UNIK 4230 – Mobile Communications

Spring 2015

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Spectrum Management

7 May 2015

Support material:

Tjelta T., Struzak R. Spectrum management overview, *The Radio Science Bulletin*, No 400, March 2012.

(not the only source)

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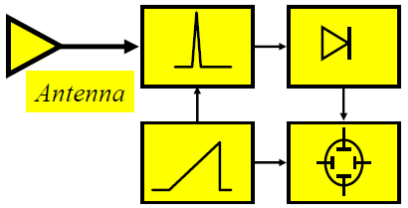
What is spectrum?

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

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

- **Measurable physical 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



- **Common (public) resource?**
  - A natural freely accessible public resource: everybody can profit from its exploitation
    - 1901: First transatlantic wireless transmission
- **Marketed commodity?**

Contents

- What is spectrum? A brief history of spectrum management
- Global, regional and national regulations
- Spectrum management for mobile and wireless
- Spectrum sharing and trading concepts
- Future spectrum management enablers – cognitive radio

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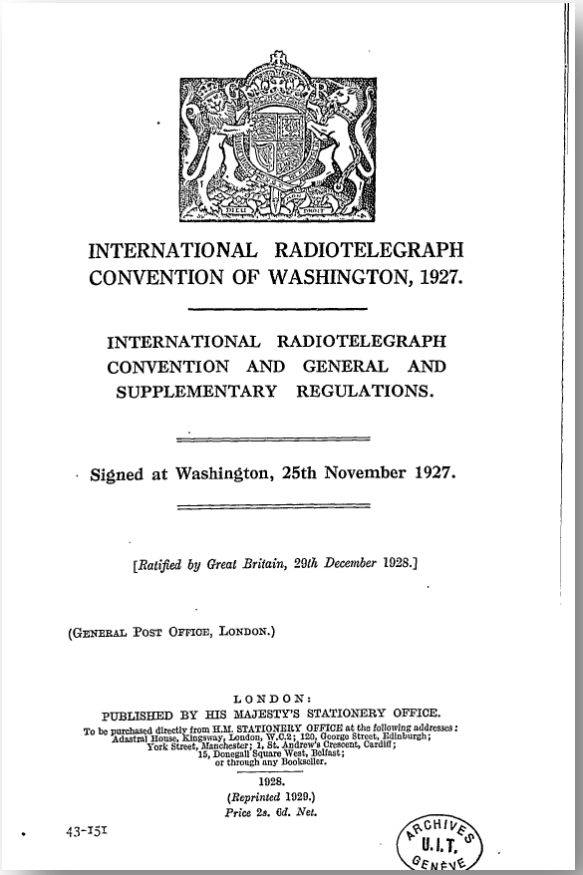
Commercial use of spectrum started with maritime radio telegraphy

- Intense unregulated competition resulted in interference
  - And commercial restrictions on use
- The Marconi Wireless Company was very aggressive in its effort to create a monopoly
  - Established shore stations
  - Prohibited handling messages from ships not using Marconi equipment
- Others, e.g. Telefunken, did the same

- 1902:
  - Prince Henry of Prussia attempts to send a message from his ship to President Roosevelt of the U.S
  - Refused handled by a Marconi operator
  - Contacts Kaiser Wilhelm of Prussia who proposes an international Convention to regulate maritime communications
- 1903:
  - Preliminary Conference on Wireless Telegraphy
  - Proposes a protocol to require all stations to inter-communicate and to accept messages from all ships
- 1906:
  - The first International Radiotelegraph Convention was signed
- 1912:
  - The Titanic disaster

The birth of spectrum management came with the rise of broadcast radio

- 1927
  - General and Supplementary regulations
  - Articles about frequency allocations
  - Frequencies are allocated to specific service:
    - Fixed, Mobile, Broadcast, Amateur, ..
  - The creation of the International Technical Consultative Committee - CCIR



INTERNATIONAL RADIOTELEGRAPH CONVENTION OF WASHINGTON, 1927.

INTERNATIONAL RADIOTELEGRAPH CONVENTION AND GENERAL AND SUPPLEMENTARY REGULATIONS.

Signed at Washington, 25th November 1927.

[*Ratified by Great Britain, 29th December* 1928.]

(General Post Office, London.)

LONDON:
PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE.
To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:
Adastral House, Kingsway, London, W.C.2; 120, George Street, Edinburgh;
York Street, Manchester; 1, St. Andrew's Crescent, Cardiff;
15, Donegall Square West, Belfast;
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1928.
(*Reprinted* 1929.)
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Spectrum is today managed on three levels

- **Global level:**
  - By the *International Telecommunications Union Radio Sector* – ITU-R, the continuation of CCIR (www.itu.int)
    - From 1947 ITU is a UN Agency
- **The regional level:**
  - In Europe by CEPT/European Communications Committee (ECC) (www.cept.com/ecc)
- **The national level:**
  - The national regulators:
  - In Norway the National Communications Authority – NKOM (www.nkom.no)
  - Other important national regulators are Ofcom in the UK (www.ofcom.org.uk) and FCC in the US (www.fcc.gov)

Global management: The International Telecommunications Union Radiocommunication Sector – ITU-R

- **The ITU Radiocommunication Sector (ITU-R)**
  - One of the three sectors (divisions or units) of the International Telecommunication Union (ITU) and is responsible for radio communication.
- **Role**:
  - Manage the international radio-frequency spectrum and satellite orbit resources
  - Develop standards for radiocommunication systems with the objective of ensuring the effective use of the spectrum.
- **ITU-R is required** to allocate spectrum and register frequency allocation, orbital positions and other parameters of satellites, “in order to avoid harmful interference between radio stations of different countries”
  - The international spectrum management system is based on regulatory procedures for frequency coordination, notification and registration.

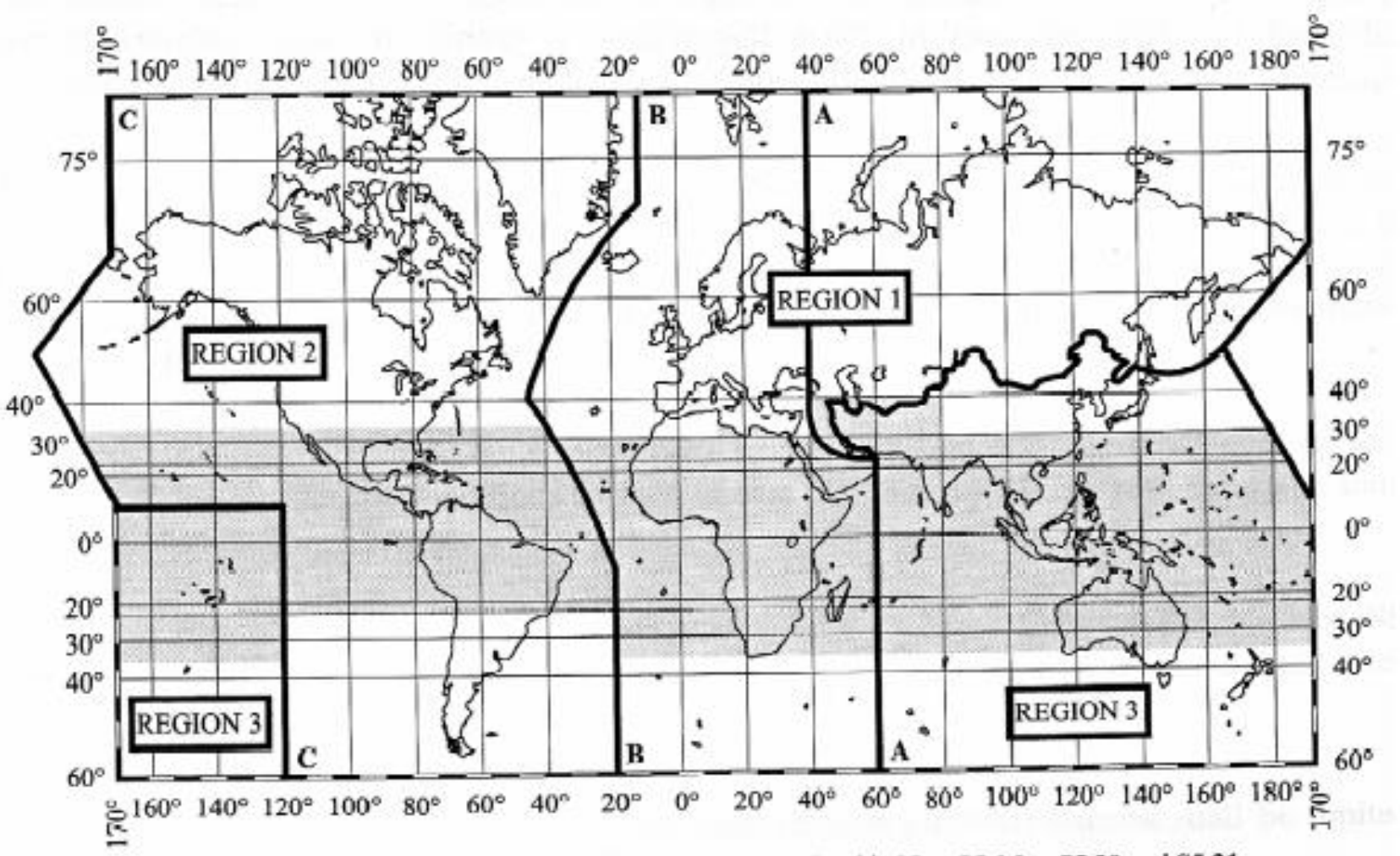
- **The strategic goal of the ITU-R** is threefold, and includes (source: www.itu.int):
  - To ensure interference-free operations of radiocommunication systems by implementing the **Radio Regulations** and regional agreements, as well as updating these instruments in an efficient and timely manner through the processes of world and regional radiocommunication conferences;
  - To establish Recommendations intended to assure the necessary performance and quality in operating radiocommunication systems;
  - To seek ways and means to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum and satellite-orbit resources and to promote flexibility for future expansion and new technological developments.

The ITU-R Radio Regulations (RR) are issued every three to four years

- Global:
  - An international Treaty that defines how radio waves and satellite orbits should (or should not) be used and managed
    - Ratified by, and legally binding in, all countries (~190 in total)
    - Basic set of rules
    - Three regions
    - Frequency allocation table
    - Frequency Plans' databases
    - Master International Frequency Register (MIFR) database
    - What to do in case of harmful interference

- Discussed and revised on *World Radio Conferences (WRC)*
  - Next is this year: WRC-15

The ITU-R regions



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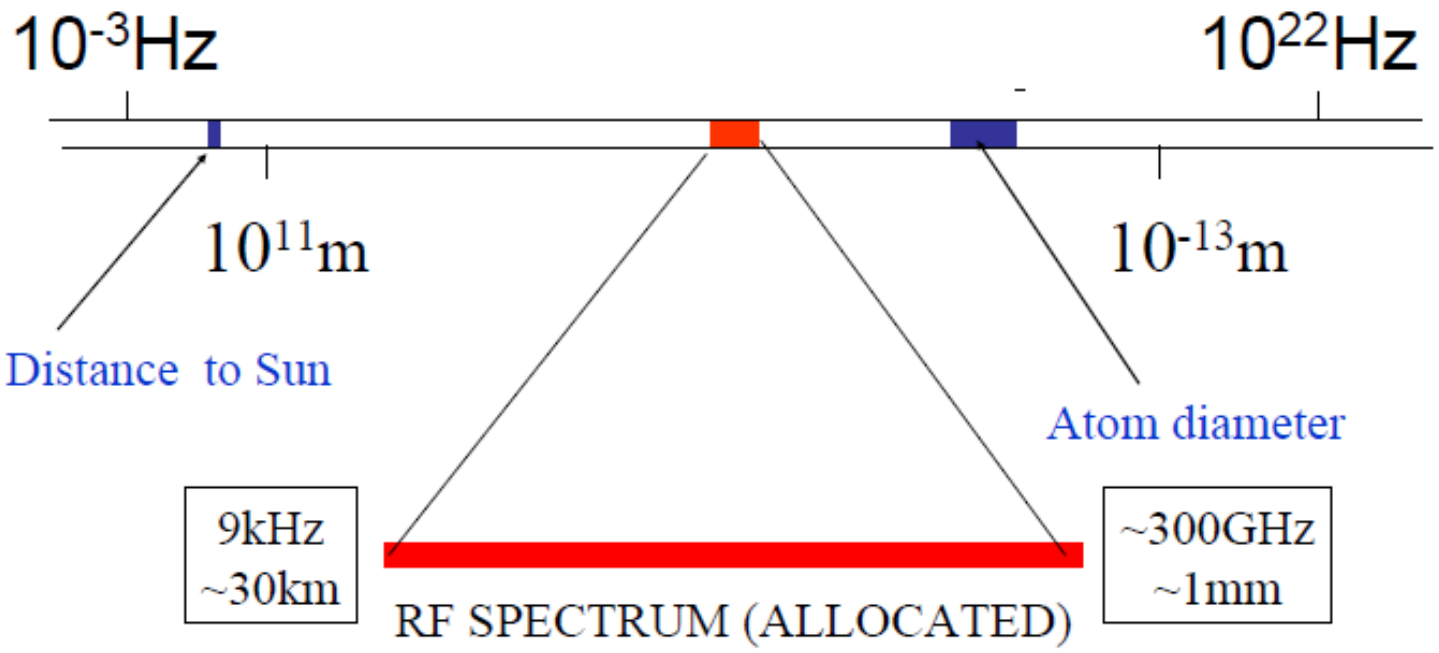
What part of spectrum is regulated?



Definitions from the RR

		Example
Administration:	Any governmental department or service responsible for discharging the obligations undertaken in the Constitution of the International Telecommunication Union, in the Convention of the International Telecommunication Union and in the Administrative Regulations.	The Norwegian Communications Authority (NKOM) Ofcom – UK FCC - US
Allocation (of a frequency band):	Entry in the Table of Frequency Allocations of a given frequency band for the purpose of its use by one or more terrestrial or space radiocommunication services, or the radio astronomy service under specified conditions. • ***distribution of frequencies to radio services*** *(on a primary or on a secondary basis)*	
Allotment (of a radio frequency or radio frequency channel):	Entry of a designated frequency channel in an agreed plan, adopted by a competent conference, for use by one or more administrations for a terrestrial or space radiocommunication service. in one or more identified countries or geographical areas, and under specified conditions. • ***distribution of frequencies to geographical areas or countries***	The 3GPP band designations for mobile
Assignment (of a radio frequency or radio frequency channel):	Authorization given by an administration for a radio station to use a radio frequency or radio frequency channel under specified conditions. • ***distribution of frequencies to users or radio stations.***	Operators' licenses

The Frequency Allocation Table (FAT)
ITU-R RR Article 5

Allocation to services		
Region 1	**Region 2**	**Region 3**
890-942 FIXED MOBILE except aeronautical mobile 5.317A BROADCASTING 5.322 Radiolocation 5.323	**890-902** FIXED MOBILE except aeronautical mobile 5.317A Radiolocation 5.318 5.325 **902-928** FIXED Amateur Mobile except aeronautical mobile 5.325A Radiolocation 5.150 5.325 5.326 **928-942** FIXED MOBILE except aeronautical mobile 5.317A Radiolocation 5.325	**890-942** FIXED MOBILE 5.317A BROADCASTING Radiolocation 5.327
942-960 FIXED MOBILE except aeronautical mobile 5.317A BROADCASTING 5.322 5.323	**942-960** FIXED MOBILE 5.317A	**942-960** FIXED MOBILE 5.317A BROADCASTING 5.320
960-1 164	AERONAUTICAL MOBILE (R) 5.327A AERONAUTICAL RADIONAVIGATION 5.328	
1 164-1 215	AERONAUTICAL RADIONAVIGATION 5.328	

Regional and national management

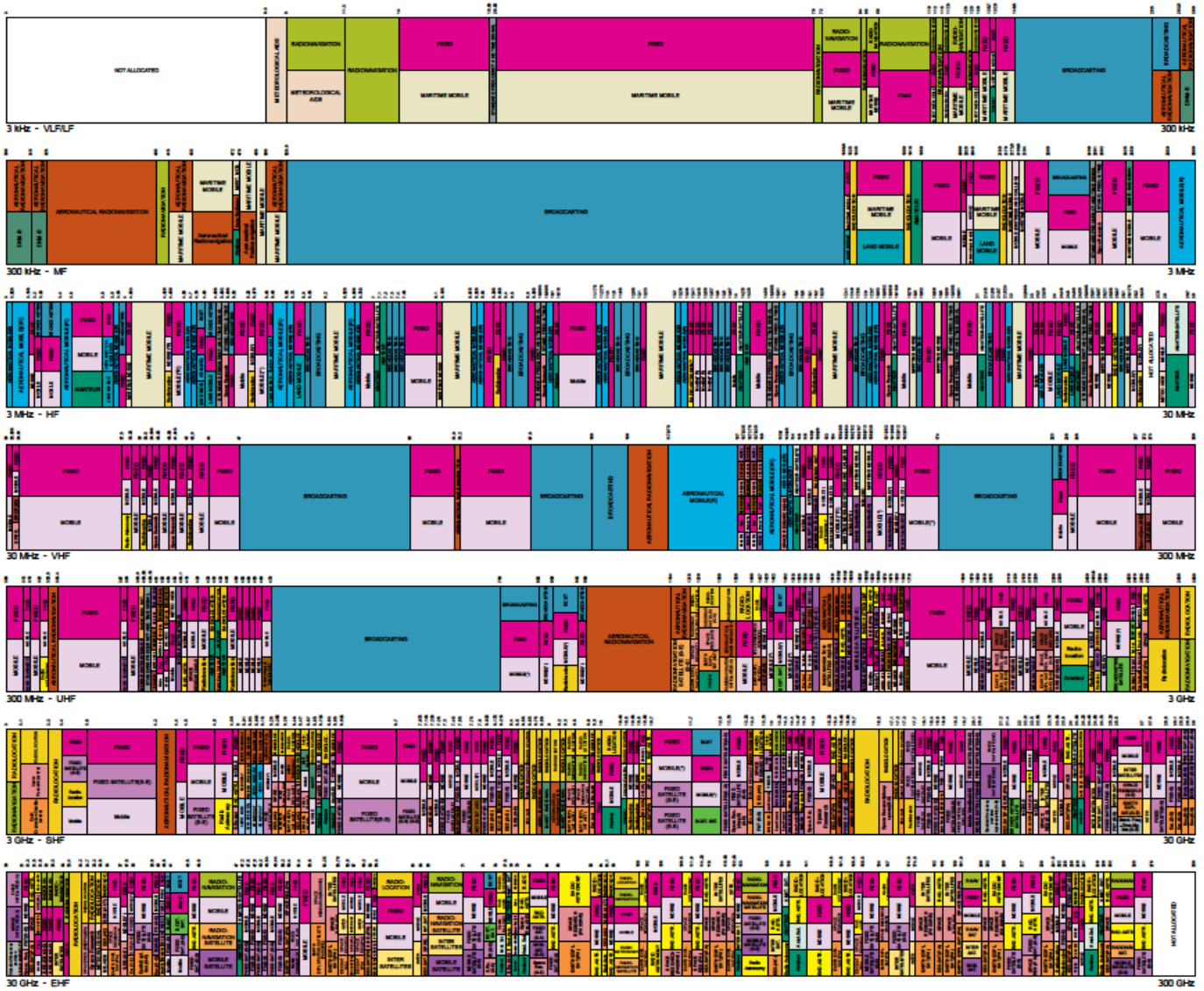
- The regional level is used for harmonization within a geographical area and sometimes to align policies
  - Europe: CEPT/ECC – European Communications Comittee - http://www.cept.org/ecc/

- National regulatory authorities manage spectrum following three different models:
  - Administrative model
    - Authority decides in much detail on the rights to use spectrum
  - Trading model
    - Spectrum is auctioned, especially used for mobile
  - Free model
    - Spectrum commons, like spectrum for WLAN

NORWAY

FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



Frequency Allocations Table (FAT) – Norway example

Søk i nasjonal frekvensplan http://frekvens.nkom.no/Frekvensportalen/index.xhtml;jsessionid=f1988a70a62a4b20740e70f2bee3....

Nasjonal kommunikasjons-myndighet

Søk i nasjonal frekvensplan

Sist oppdatert 05.03.2015

Tilbake til normal visning

Frekvensbånd	Allokering	Bruk	Alle dokumenter	Tillatelser
790 - 862 MHz Fotnoter: 5.312 5.314 5.315 5.316 5.316A 5.319	BROADCASTING MOBILE EXCEPT AERONAUTICAL MOBILE FIXED	IMT Radio microphones and ALD	Dokumenter	Tillatelser
862 - 890 MHz Fotnoter: 5.319 5.323	MOBILE EXCEPT AERONAUTICAL MOBILE FIXED BROADCASTING	Alarms Radio microphones and ALD Non-specific SRDs RFID Wireless audio applications Short Range Devices Digital cellular GSM-R Digital cellular	Dokumenter	Tillatelser
890 - 942 MHz Fotnoter: 5.323	MOBILE EXCEPT AERONAUTICAL MOBILE FIXED BROADCASTING Radiolocation	Digital cellular Short Range Devices Digital cellular GSM-R Digital cellular	Dokumenter	Tillatelser
942 - 960 MHz Fotnoter: 5.323	BROADCASTING FIXED MOBILE EXCEPT AERONAUTICAL MOBILE	Digital cellular	Dokumenter	Tillatelser
960 - 1164 MHz	AERONAUTICAL RADIONAVIGATION Aeronautical Mobile (R)	Aeronautical navigation	Dokumenter	Tillatelser
1164 - 1215 MHz Fotnoter: 5.328A	RADIONAVIGATION-SATELLITE (SPACE-TO-EARTH) (SPACE-TO-SPACE) AERONAUTICAL RADIONAVIGATION	Aeronautical navigation Satellite navigation systems GALILEO GLONASS	Dokumenter	Tillatelser

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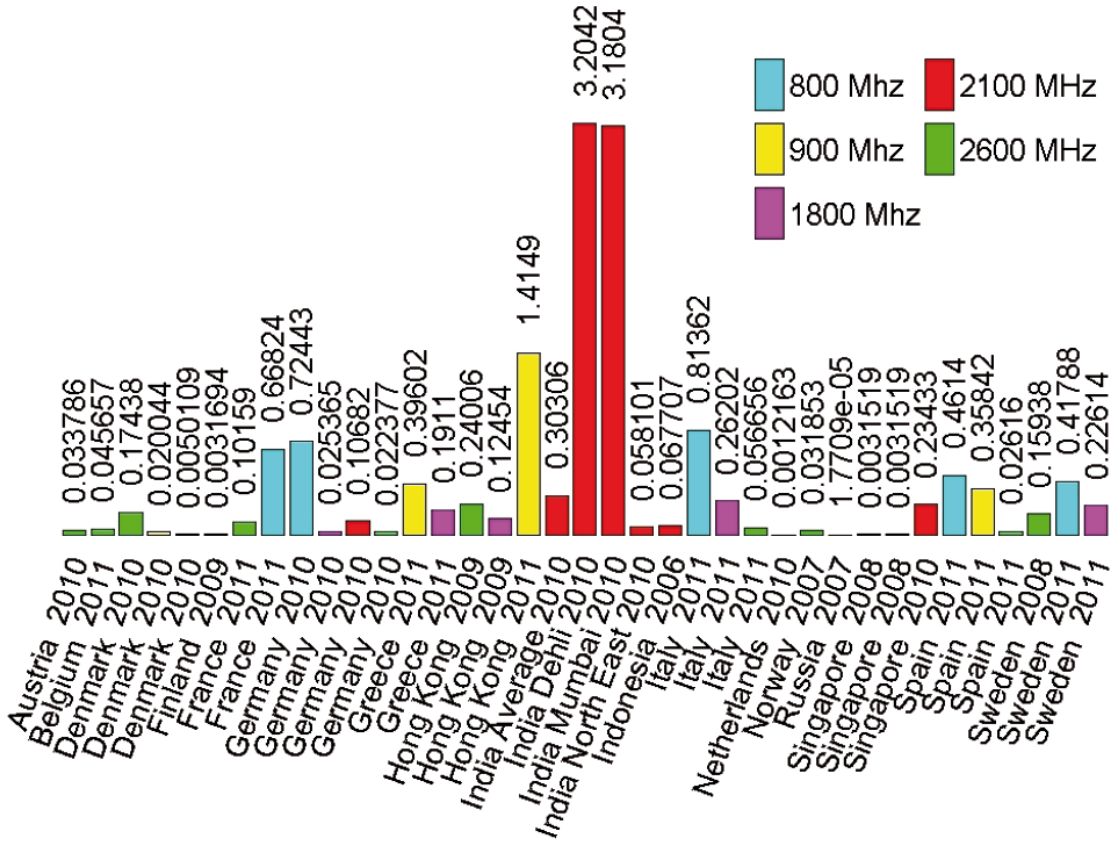
Mobile frequency licenses in Norway (www.nkom.no, 11.09.2014)

	Frequency band	Total available bandwidth	Use/expected use in Norway	Operators
450 MHz	452.5-457.5 462.5-467.5	2 x 4 MHz	CDMA2000	ICE
800 MHz	791-821 832-862	2 x 30 MHz	LTE	ICE Netcom Telenor
900 MHz	880-915 925-960	2 x 35 MHz	GSM, UMTS	ICE Netcom Telenor
1800 MHz	1710-1785 1805-1880	2 x 75 MHz	GSM, LTE	Telenor Netcom ICE
2100 MHz	1920-1980 2110-2170	2 x 60 MHz	UMTS	Netcom Telenor Mobile Norway
2600 MHz	2500-2570 2620-2690	2 x 70 MHz	LTE	Telenor Netcom Cloudberry Mobile

NKOM is planning an auction of 2x15 MHz in the 1800 MHz band in November 2015

Mobile communications: Spectrum auctions



Auction prices given in EUR/MHz/Pop for paired spectrum over a five year period (2006 – 2011)

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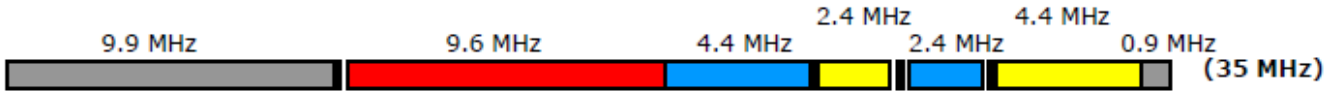
Refarming of spectrum

- In agriculture:
  - Switch from growing one type of product to another: E.g. from potato to carrot.
- In mobile communications:
  - Switch from one technology to another (in the same frequency band) – e.g. from GSM to GSM + UMTS

- Requirements:
  - Licenses are technology neutral
  - (Often) Spectrum holding is contiguous
  - Operators have a minimum amount of spectrum each

Refarming example 900 MHz

Before:



9.9 MHz + 0.9 MHz not allocated

Only red operator are able to refarm from GSM to GSM + UMTS (requires ~10 MHz and contiguous spectrum)

After

Government has:

- **Allocated the unassigned spectrum to the three operators**
- **Reshuffled the spectrum so that all operators have contiguous spectrum**
- **All operators can refarm from GSM to GSM + UMTS**

Legends: **Red operator** | **Blue operator** | **Yellow operator** | **Unassigned**

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The value of an amount of spectrum

- **Case Example – Mobile Broadband in Oslo:**
- Urban part of Oslo:
  - Area: 135 km^2
  - Population: 560.000 people
- Expected penetration: 40%
- Average usage in peak hour: 100 kbit/s (downlink, mobile receive)

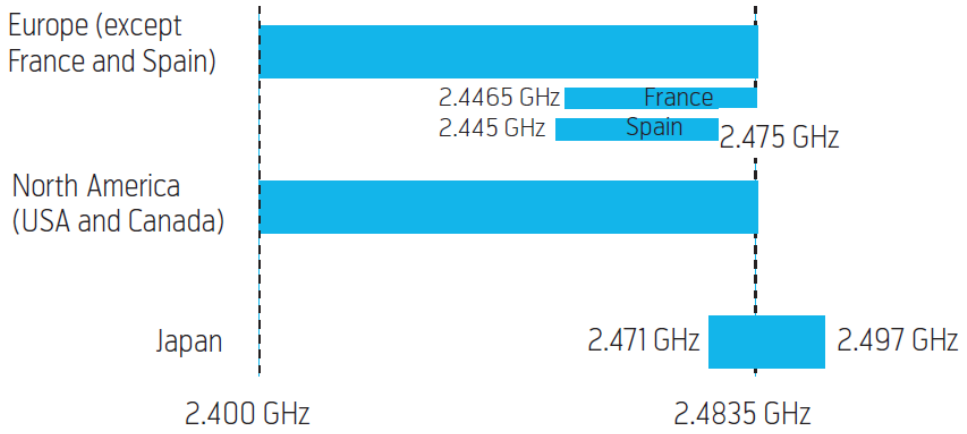
- **Case 1 – 2x10 MHz spectrum:**
- Traffic / site: 24 Mb/s
- Number of sites needed: 930

- **Case 2 – 2x20 MHz spectrum:**
- Traffic / site: 48 Mb/s
- Number of sites needed: 465

- **Conclusion:**
- (provided Case 1 is profitable) The value of the additional 2x10 MHz spectrum in this example is equal to the cost of 465 sites (930 – 465)

Unlicensed spectrum - commons

- The band between 2.40 and 2.50 GHz is used for e.g. Wi-Fi and Bluetooth
  - ISM-band (Industrial, Scientific and Medicine)
- This spectrum is shared among the users based on a few simple rules
- There is no need for a license to use this spectrum as long as the basic rules are respected:



Region/country	Available frequencies	Transmit power constraints
North America (USA and Canada)	2.4 – 2.4835 GHz	1 W (30 dBm) transmitter power
Europe (except France and Spain)	2.4 – 2.4835 GHz	100 mW (20 dBm) EIRP[1)] maximum
France Spain	2.4465 – 2.4835 GHz 2.445 – 2.475 GHz	The power can be adjusted in the equipment in order to intentionally reduce the range
Japan	2.471 – 2.497 GHz	500 mW (27 dBm) transmitter power

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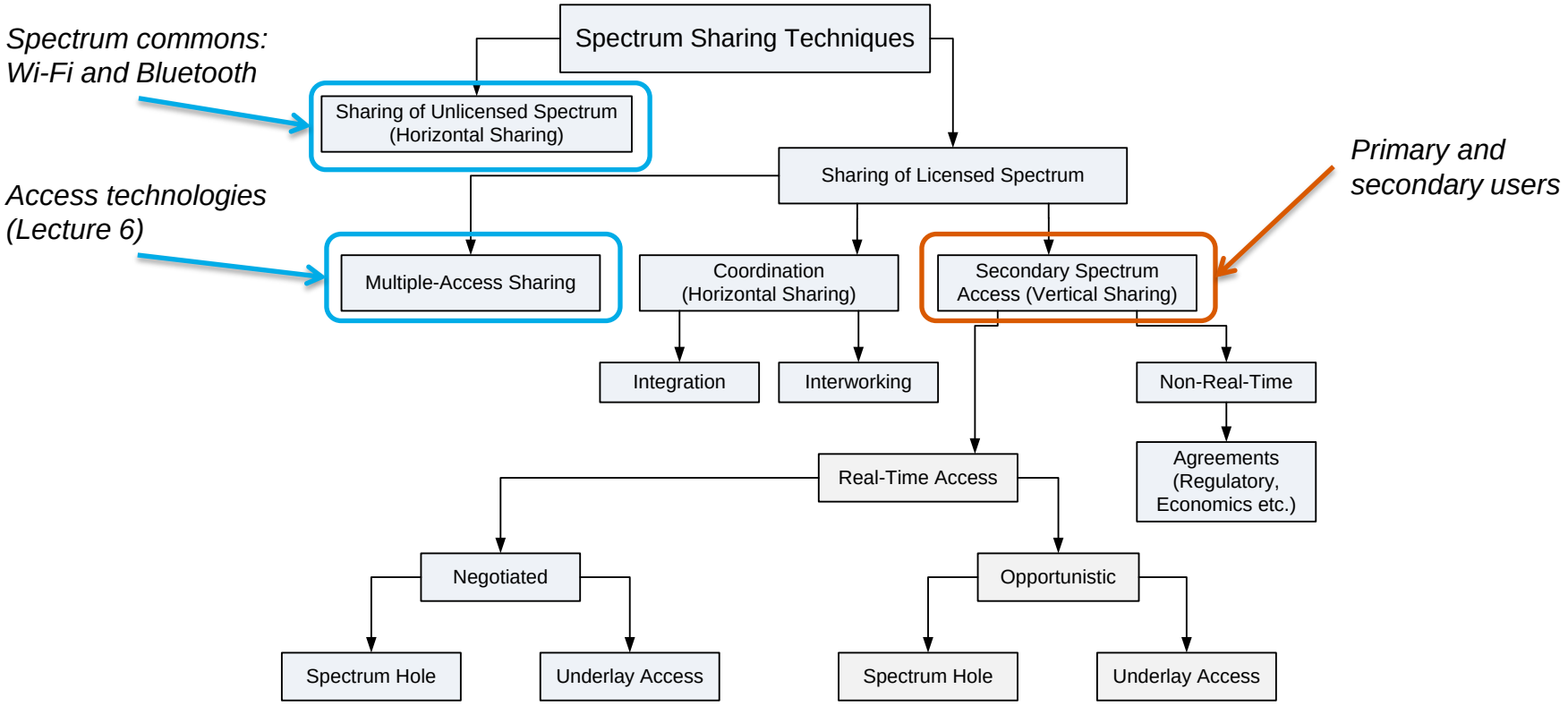
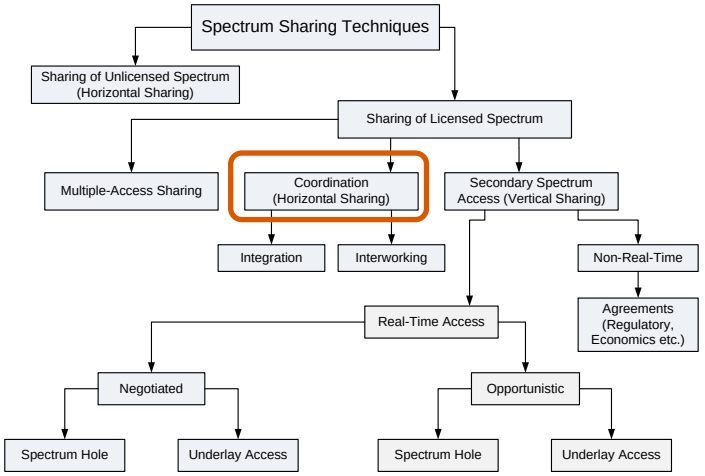
Future trends: Spectrum sharing and trading



- Source: Wyglinski A M., Nekovee M., Hou Y T. *Cognitive Radio Communications and Networks*. Academic Press (Elsevier), MA, USA. 2010. ISBN 978-0-12-374715-0.

Spectrum pooling



- Network sharing among operators are becoming commonplace
  - The next step in providing more cost-efficient networks
  - Operators share a common network infrastucture: base stations, etc.

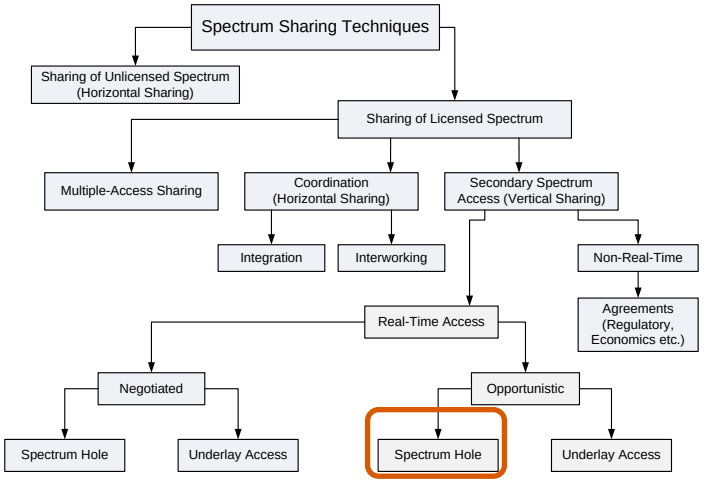
- Network sharing can be done on several levels:
  - Site sharing, RAN sharing, shared core etc.

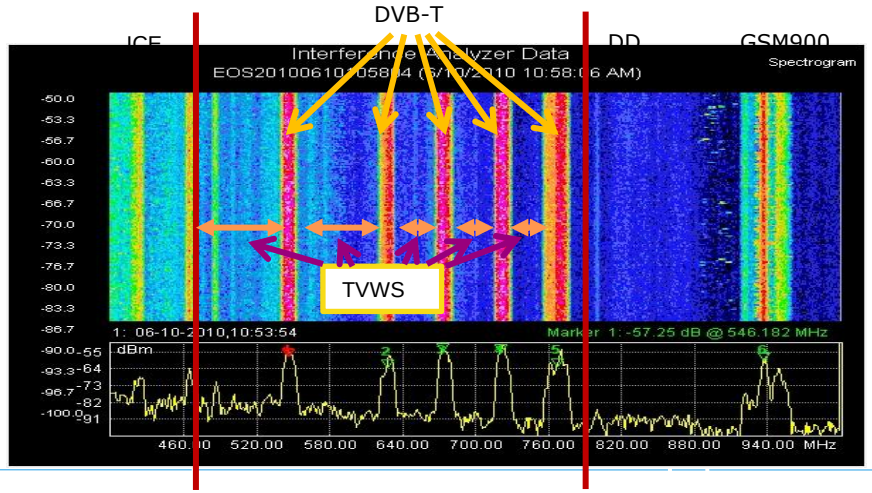
- Spectrum sharing can be a part of it, if the national regulator allows
  - This is called spectrum pooling

- Telenor and Magyar Telekom in Hungary has entered network sharing including spectrum pooling for 4G in the 800 MHz band
  - https://www.telenor.hu/en/press/pressreleases/1146

Opportunistic access

- **«White Space» access**
  - 'White Space' is a label indicating a part of the spectrum, which is available for a radiocommunication application (service, system) at a given time in a given geographical area on a non-interfering / non-protected basis with regard to other services with a higher priority on a national basis (CEPT Report 24).
- **Primary and secondary users**
- Spectrum holes are identified by use of a database, possibly assisted by sensing
  - Secondary user must not interfere with primary user
- Allowed in the UK and US for the TV-band: 470 – 790 MHz
- Commercial spectrum databases are driven on a licensed basis:
  - E.g. Google and Microsoft





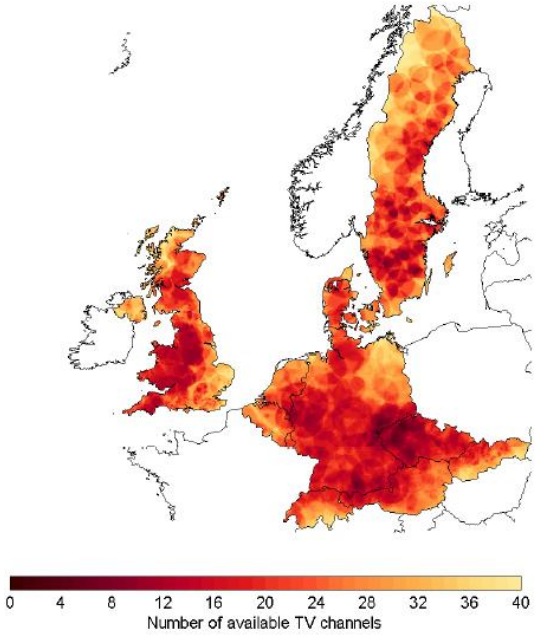


Fig. 2. White space map of $S(\mathbf{x})$ for 11 European countries.

Spectrum trading

- Current practices in spectrum trading (CEPT/ECC):
  - "General authorizations" is basically the type of regulation used for licence-exempt bands like the 2.4 GHz ISM band.
    - Frequency bands under general authorization are not tradable.
  - "Individual right of use" is what commonly is referred to as licensed bands, like e.g. the IMT bands.
    - Legal frameworks for spectrum rights are regulated at the national level.
    - Within EU, "rights of use" are transferrable and there is a harmonised regulatory framework in the context of Electronic Communications Networks & Services (ECN&S).
    - The framework also distinguishes between trading and leasing with a focus on trading.
- In Europe, 18 of the 22 CEPT countries allow trading of usage rights. It has been allowed since 1997 (in Denmark) and most of the other countries opened for this between 2002 and 2006.

CEPT/ECC. *Description of Practices Relative to Trading of Spectrum Rights of Use*. ECC Report 169. Paris, May 2011.

Research: Spectrum micro-trading

- We define spectrum micro-trading as the possibility to buy and sell spectrum resources on a smaller scale than has currently been used in one or more of the spatial, temporal and frequency dimensions.

- Micro-trading is different from real-time trading, but micro-trading could support real-time trading.

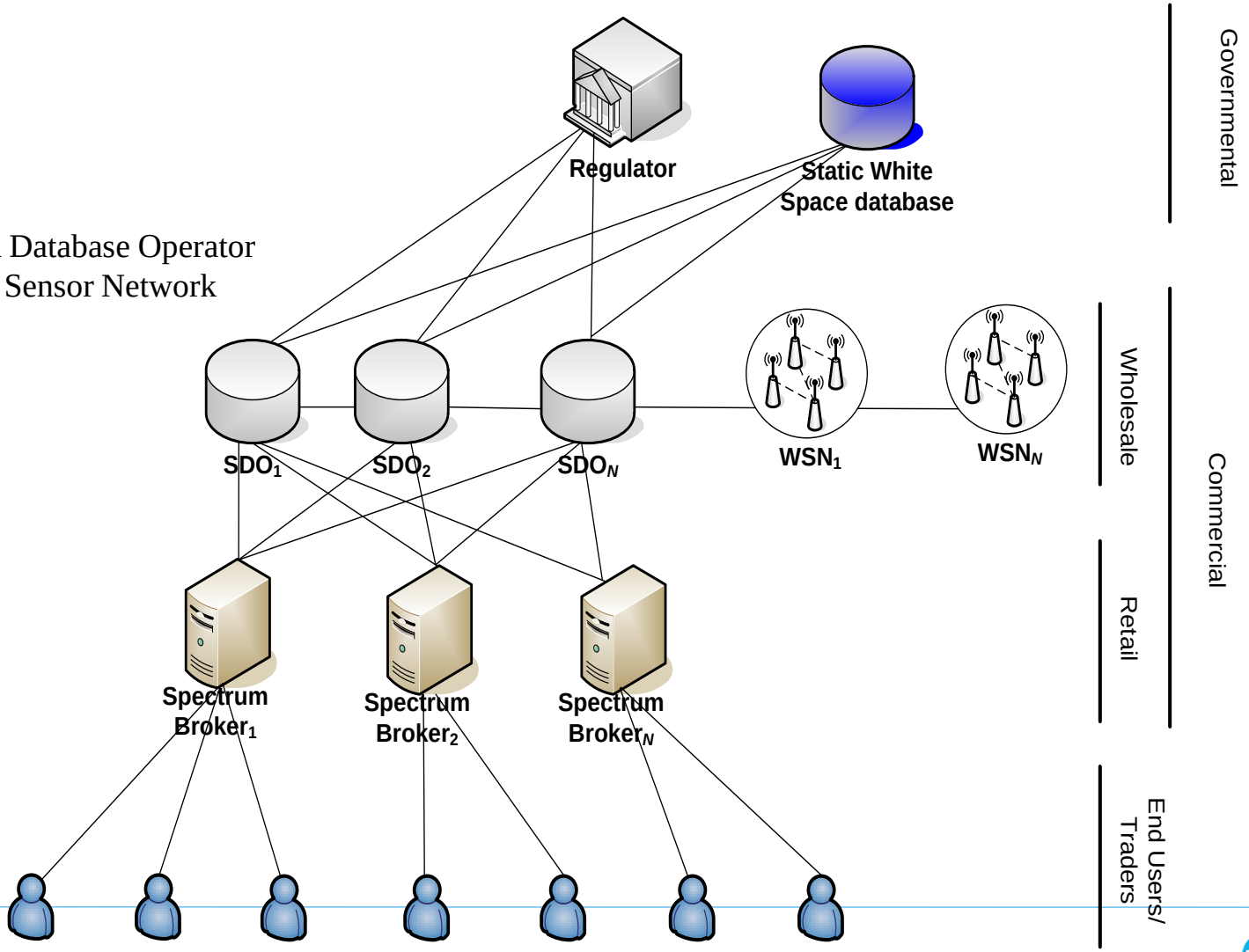
- Will enable wireless service providers to acquire spectrum:
  - for small or wide geographical areas,
  - for short or long time periods,
  - for narrow or wide bandwidths.

- Might increase spectrum utilization and the opportunity to acquire spectrum resources when optimizing metrics and policies properly.

Source: P-Grønsund, R.MacKenzie, P.H. Lehne, K. Briggs, O.Grøndalen, P.E. Engelstad, T. Tjelta: «Towards Spectrum Micro-trading». *Future Network & Mobile Summit 2012*, Berlin, 4-7 July 2012.

A spectrum broker can mediate between buyers and sellers

SDO: Spectrum Database Operator
WSN: Wireless Sensor Network



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A set of parameters enabling spectrum micro-trading can be defined

The main parameter is information about available spectrum resources:

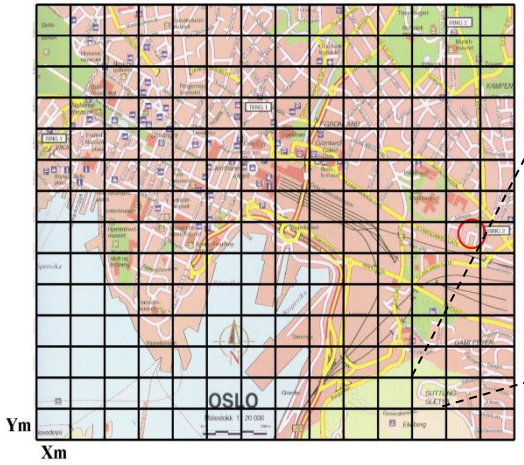
- **Spatial dimension** (geographical area, height extent)
- **Temporal dimension** (time interval)
- **Frequency dimension** (frequency band, frequency bandwidth)

Other relevant parameters:

- allowed effective radiated power (ERP),
- height above terrain (HAAT),
- terrain data (e.g. hilly, flat),
- directional antenna radiation pattern,
- spectrum masks,
- limitations on technology allowed (modulation types, duplex mode),
- restrictions on organisations allowed to use the spectrum resource.

A Practical Approach:
The ”Spectrum Micro-trading Pixelation” Model

Spatial Dimension



Pixel

- Population
- Height above sea
- Vegetation (trees, hills, building heights/density)
- …

Y m

X m

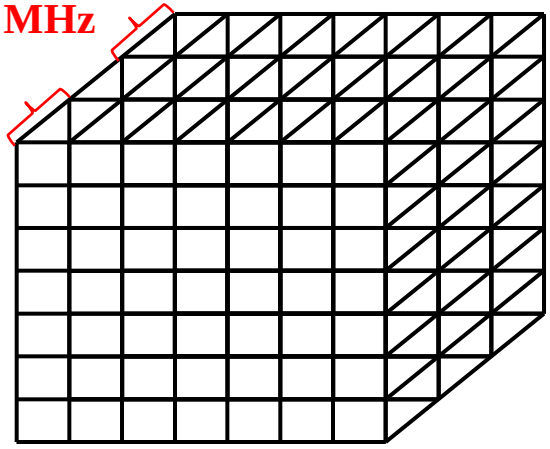
Temporal Dimension

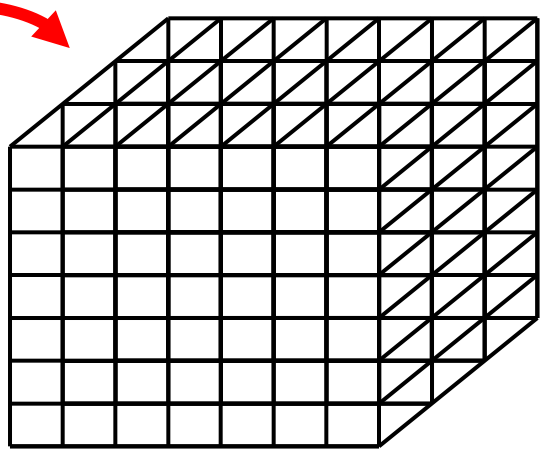
T (e.g. 1 sec)

B_N MHz

B_1 MHz

Frequency Dimension





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Pixelation – The Tradable Unit

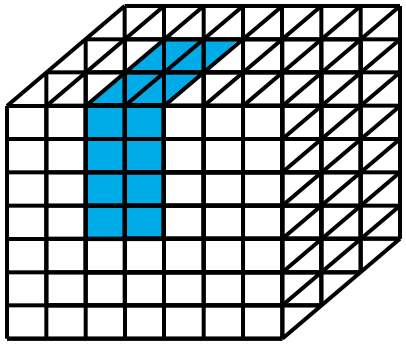
Let the minimum tradable unit be:

$$\mathbf{Pixel} * \boldsymbol{B} * \boldsymbol{T}$$

A trading bid or ask in a spectrum market can be described by:

$$\boldsymbol{a}\mathrm{Pixel} * \boldsymbol{b}B * \boldsymbol{c}T$$

where **a**, **b** and **c** are variables that determines the amount of consecutive pixels, bandwidth and time to be traded.



Example:

- **Market**: Pixel=100X100m, *B*=1MHz, *T*=1hour
- **Bid**: *a*=8, *b*=2, *c*=720
- **Total**: 800m^2, 2 MHz, 1 month

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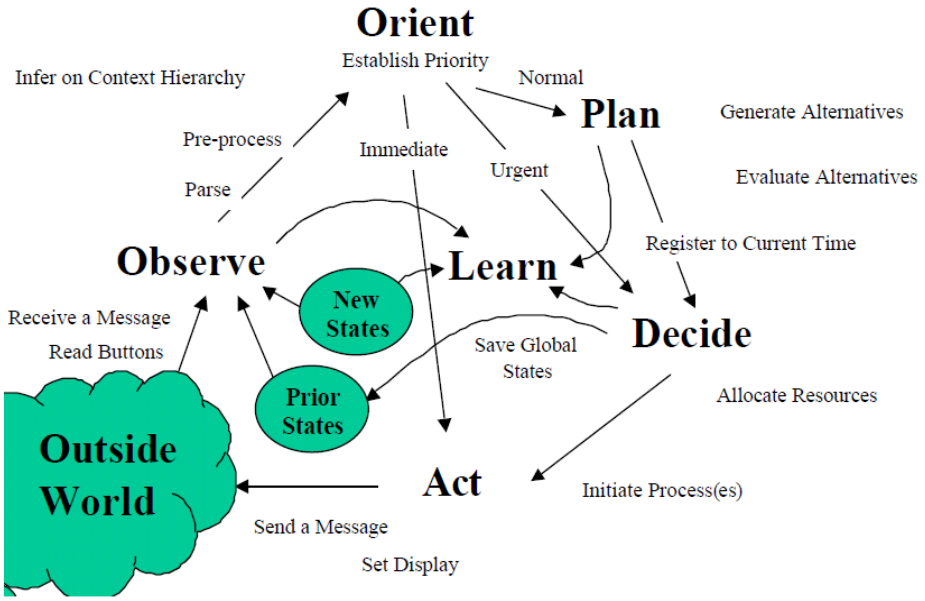
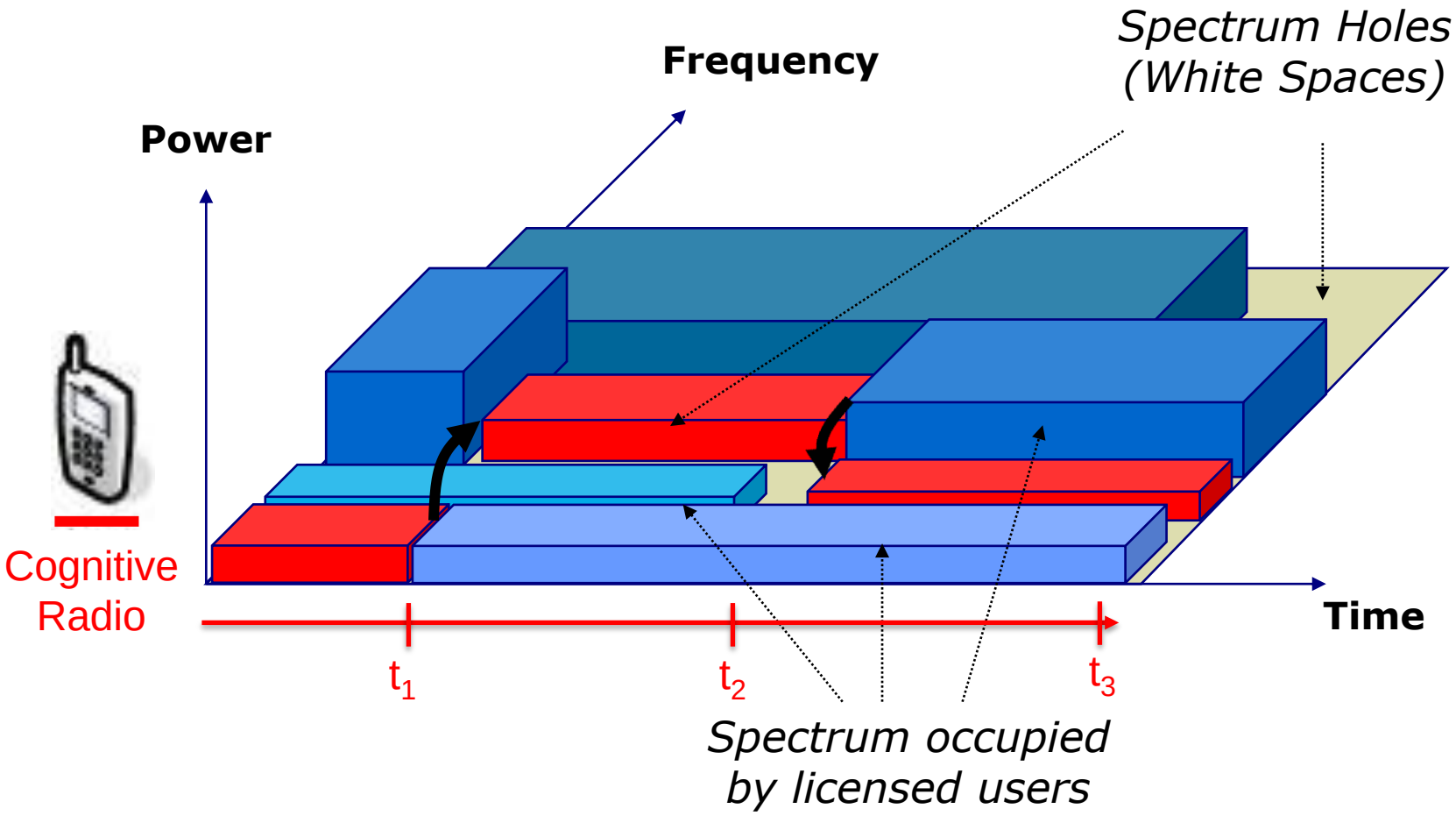
Cognitive radio – an enabler for new spectrum sharing and trading

- "**a really smart radio** that would be self-aware, RF-aware, user-aware, and that would include language technology and machine vision along with a lot of high-fidelity knowledge of the radio environment"
  - J. Mitola in: EETimes. The inventor of cognitive radio. EETimes, News & Analysis. 28th Nov 2005: http://www.eetimes.com/electronics-news/4056921/The-inventor-of-cognitive-radio.



- **Cognitive radio according to ITU-R:**
  - "A radio system employing technology that allows the system to obtain *knowledge* of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously *adjust* its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to *learn* from the results obtained."

Cognitive Radio can be used to dynamically access spectrum that is underutilized



Spectrum management - summary

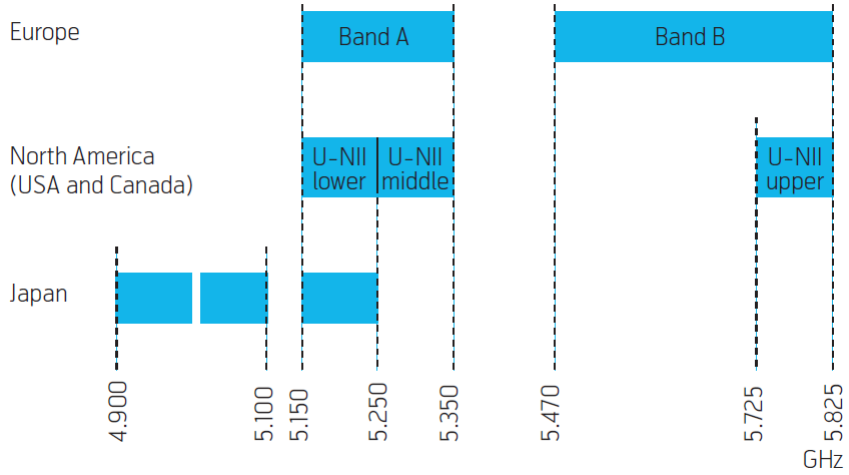
- Spectrum management became neccesary to avoid interference and regulate competition
  - Maritime communication was the first area
- Spectrum management is done on three levels: global, regional and national
- Global spectrum management is handled by the ITU – a UN body
  - Defines global frequency plans - allocations
- Regional spectrum management is in Europe handled by the CEPT
  - Harmonization and policies
- National spectrum management is done by the regulators
  - Grants licenses – assignments
- Mobile spectrum is usually granted using spectrum auctions
- Certain parts of the spectrum are «commons», which requires no license to use, only conformance to certain rules on emission
  - Wi-Fi and Bluetooth uses commons in the 2.45 GHz band
- New trends are spectrum sharing
  - Spectrum pooling among operators as part of network sharing
  - Opportunistic access of TV white spaces
- New approaches to spectrum trading on a micro-level are proposed

Extras

Unlicensed spectrum – commons
The 5 GHz bands

- The band between 4.9 and 5.825 GHz can be used for Wi-Fi

- This spectrum is shared among the users based on a few simple rules
- There is no need for a license to use this spectrum as long as the basic rules are respected:



Region/country	Available frequencies	Transmit power constraints
North America (USA and Canada)	5.15 – 5.25 GHz (U-NII[2] lower band) 5.25 – 5.35 GHz (U-NII middle band) 5.725 – 5.825 GHz (U-NII upper band)	40 mW (16 dBm), 6 dBi antenna 200 mW (23 dBm), 6 dBi antenna 800 mW (29 dBm), 6 dBi antenna
Europe	5.15 – 5.35 GHz (band A) 5.47 – 5.725 GHz (band B)	200 mW (23 dBm) EIRP, indoor 1 W (30 dBm) EIRP, outdoor
Japan	4.9 – 5.1 GHz 5.15 – 5.25 GHz	250 mW (24 dBm) transmitter power 125 mW (22 dBm) transmitter power

Regulatory constraints in TVWS

Primary system:

- DVB-T – digital terrestrial TV
  - 8 MHz channel width (Europe)
  - Tx power up to several kW
- Also used for PMSE – program making and special events: wireless microphone systems and audio links
  - Narrow channels: 200 – 600 kHz
  - Tx power 0-17 dBm (handheld); 47 dBm for audio p2p links

Parameter	FCC (US)	OFCOM (UK)
Power for FD in adjacent band	Not allowed	Not applicable
Power for FD in non-adjacent band with geo-location capability	**30dBm (1W)** (36dBm EIRP with 6dB gain antenna)	Not applicable
Power for PPD in adjacent band	**16dBm (40mW)** (Gain antenna not allowed)	4dBm
Power for PPD in non-adjacent band with geo-location capability	**20dBm (100mW)** (Gain antenna not allowed)	17dBm
Power for PPD in non-adjacent band without geo-location capability	**17dBm (50mW)**	

FD: Fixed Device; PPD: Personal Portable device

Future trend: Licensed Shared Access (LSA)

- Proposed in 2010 by Qualcomm and Nokia in an answer to a hearing on cognitive technologies by the EU

- LSA is a framework to share spectrum between a limited amount of users
  - Under this concept, the existing spectrum user(s) (“the incumbent(s)”) would share spectrum with one or several licensed LSA users (”LSA licensee(s)”) in accordance with a set of pre-defined conditions
  - the LSA concept is primarily about granting “individual authorisations” of the use of a frequency band which is already licensed to another incumbent usage(s), e.g. defence service, satellite service or wireless camera operation
- Two basic levels of spectrum access are foreseen:
  - *Incumbent user*, who is the current spectrum licensee. This could be an individual license holder or a governmental organisation with priority rights in order to deliver public services (defence, civil aviation, emergency communications,…)
  - *The LSA licensee*, who must not interfere with the incumbent spectrum user. There will also be imposed emission and power limits by the regulator. A spectrum guarantee may also be defined reflecting the rights of the incumbent user.
- A key feature of LSA is to ensure a predictable QoS for all spectrum rights of use holders, network operators and consumers.

The LSA architecture

***The LSA repository*.**
- A database containing relevant information on incumbent spectrum use

***The LSA controller*,**
- Computes LSA spectrum availability based on the rules built upon LSA rights of use and the incumbent's use provided by the LSA repository.

The network Operation, Administration & Maintenance (OA&M),
- Corresponds to the OA&M of mobile broadband networks.
- It takes care of the actual management of LSA licensed spectrum, practically translating spectrum availability information into radio resource management commands.