ICTP-ITU-URSI School on Wireless Networking for Development
The Abdus Salam International Centre for Theoretical Physics ICTP, Trieste (Italy), 5 to 24 February 2007

Spectrum Management & Regulatory Issues

Ryszard Struzak

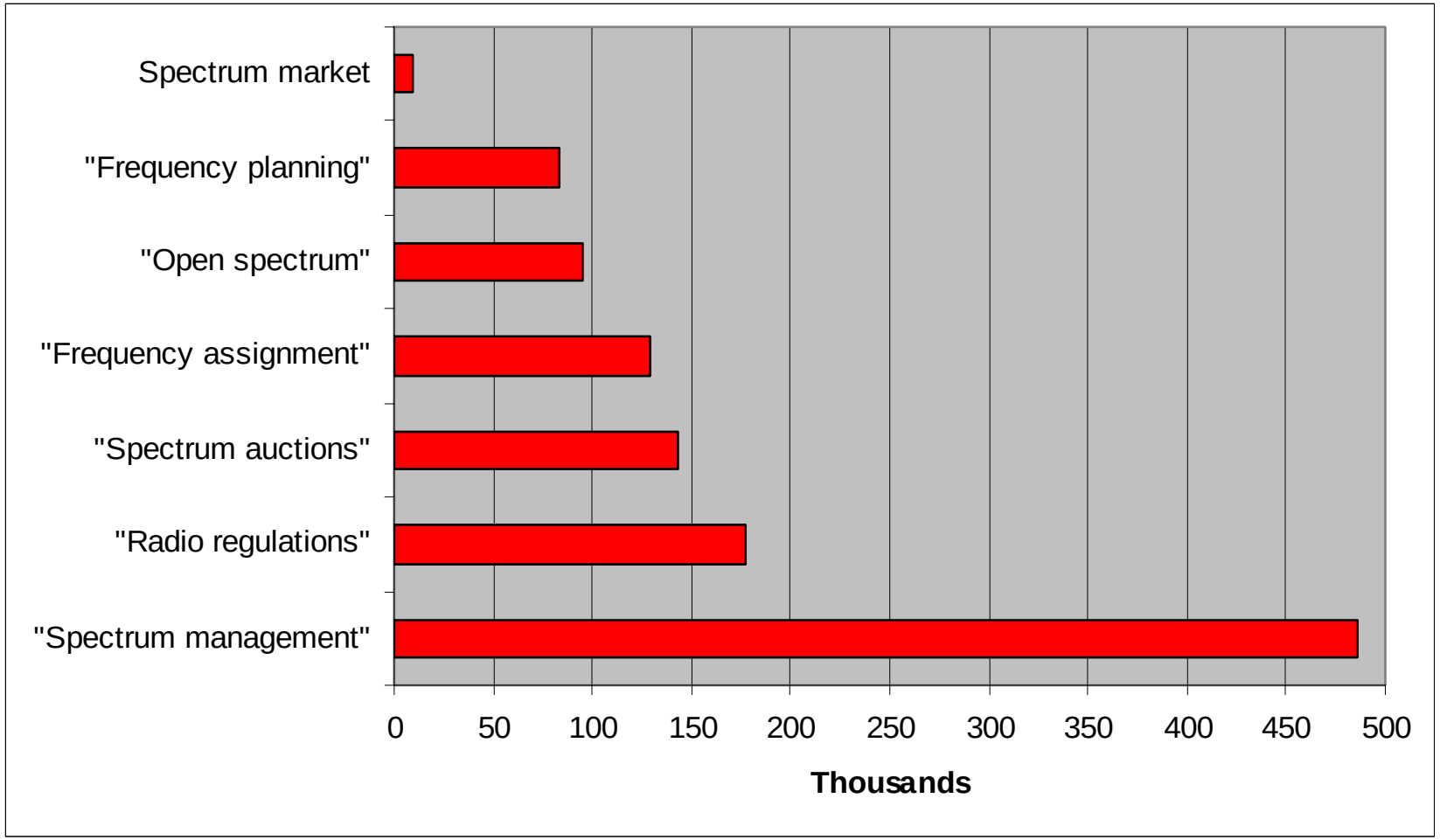
Note: These are preliminary notes, intended only for distribution among the participants. Beware of misprints!

Purpose

- to review regulations that specify how radio systems of any kind should (or should not) be used in all countries
- to complement my earlier talks on radio links, interference, and coexistence

Google statistics

Number of www pages listed by Google in response to some key words



Main topics for discussion

- What is spectrum management?
- What are the Radio Regulations?
- Who created them and how?
- What are new trends?

Note: We shall review basic topics and only touch on more advanced issues.
(To cover any of the many topics in detail, much more time would be needed.)

Radio = development

- It is widely accepted that the uses made of radio will contribute significantly to the economic growth and improvement of the living standard in the next few decades
- How these uses are regulated has thus profound impact on the society
  - security, prosperity, culture, education, propaganda, …

What is the spectrum?

- Our understanding of the spectrum has been changing:
  - *Mathematical concept?*
  - *Measurable physical quantity?*
  - *Common (public) resource?*
    - with satellite orbits included later
  - *Marketed commodity?*

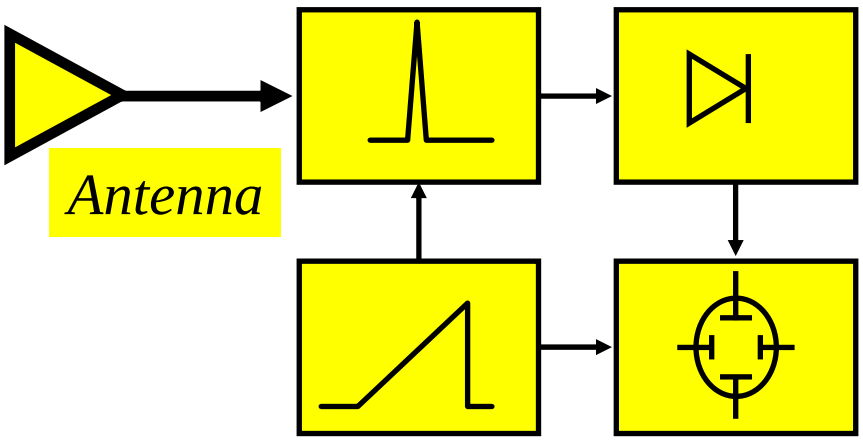
Spectrum = math. concept?

- 1822: An abstract concept of no practical value, only later accepted as mathematical tool
  - 1822: Concept of spectrum (J-B Fourier, 1768-1830)

$$S(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$

- 1873: Theoretical possibility of EM waves (J-C Maxwell, 1831-1879)

Spectrum = measurable quantity?



- A physical object
  - 1888: Hertz experiments
- Radio waves can transport energy and information at distance with no wires
  - 1895: Marconi and Popov experiments & *applications*
- Now: Spectrum analyzers

Spectrum = common resource?

- A natural freely accessible public resource: everybody can profit from its exploitation
  - 1901: First transatlantic wireless transmission
- Time of plenty
  - Competition - Unrestricted growth - technological progress - boom of civilian radio

Commons: major problems

- Interconnection and tariff problems due to free (unregulated) competition
    - 1912: Titanic disaster, London Conference
- Radio interference problems due to competition (‘power race’) and primitive technology

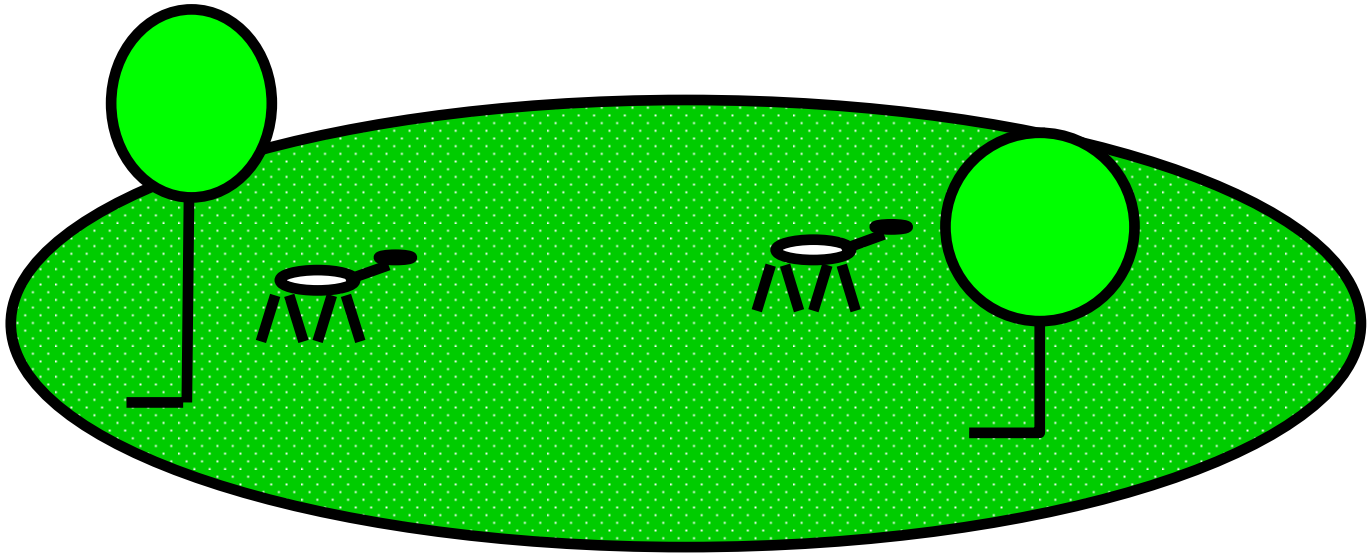
    » spectrum scarcity/ congestion, chaos

  – 1903/ 1906: Berlin Radiotelegraph Conference (27 States) contained a provision that radio services be organized to avoid interference between stations

Spectrum = scarce resource?

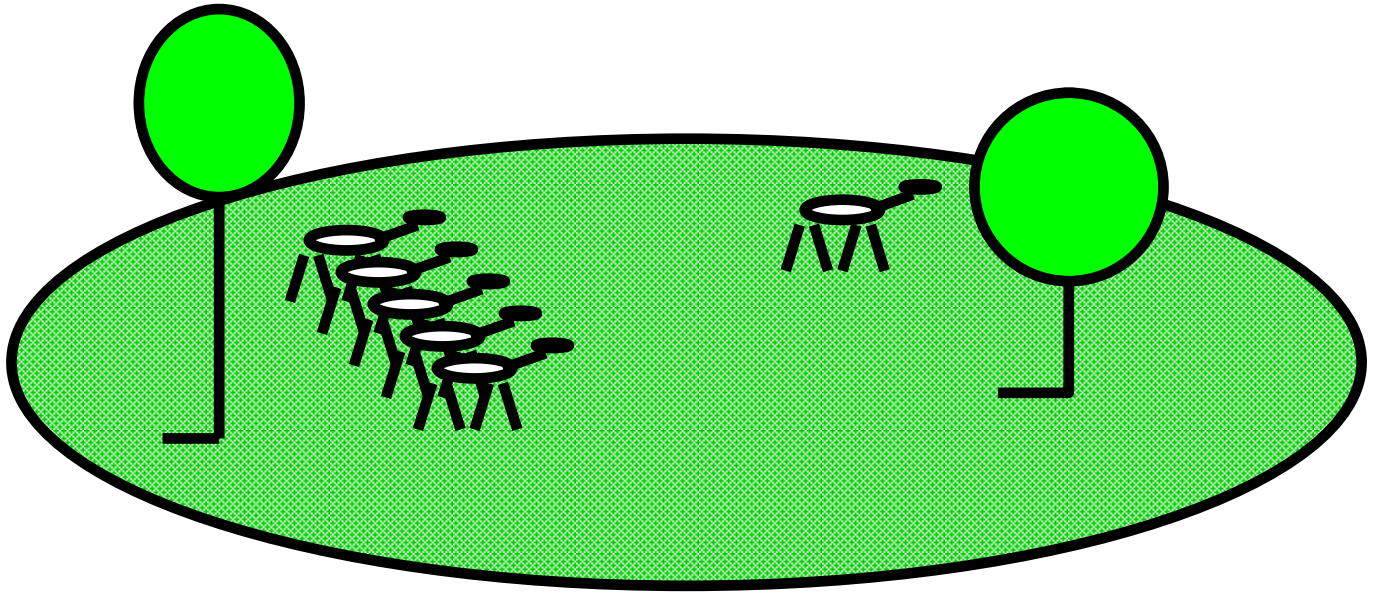
- 1925 “...no more spectrum available…”
  - » declares a US Secretary of Commerce
- In 1910, the US Navy petitioned to shut down ~4000 amateur radio stations because of RFI to ~1000 governmental & commercial stations.
  - The US Radio Act of 1912 solved this interference problem by relegating the amateurs to the “useless wavelengths of 200 meters and shorter” and by limiting their power to 1kW.
    - » Source: DD Hoolihan1, N Carter: A General History of the Evolution of the Discipline of EMC; EMC Zurich 2005

How do commons work?



- Model: A free pasture (but of limited area), open to any herdsman with cattle; no regulations
- The only aim of each herdsman: to maximize his ***individual gain*** (which comes from selling cattle)

Time of plenty..



Following his best interest, each herdsman adds 1 animal more, and more… The number of cattle increases, and the wealth of the men follows …

Limit to growth

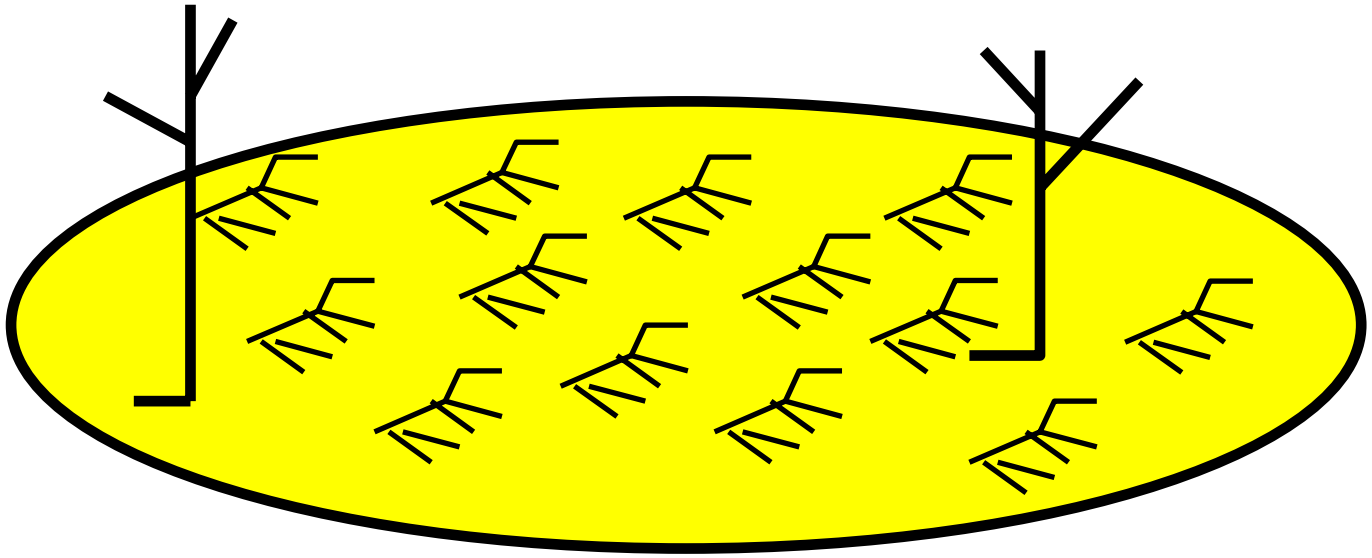
- How long such a growth can continue?
  - Until the pasture saturation, when the capacity limit is reached – and overgrazing begins
- At that point, a herdsman considers the pros and cons of adding 1 more animal:
  - Pros = 1 (the full gain from selling goes to me!)
  - Cons < 1 (the overgrazing effect is shared among all)
  - Conclusion: better to add one more animal!
- Each and every herdsman comes to such a conclusion!

Impasse

- Seeking individual gain, no one is caring of others and of commons, as it requires some self-sacrifice
- Nobody is motivated to limit his herd to avoid overgrazing or to invest in possible improvements

Tragedy of commons

- "...*Ruin is the destination toward all men rush, each pursuing his own best interest, in a society that believes in the freedom of the commons*...“ [Hardin]



Commons: history

- Farmland
- Pasture areas
- Forest areas
- Hunting areas
- Fishing areas
- GSO?
- RF spectrum?
- Deforestation
- Desertification
- Water pollution
- Air pollution
- Ground-contamination
- Climate warming

Possible solutions

- Regulation
  - *Administrative* allocation
  - Allocation by lottery
  - Allocation according to criteria:
    - Merits/ needs: “Beauty contest”
    - Seniority: “First-come, first-served”
- Regulation by the “*invisible hand of the market*” demand, supply, price (= wealth criterion)
- Open spectrum + etiquette + self-disciplie (example: radio amateurs)

Is any ‘best’ way?

- Society is not uniform - consists of various groups, each group with its own traditions, beliefs, hierarchies of values, needs, goals, interests, etc.
- The goals and hierarchies of values of different groups may be mutually inconsistent and partially in conflict
- What is good for ones may be not good for the others

International spectr. management

- Very early, all interested parties come to the conclusion that collaboration is necessary to solve interconnection (tariffs) and mutual interference problems
- These are best managed by an intergovernmental treaty (regulations)
  - A similar treaty regulating wired telecommunications existed since 1865

- To facilitate negotiations, the International Radio Consultative Committee (CCIR) was created in 1927 within the ITU
  - Goal: to arrive at common understanding of a number of technical, regulatory and operational questions
- The CCIR proposed administrative spectrum management via the concept of radio services and spectrum allocation
    - 1927: the 1st Radio Services definition and 1st International Frequency Allocation Table (10 kHz - 60 MHz)

- 1932: International Telecommunication Union (ITU) treaty of 1865 extended to cover radiocommunications
  - to avoid/ solve conflicts and to coordinate regulatory, standardization, and tariff activities among the member countries
  - 1949: The ITU became the United Nations' Specialized Agency for Telecommunications

ITU / UIT

Source: ITU News 1/90

International Telecommunication Union
Place des Nations, CH-1211 Geneva 20
http://www.itu.int

Hamadoun
Touré

Houlin
Zhao

Valery
Timofeev

http://www.itu.int

How does the ITU system work?

Plenipotentiary Conference

Council

World Conference on International Telecommunications

ITU Policy Forum

General Secretariat

Development Sector (ITU-D)

Telecommunication Standardization Sector (ITU-T)

Radiocommunication Sector (ITU-R):
Member Countries and Sector Members

RADIOCOMMUNICATION CONFERENCES
RADIO REGULATIONS BOARD

Radiocommunication Assembly & Study Groups

Radiocommunication Bureau

Plenipotentiary Conference

Source: ITU Newsletter 10/94

ITU spectrum management

- *Based on collaboration, mutual trust, goodwill (negotiations, no enforcement)*
  - *Sovereignty doctrine*
  - *Common heritage doctrine (free access) on the international forum*
  - *Common benefit doctrine (consensus)*

- *Equitable access doctrine*
- *Seniority doctrine (First-come, first-served)*
- *Static allocation (~40 services)*
- *Hierarchy of services (primary, secondary)*
- *Special needs of developing countries doctrine*

- 1947: To implement the seniority principle, the ITU PP decided all radio stations that need an international recognition must be recorded in the '***Master International Frequency Register*** *(MIFR)*' under the supervision of independent (elected) ***International Frequency Registration Board*** (IFRB)

MIFR

- 1 265 000 terrestrial frequency assignments
- 325 000 assignments related to 1 400 satellite networks
- >4 250 assignments related to satellite earth stations

» Source: Radio Spectrum Management for a converging world, ITU 2004, p. 15

IFRB - RRB

The RRB members "*shall serve, not as representing their respective Member States nor a region, but as* ***custodians of an international public trust***" 1994: CCIR and IFRB Secretariat integrated into ITU Radiocommunication Sector; IFRB transformed into Radio Regulations Board (RRB) [ITU constitution, 1999];

Photo: 1998 RRB members

- Internationally harmonized uses of the spectrum uses (through regulations and standards) assure
  - Interoperability of systems
  - Preventing & solving conflicts & interference
  - Large international markets for equipment and services
  - Lower costs (equipment and services)
  - Conveying common policy goals

What are Radio Regulations?

- An International Treaty that defines how radio waves and satellite orbits should (or should not) be used and managed
  - A mixture of legal and technical provisions
    - exist since 1947
    - updated regularly every 2yrs or so at WRCs
  - Ratified by, and legally binding in, all countries (~190 in total)
  - Published in 4 Volumes of >1000 pages

What is the RR contents?

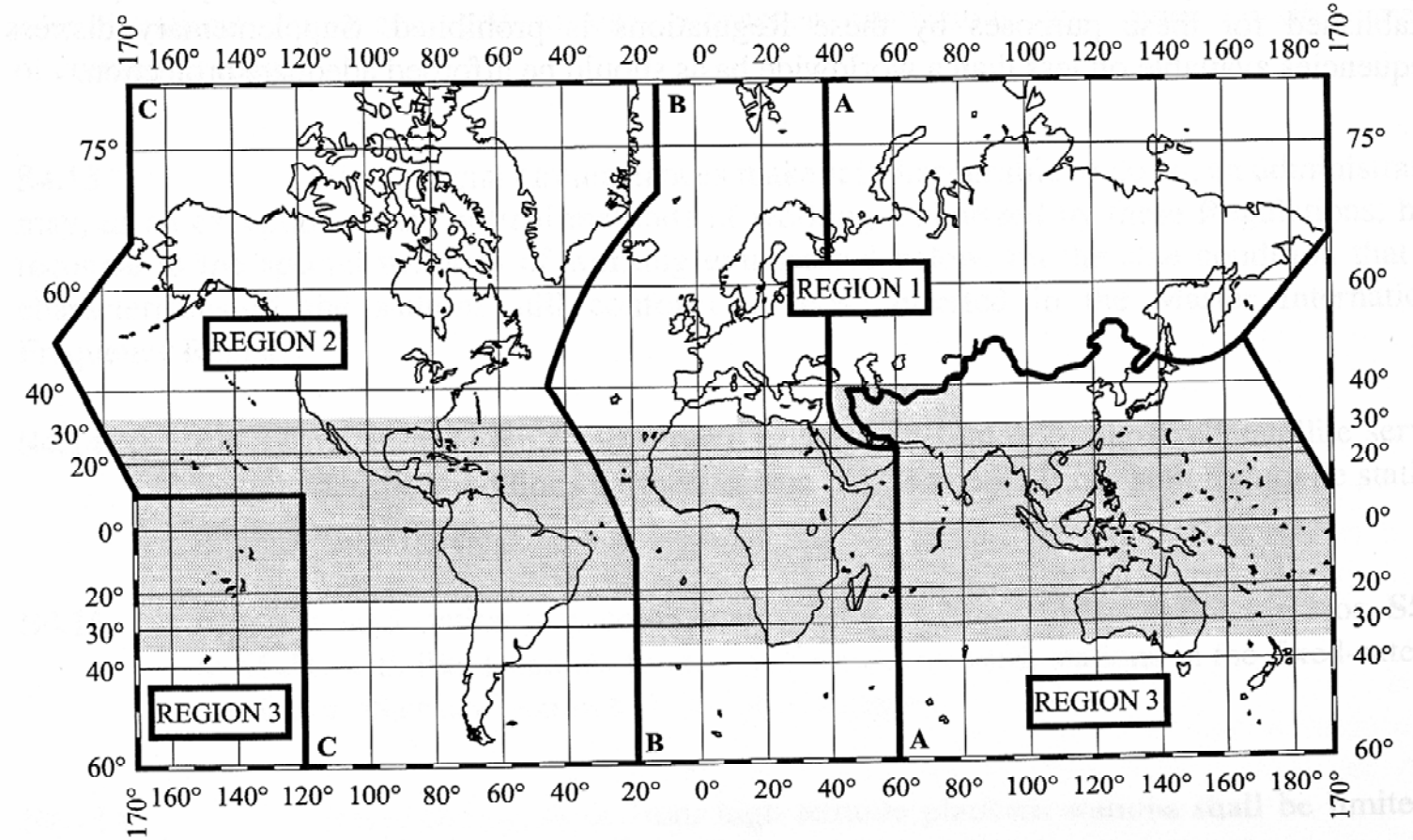
- Principles and provisions, rules, technical characteristics, formulas, data, maps, and plans dealing with international aspects of the use and management of RF spectrum/ orbit resources and the operation of radio services of all kinds
  - » Frequency Allocation Table
  - » Frequency Plans' databases
  - » Master International Frequency Register databases
  - » What to do in case of harmful interference

RRS04

"All [radio] stations…must be established and operated in such a manner as not to cause harmful interference to the radio services…of other [ITU] Members…which operate in accordance with the provisions of these regulations."

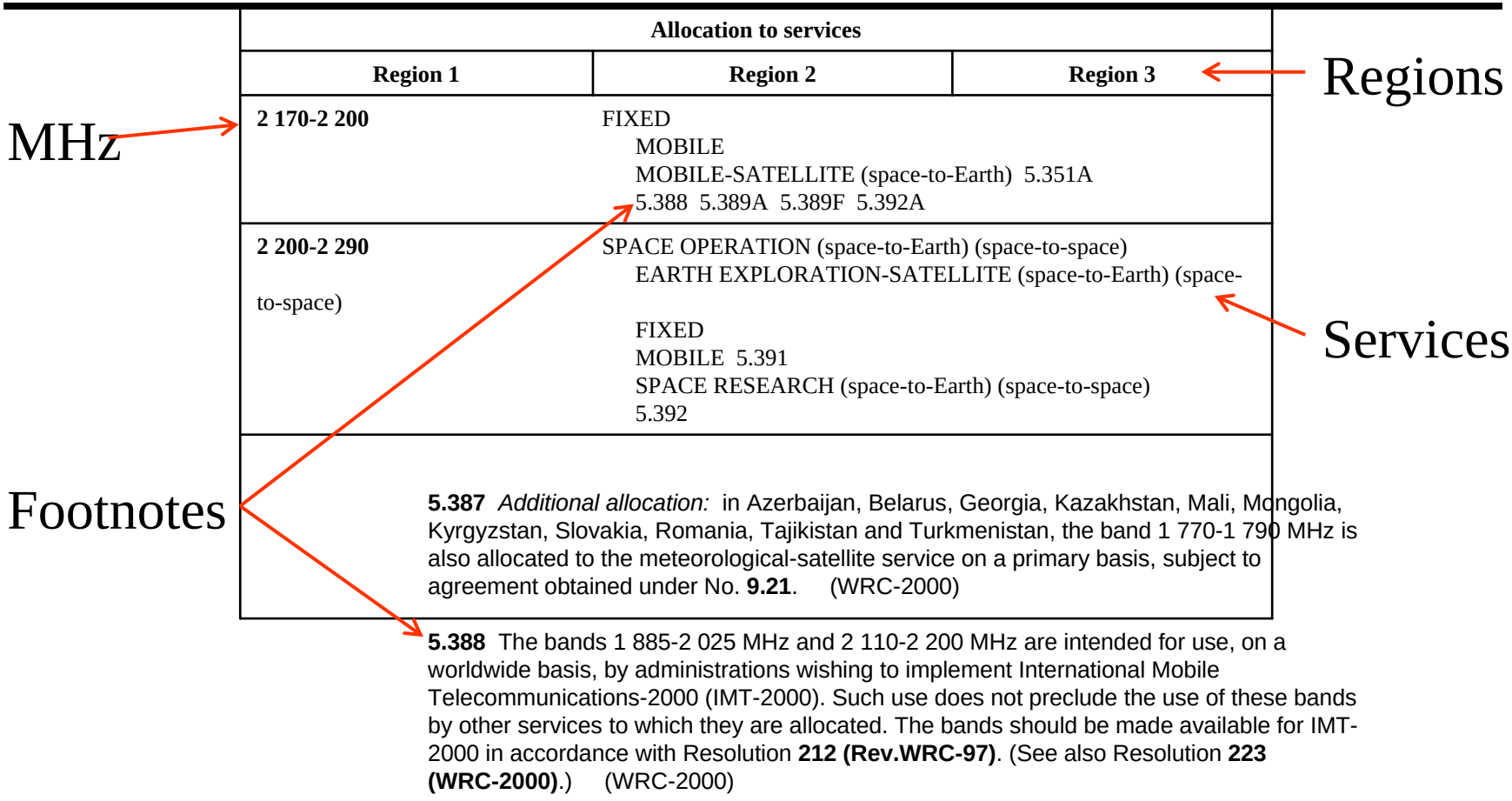
» **[RRS04 and No.197 of the ITU Constitution]**

RR Regions



The shaded part represents the Tropical Zones as defined in Nos. **S5.16** to **S5.20** and **S5.21.**

S5-01



Allocation to services		
Region 1	**Region 2**	**Region 3**
2 170-2 200	FIXED MOBILE MOBILE-SATELLITE (space-to-Earth) 5.351A 5.388 5.389A 5.389F 5.392A	
2 200-2 290 to-space)	SPACE OPERATION (space-to-Earth) (space-to-space) EARTH EXPLORATION-SATELLITE (space-to-Earth) (space- FIXED MOBILE 5.391 SPACE RESEARCH (space-to-Earth) (space-to-space) 5.392	

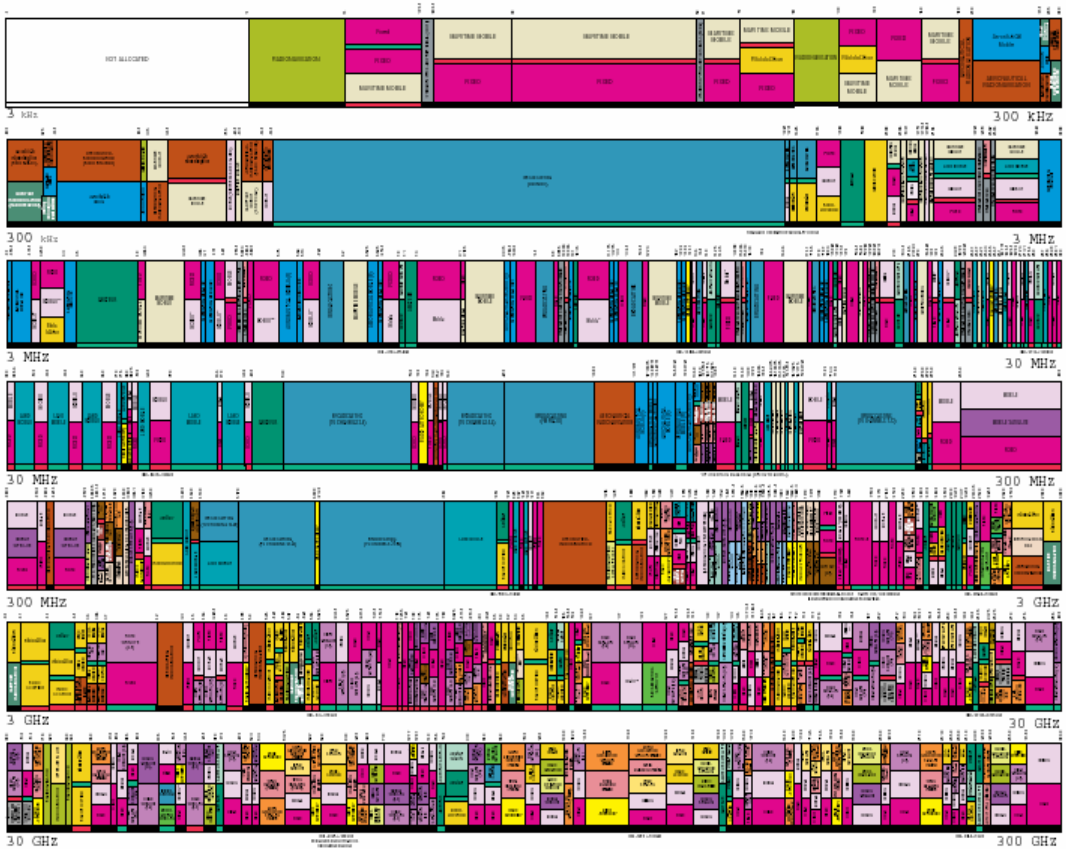
5.387 *Additional allocation:* in Azerbaijan, Belarus, Georgia, Kazakhstan, Mali, Mongolia, Kyrgyzstan, Slovakia, Romania, Tajikistan and Turkmenistan, the band 1 770-1 790 MHz is also allocated to the meteorological-satellite service on a primary basis, subject to agreement obtained under No. **9.21**. (WRC-2000)

5.388 The bands 1 885-2 025 MHz and 2 110-2 200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile Telecommunications-2000 (IMT-2000). Such use does not preclude the use of these bands by other services to which they are allocated. The bands should be made available for IMT-2000 in accordance with Resolution **212 (Rev.WRC-97)**. (See also Resolution **223 (WRC-2000)**.) (WRC-2000)

RR sample

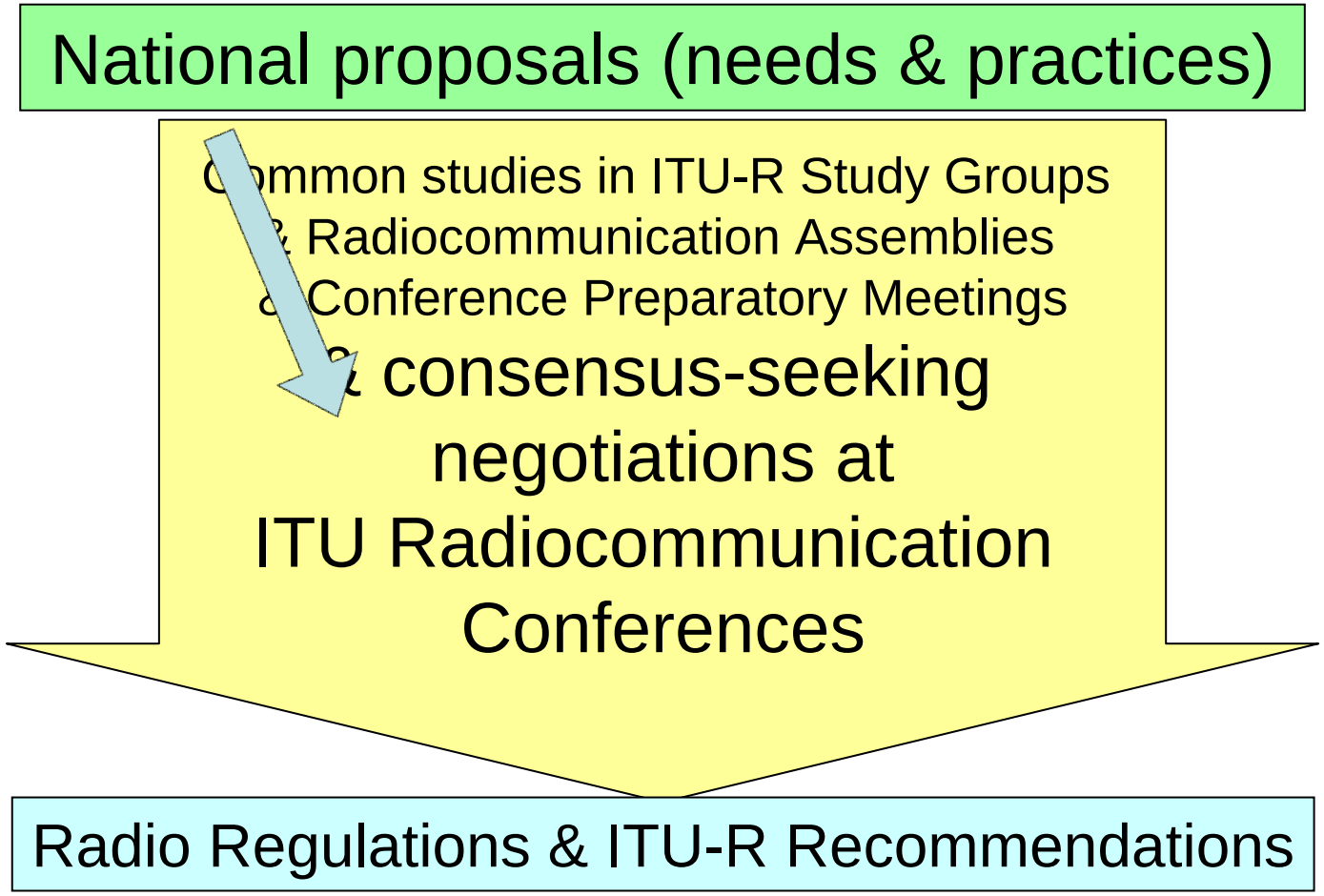
- ICTP - The Abdus Salam International Centre for Theoretical Physics
  ICTP Lecture Notes Series Volume XVI (ISBN 92-95003-23-3) - *February 2003*
- *R. Struzak:* **Introduction to International Radio Regulations**
  - Download from ICTP: Pages 1 – 72 (Lecture Notes): PDF; pages 73 – 233 (RR Frequency Allocation Table): PDF;
    All Volume XVI: lns016.tar.gz

Abstract space of radio waves

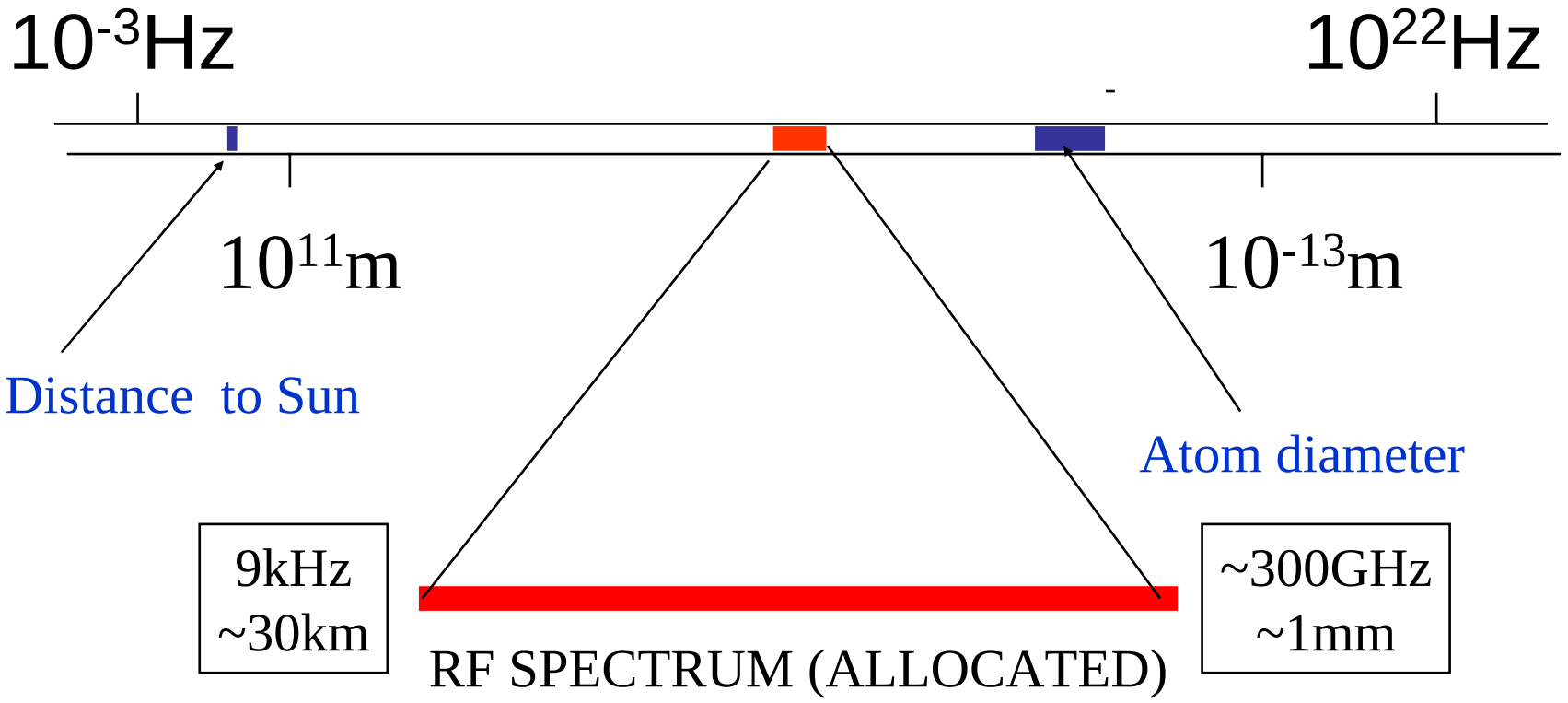


- Radio Regs. involve frequency = = 1D space

How are RR created?



What part of spectrum is regulated?



‘Spectrum commons’ - ISM bands

- ‘ISM’, or ‘free-radiation’ frequency bands
- Allocated originally for exclusive non-telecommunication applications (industrial, scientific, domestic and medical)

6.765 - 6.795	MHz
13.553 - 13.567	MHz
26.957 - 27.283	MHz
40.66 - 40.70	MHz
433.05 - 434.79*	MHz
902* - 928*	MHz
2.4 - 2.5	GHz
5.725 - 5.875	GHz
24 - 24.25	GHz
61 - 61.5	GHz
122 – 123	GHz
244 – 246	GHz

- Some ISM bands are now used also for radiocommunications (e.g. WiFi, Bluetooth)
- Radiocommunication systems must accept any interference in the ISM bands
- Many countries set nationally additional regulations (e.g. limited power radiated and other technical characteristics)

National spectrum management

- Example: the FCC (USA)
  - Created in 1934 as an independent government agency, responsible to Congress, to regulate national (non-governmental) communications by radio, television, wire, satellite and cable, and to represent USA (with the NTIA and Department of State) at international forums (including ITU)
  - Directed by 5 Commissioners appointed by the President (for 5-year terms) and confirmed by the Senate
  - Working in a fully transparent way with wide public consultations
    - » Only three Commissioners may be members of the same political party. None of them can have a financial interest in any Commission-related business
    - » FCC documents available at http://www.fcc.gov/

National RR

- Each country has the sovereign right to regulate its telecommunication and to interpret the international RR
- National spectrum management must follow the ITU RR

Licensing

- Licensing is an orderly way to manage who, when, where and how can use the spectrum/ orbit resource
- Governments define the rules and conditions of the frequency use
- Details that are not explicitly included in the ITU treaties may differ from country to country (also “footnotes”)

- Individual licenses specify portions of the spectrum resource assigned to specific users by governments
- Independently
  - governments may require a formal certification that a given radio equipment comply with specific technical standards
  - additional license may be required to offer telecom services

- Licensing implies QoS guaranteed via standards, regulations, etc. as referred to in the license, and via clear legal responsibility for interference
- This implies also governmental monitoring (are all license conditions fulfilled?)
- This implies also enforcing mechanism (punishment)

License-exempt equipment

- Some equipment may get the generic license under specific conditions (e.g. RF Identification ‘RFID’ tags, or WiFi)
- Such an equipment (known as ‘certified’) is allowed to operate without an individual license

- Radio Regulations Article 4.4 says that a station can use any frequency under the condition that it
  - ...*shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the* [ITU] *Constitution, the Convention and these Regulations…*

ITU system weakness

- The ITU RR consider the spectrum/ orbit resources as a common heritage shared freely by the whole of humanity
- It is so since the times when the radio and space activities were the governments' monopoly

- No mechanism to enforce the regulations
- No mechanism to know the real spectrum uses
  - The MIFR reflects declarations and not factual data
- No mechanism to encourage spectrum economy/ conservation
  - The MIFR records contain ‘dead wood’
- Result: apparent scarcity of spectrum/ orbit resources

Changing environment

- With privatization, government monopolies are disappearing and the role of non-governmental entities is growing
    - At the same time, the availability of spectrum/ orbit resources is diminishing
- There are opinions that the present management system needs to be modified to follow these changes

New concepts

- Neo-liberal economists believe that market mechanism is better than the present ‘administrative’ spectrum management
- Portions of spectrum/ orbit resources are to be treated as private property, e.g. land
- Some (limited) amount of the spectrum reserved for public and governmental services

Spectrum market

- The owner has exclusive and transferable rights to aggregate, divide, buy, sell, lease, and to determine the usage of the spectrum resources at will
- With clear property rights, responsibilities are also clear:
  - Coordination of the uses made of the resource, monitoring, and solving conflicts/ interference
  - Many of governmental spectrum management activities replaced by court proceedings

- Standards set by industry with no (or minimal) government involvement
- International negotiations at the World Trade Organization (WTO) and not at ITU
- At the beginning, the spectrum may be auctioned to generate revenue for the government

- Proponents of spectrum market focus on similarities between the spectrum and real estate
- However, the similarity is limited because
  - The boundary of the spectrum/orbit resource owned are difficult (if possible) to determine with a precision
  - The interference potential and responsibilities are difficult to determine, which may generate an excessive number of costly legal disputes

- The free market proponents believe that maximizing the owner's profit coincide with maximizing public good
- Not everybody shares that view, as sometimes it may be the opposite
    - Maximizing auction revenues may not always be in the national interest, as the auction participants are trying to maximize their profits rather than serve the public good
    - Bidding on a license that would give the winner a monopoly, would be not in the public interest [Peha]
    - Universal access could not be assured

Spectrum market history

- 1989 - New Zealand, 1993 - USA (FCC) spectrum auctions
  - NZ withdraw liberalization in 2005!
- European auctions of UMTS licenses in recent years: ~US $100 billion
  - Electoral argument of the ruling party
  - Blocking competitors rather than building networks
  - The cost must be covered by the users - high prices of telecom services
    - Some believe that they contributed to bankruptcy of a number of telecom companies and to the general crisis of 2000s
- Unsolved apparent inconsistency between the private (nationally) and the public (internationally) spectrum

Rebirth of ‘commons’ concept

- ITU spectrum management ‘philosophy’: each (country) gets for free what it wants (spectrum reservation), if this does not harm other spectrum users
- But the process is static, slow, and costly, as it involves a series of formal co-ordinations/ negotiations among governments (with private sector involved)

- Advanced technology could do similar co-ordinations and ‘negotiations’ automatically and dynamically (real-time), via built-in algorithms and protocols
- That makes it possible to apply the “Commons” model with no property-rights, and no (individual) licensing, and no bureaucracy

License-exempt spectrum

- Access to the spectrum-orbit resource for specific equipment subject certain restrictions (e.g. to protect passive services)
  - open-access spectrum for low power (short range) devices
  - Spectrum commons (radio amateur bands, ISM, IEEE 802.11… bands)

- Users share frequencies and any device is allowed to transmit (the ‘Internet spirit’) following the agreed conditions (etiquette)
  - Limited to ISM unlicensed and amateur bands
  - No legal responsibility for interference, no rights for protection from interference,
- Maximize the number of users having access to spectrum resources
  - Examples: WiFi, WiMax, Bluetooth, etc.

Possible future

- Eventually, technology may remove the need for most functions now included in spectrum management also in other frequency bands
- Future radio systems may be able to automatically coordinate (automatically) among themselves the best use of spectrum/ orbit resources in real time (e.g. software-defined radio)

- Research work underway on the best algorithms (strategies) to be used by the equipment
  - E.g. based on Game Theory
- Different viewpoints (interests)
  - service-provider, regulator, individual user, community, society, …
  - various behaviors (including cheating)

- Example 1:
  - An emergency phone network shares the common spectrum resources enjoying the highest priority.
  - When operating, it has the exclusive access to spectrum automatically.
  - When it does not operate, the resource is open for other users.

- Example 2:
  - ‘Intelligent’ radio equipment explores automatically the local environment
  - Identifies the spectrum users/ owners, frequencies, protocols, etc.
  - Negotiates conditions and priorities

- Obtains authorization to transmit
- When authorized, starts and completes the processes of authentication, transmission, and monitoring (and payment transfer, if necessary)

Advanced technologies

- *Ultra-wideband (underlying) radio*
- *Multi-use software-defined radio*
- *Mesh networks*
- *Nanotechnology and quantum communications (that makes direct use of distinctively quantum-physical phenomena)*

Ultra-wideband sharing…

- Ultra-wideband systems are able to share common frequency, time and service area with other systems in a compatible way
  - They use (underlying) signals of a very low power density, well below the sensitivity floor of the other systems so that their operation remains ‘unnoticed’ (except for radioastronomy and passive earth exploration services)
  - To transmit the required amount of information in such conditions, they must use a very wide frequency bands

Nanotechnology

- *Nanotechnology* as a collective term refers to technological developments on the nanometer scale, usually 0.1-100nm.
- Quantum computing and communications exploit new quantum-effects such as the spin quantum state

Nanotechnology

“Artificial insects”
“Smart Dust Motes“
“Pico-satellites”
Tiny, autonomous radios combined with sensors

http://robotics.eecs.berkeley.edu/~pister/SmartDust/ (Last visited 16 Sept 2004)
Guizzo E: Flying away; IEEE Spectrum, Jan 2004, p32-33

When?

- New concepts and new technologies are now intensively developed
- However, in view of enormous investments in the “old” equipment, the “new” systems will not be very popular soon (unless a low price and viable business model justify the replacement)

What have we learned?

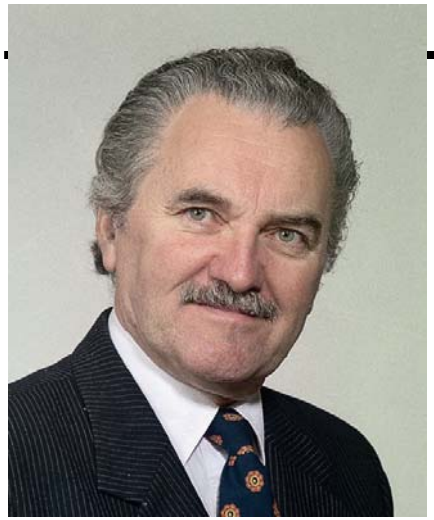
- What is, and how works, the international (and national) management of spectrum/ orbit resources
- What are the Radio Regulations, how are they created and updated, and why they should be followed by all those involved in wireless technologies
- What might be expected in future

Selected references

- Peha JM, Panichpapiboon S: Real-time Secondary Markets for Spectrum; IEEE 1998; http://www.comsoc.org/livepubs/surveys/public/4q98issue/pdf/Peha.pdf
- Peha JM: Spectrum Management Policy Options; http://www.comsoc.org/livepubs/surveys/public/4q98issue/pdf/Peha.pdf; http://www.ece.cmu.edu/~peha/policy.html
- Radio spectrum management for a converging world; ITU 2004; www.itu.int/spectrum
- Raja S, Bar F: Transition paths in a spectrum commons regime; 2003 http://tprc.org/papers/2003/235/Raja-Bar-TPRC2003.pdf
- Struzak R: Introduction to international radio regulations (with an extract from ITU RR); http://www.ictp.trieste.it/~pub_off/lectures/
- Struzak R: Spectrum Management for Wireless Services of the 21th Century; Global Communications – Interactive 97, Hanson Cooke Ltd. 1997, pp. 379-383
- Struzak R: Evolution of Spectrum Management Concepts; Proceedings of 18th International Wroclaw Symposium on Electromagnetic Compatibility, Wroclaw, 28 – 30 June 2006; www.emc.wroc.pl
- Struzak R: Flexible Spectrum Use and Laws of Physics; The ITU/FUB Workshop on Market Mechanisms for Spectrum Management, Geneva 21-22 January 2007 http://www.itu.int/osg/spu/stn/spectrum/material.html ; http://www.itu.int/osg/spu/stn/spectrum/speakers_pres.html http://www.itu.int/ibs/sg/spu/200701spectrum/index.html ;
- http://www.itu.int/osg/spu/stn/spectrum/resources.html

Any questions?

Thank you for your attention



Ryszard STRUZAK *PhD., DSc.*
Co-Director, ICTP-ITUD School on Wireless Networking, IT
Academician, International Telecommunication Academy
Life Fellow IEEE
ryszard@struzak.com
www.ryszard.struzak.com

Important notes

Beware of misprints!!! These materials are preliminary notes for my lectures and may contain misprints. If you notice some, or if you have comments, please send these to r.struzak@ieee.org.