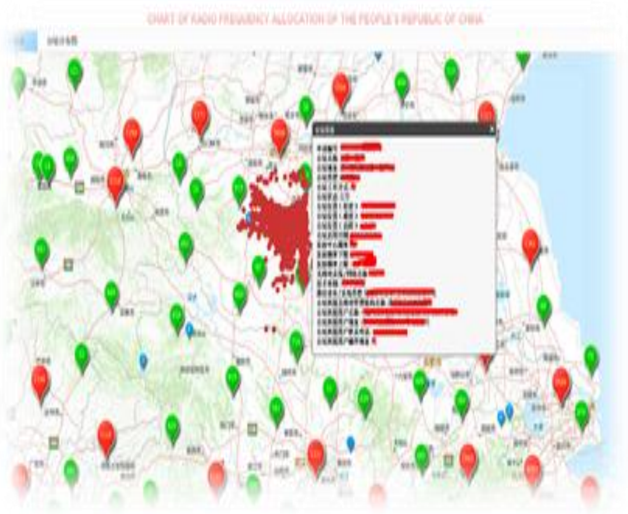
- Many countries and regions have carried out spectrum usage evaluation work.
- It is called spectrum inventory / audit / survey and evaluation / review / assessment.
- Most of them are used to:
  - ✓ understand the spectrum usage
  - ✓ improve the spectrum utilization efficiency
  - ✓ promote spectrum re-farming



Spectrum utilization evaluation in 2016

Background

Frequency Allocation → Frequency Planning → Frequency Assignment … Frequency Monitoring



Data Evaluation And Visualization

Data Analysis

Data Storage

Data Collection

Frequency Evaluation

A close-loop spectrum management

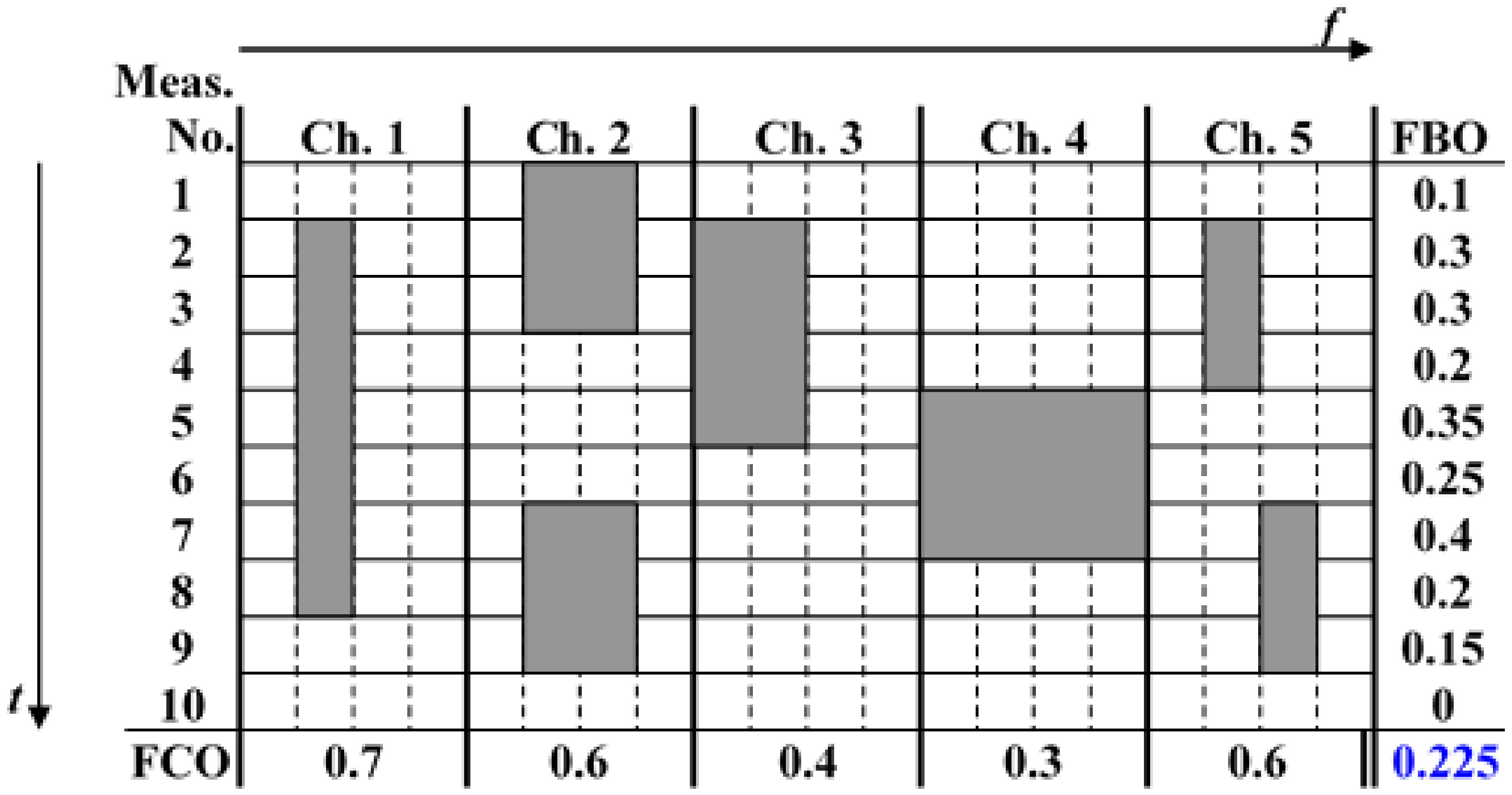
Spectrum utilization evaluation in 2016

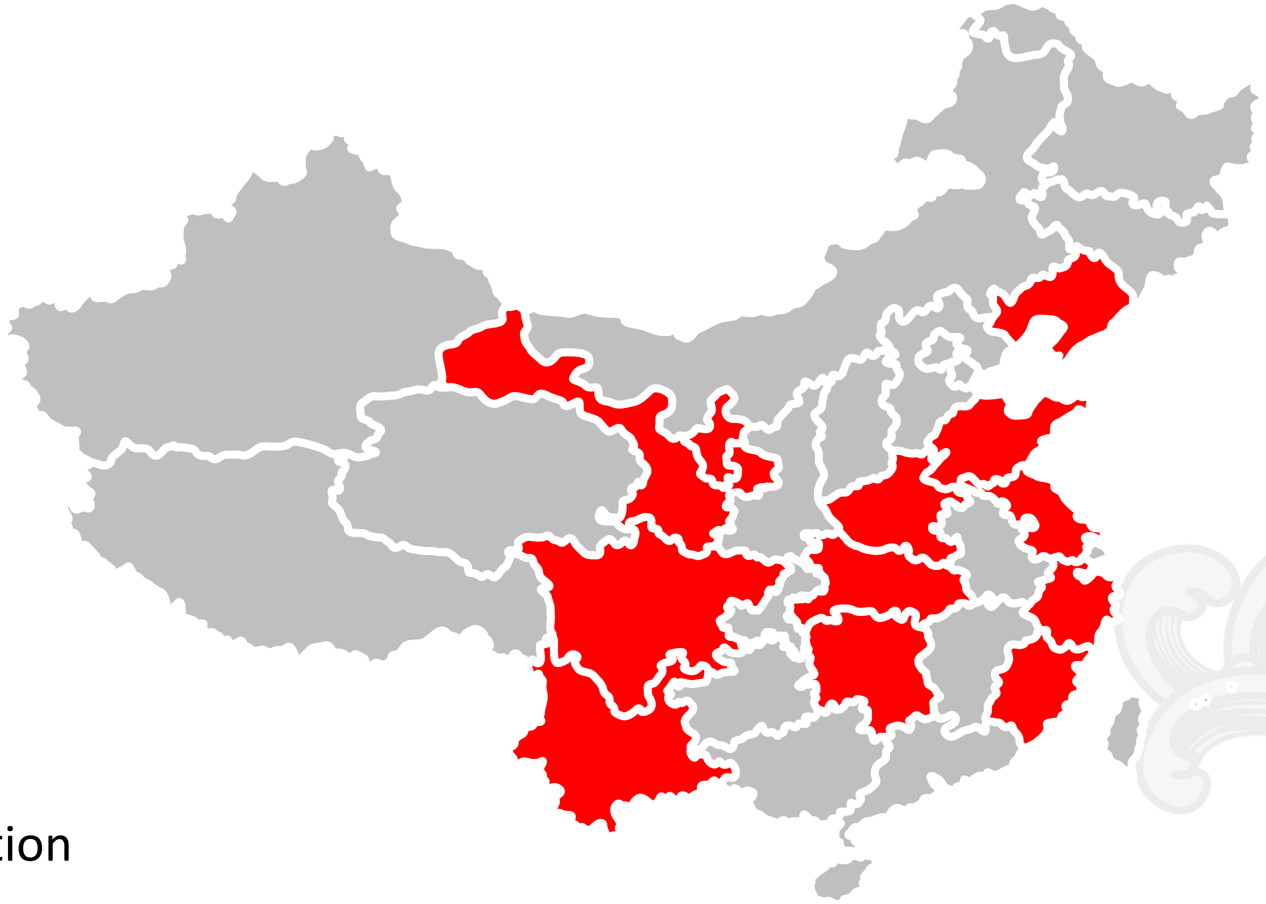
Technical Standards

- Frequency channel occupancy (FCO)*
  - A frequency channel is occupied as long as the measured level is above the threshold.

- Frequency band occupancy (FBO)*
  - The occupancy of a whole frequency band counts every measured frequency and calculates a total figure in percent for the whole band, regardless of the usual channel spacing.

- Frequency channel coverage
  - A frequency channel occupied ratio within certain geographical area, i.e. the percentage of occupied measurement to whole area measurement





*Source: Report ITU-R SM.2256 Spectrum occupancy measurements and evaluation

Spectrum utilization evaluation in 2016

Work load

- 30MHz - 3GHz Data Collection
- Analysis focus on IMT spectrum

1012
Fixed stations

392
Mobile stations

1.79million hours
Monitoring time

0.564 million km²
Geographical area

3.88 million km
distance

30TB
Data acquired

国家无线电监测中心
The State Radio Monitoring Center

Spectrum utilization evaluation in 2016

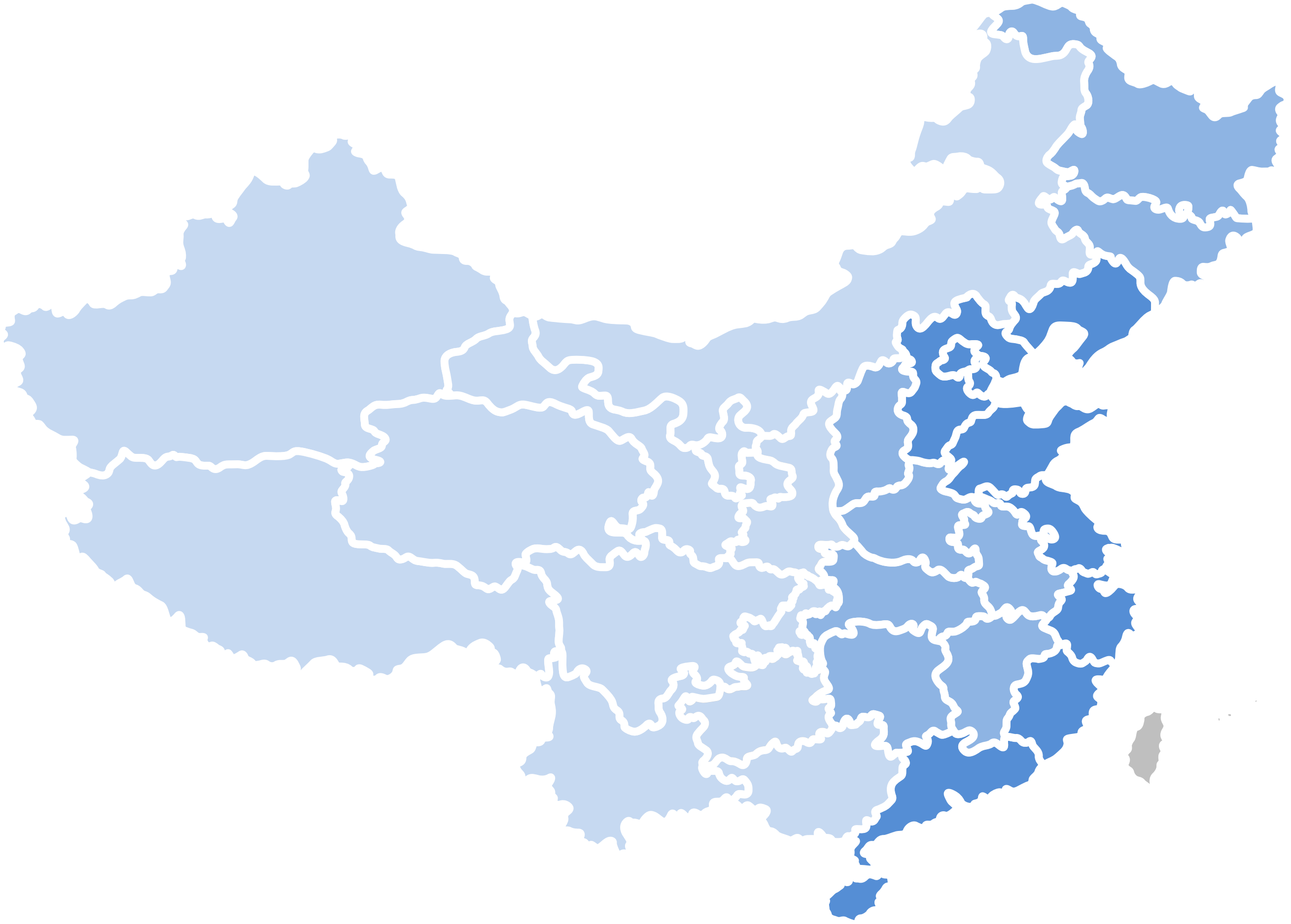
Analysis focus on IMT spectrum

Frequency band (MHz)	Systems
450 - 470	
870 - 880	CDMA/LTE FDD
930 - 934	GSM-R
934 - 954	GSM
954 - 960	GSM/U900/LTE FDD
1805 - 1830	GSM
1830 - 1845	GSM
1845 - 1860	LTE FDD
1860 - 1875	LTE FDD
1875 – 1880	
1880 - 1885	TD-LTE/TD-SCDMA
1885 - 1915	TD-LTE/TD-SCDMA

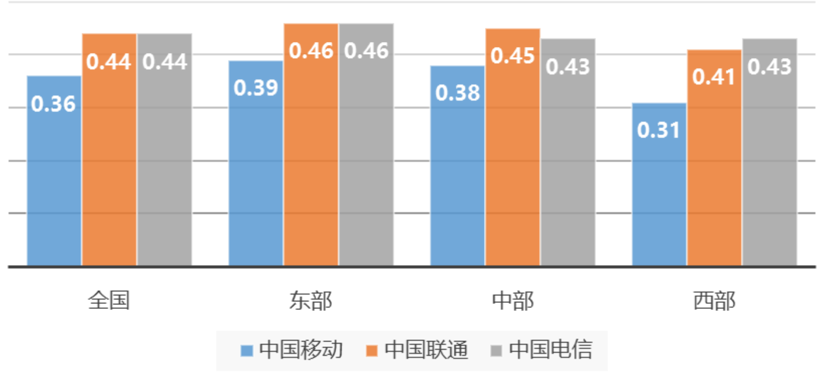
Frequency band (MHz)	Systems
1915 - 1920	
2010 - 2025	TD-SCDMA
2110 - 2130	CDMA/LTE FDD
2130 - 2155	WCDMA/LTE FDD
2155 - 2170	
2300 - 2320	TD-LTE (indoor)
2320 - 2370	TD-LTE (indoor)
2370 - 2400	
2500 - 2555	
2555 - 2575	TD-LTE
2575 - 2635	TD-LTE
2635 - 2655	TD-LTE
2655 - 2690	

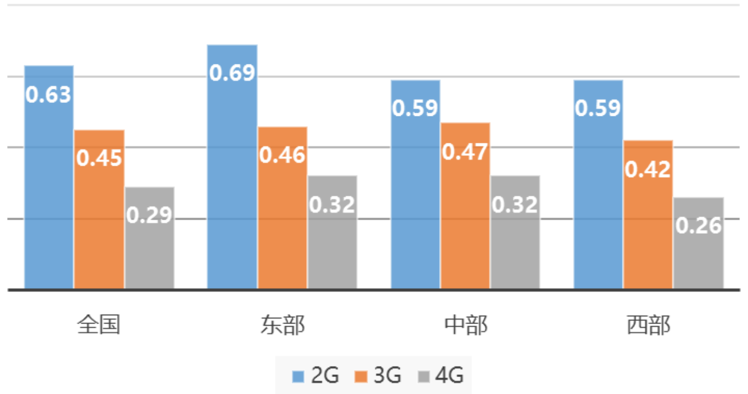
Spectrum utilization evaluation in 2016

Results – frequency and space domain

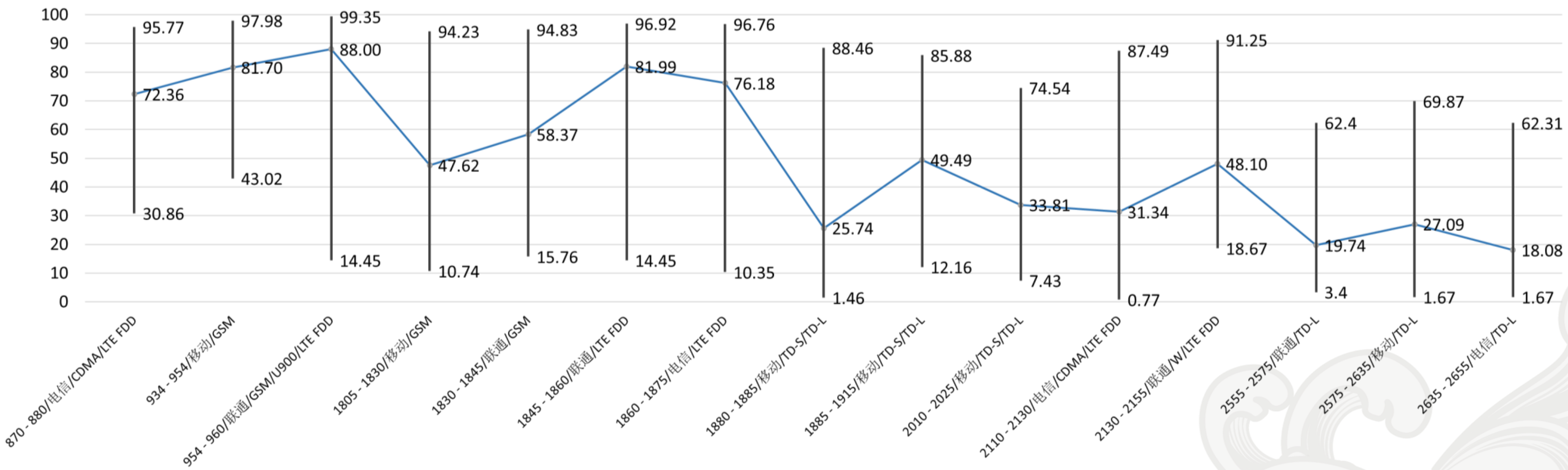


Coverage analysis of western / middle / eastern China





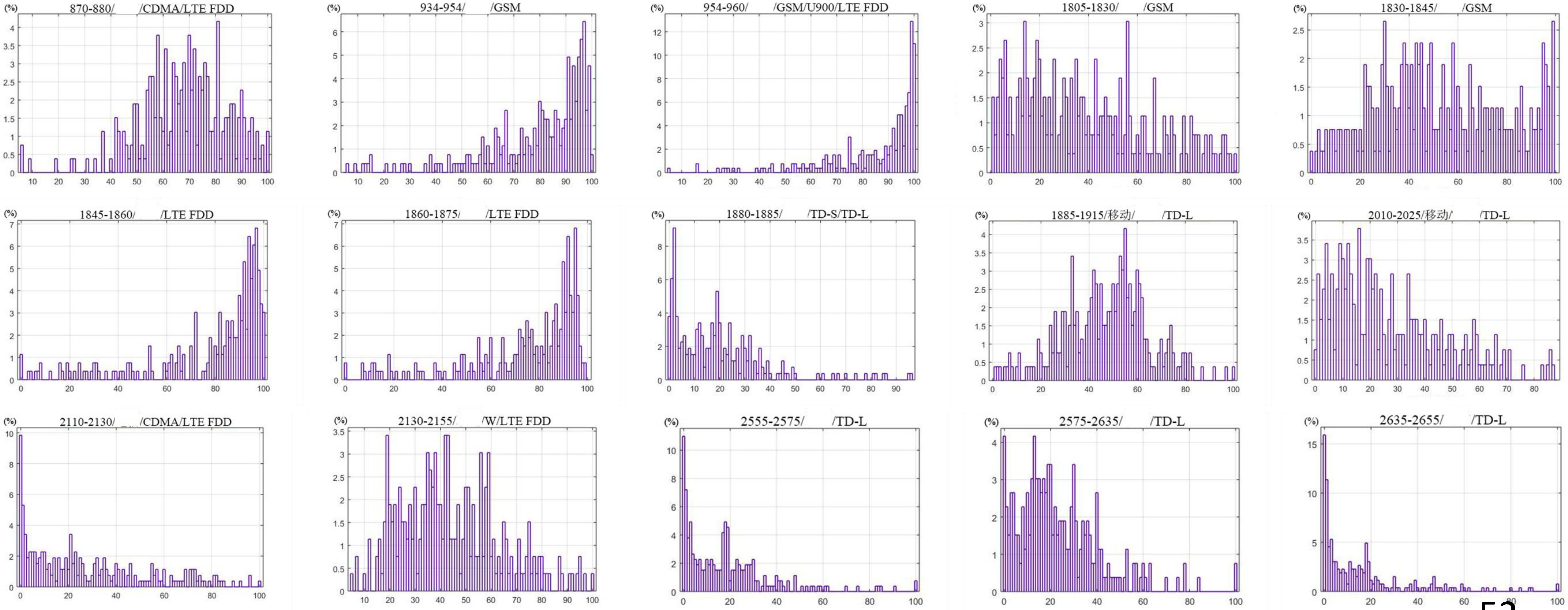
Comparisons between Operators and 2G/3G/4G



Comparisons between different frequency bands

Spectrum utilization evaluation in 2016

Results – time domain



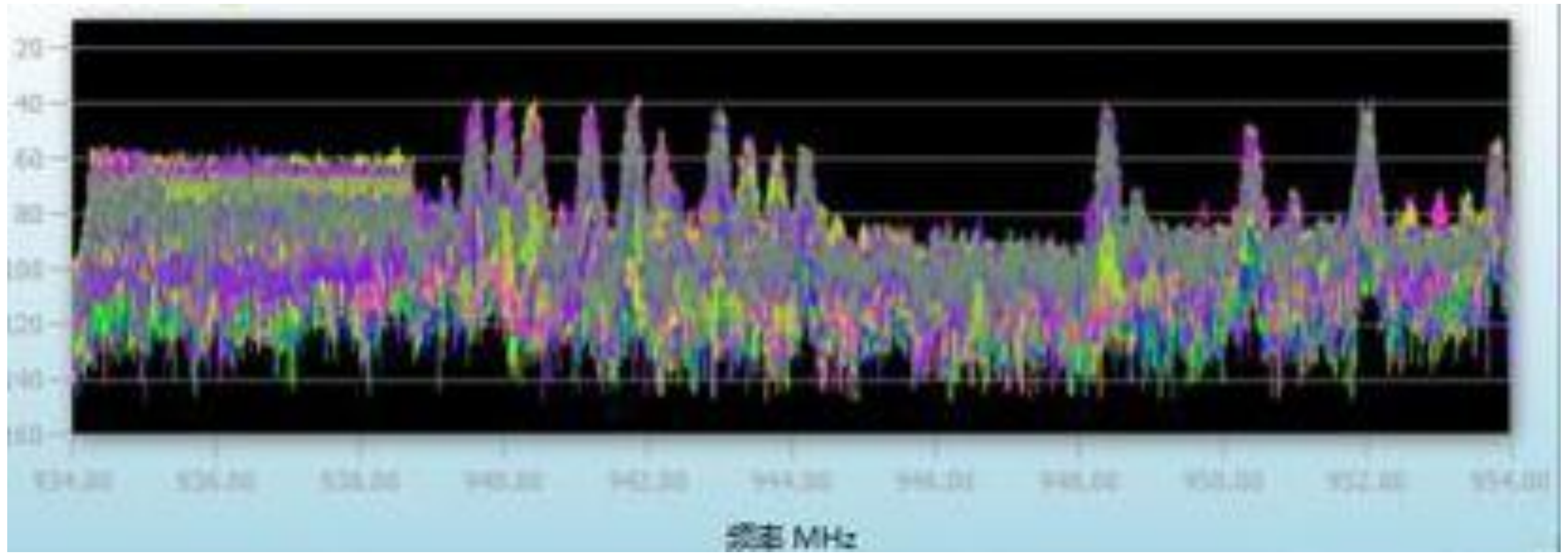
Cumulative distribution function curve for IMT frequency channels

Spectrum utilization evaluation in 2016

Results – some useful findings, as example

Tech.	Frequency (MHz)	operators
GSM	952.2	xx
GSM	953.8	xx
GSM	953.8	xx
GSM	953.8	xx
GSM	953.8	xx
GSM	953.8	xx
GSM	953.8	xx

Illegal use of some GSM frequency channels



Alter the technical system without authorization

Summary

国家无线电监测中心
The State Radio Monitoring Center

Summary

- The radio frequencies and any associated orbits, including the geostationary-satellite orbit are limited natural resources and that they must be used rationally, efficiently and economically. This is the Preamble of ITU-R Radio Regulations and also the objective of spectrum engineering.

- Before frequencies are allocated for a new radio application, compatibility with existing radio systems and with non-radio devices must be ensured. The spectrum engineers are responsible for define appropriate technical parameters, finding clearly sharing conditions, and developing interference mitigation mechanisms to ensure the compatibility between different radio services in time, frequency and space domain.

- To consider the spectrum inventory and utilization evaluation is necessary to make a close-loop management. To strengthen the supervision to the spectrum in use is a key mean to improve the utilization efficiency of the spectrum.

T hanks